Soil liquefaction problems in recent Japanese earthquakes

Problèmes de liquéfaction des sols dans les tremblements de terre japonais récents

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Since 1983, two earthquakes which occurred in Japan caused extensive damage in terms of geotechnical engineering. The Nihonkai-Chubu earthquake of 1983 caused wide-spread damage involving soil liquefaction, and the Naganoken-Seibu earthquake of 1984 caused extensive landslides in the mountains (Fig. 1). The latter is not discussed here because it was covered by Professor Kenji Ishihara elsewhere during the Conference.

The Nihonkai-Chubu earthquake of 1983 occurred on May 26, 1983, off the Japan Sea coast of northern Honshu, Japan. The origin times (local), epicenters, magnitudes, and focal depths of the main shock and the largest aftershock according to the Japan Meteorological Agency are as follows:

Main shock:
May 26, 12:00; 40.36 N, 139.08 E; M7.7; 14 km

Largest aftershock:
June 21, 15:25; 41.16 N, 139.00 E; M7.1; 6 km

As shown in Fig. 2, the epicenters of the main shock and aftershocks are scattered along the west coast of northern Honshu over a distance of about 160 km. The magnitude of 7.7 took the seismologist by surprise because it was unusually large for earthquakes originating in the Sea of Japan. The maximum horizontal accelerations along the coast were typically about 1/4 of g, somewhat stronger than those in Niigata during the Niigata earthquake of 1964.

As shown in TABLE I, the Nihonkai-Chubu earthquake caused extensive damage to road embankments, polder dikes, harbor and irrigation facilities, rice paddies, and wooden houses in primarily rural areas in Aomori and Akita prefectures, mainly due to soil liquefaction. In addition, one hundred persons were killed by the tsunami that also caused damage to boats and coast protection facilities. Note that only four persons were killed by causes other than the tsunami, and that five houses were destroyed by fire, which should be considered minor considering the scale of the earthquake. The human losses could have been greater if more trains had been running at the time of the quake, considering that the railroad tracks were damaged at 65 places.

The fact that the earthquake occurred at noon time on a sunny day in early summer provided an ideal opportunity for observing soil liquefaction. As shown in Fig. 3 the rice paddies were ponded so that the groundwater table was as shallow as it could be; yet the rice seedlings were thin enough to provide a clear view of the ground surface. One will understand the significance of these circumstances if one imagines the opposite case in which the earthquake might have occurred at midnight in the middle of winter with the whole region covered by heavy snow.

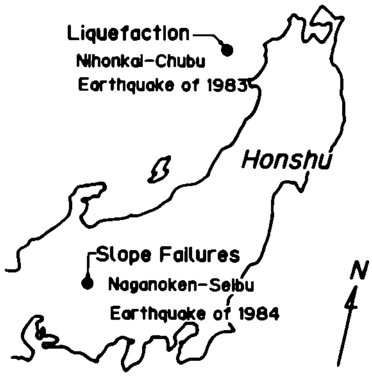

Fig. 1 Two Recent Earthquakes in Japan Causing Geotechnical Damage

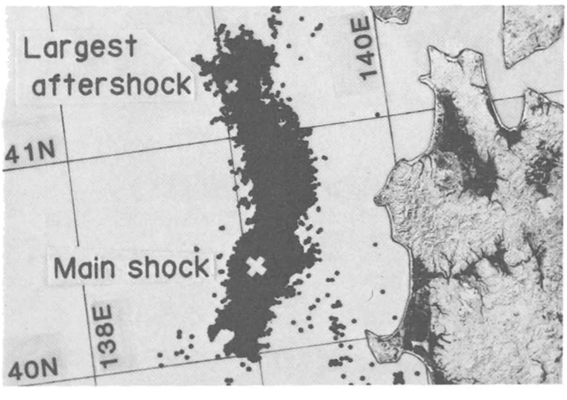

Fig. 2 Epicenters of Main Shock and Aftershocks During 1-Month Period Following Nihonkai-Chubu Earthquake of 1983

TABLE I

Damage as of July 6, 1983, Announced by the Police Agency

Persons	
killed	104
missing	-
wounded	163
Houses	
with structural damage (>50%)	934
with structural damage (20-50%)	2115
swept by tsunami	52
totally destroyed by fire	1
half destroyed by fire	4
flooded above floor	313
flooded below floor	747
with minor damage	3258
Non-residential buildings damaged	2739
Paddy fields buried (ha)	265
Paddy fields flooded (ha)	579
Fields buried (ha)	2
Fields flooded (ha)	13
Roads damaged	616
Bridges washed away	22
Dikes damaged	25
Landslides	43
Railroad tracks damaged	65
Damage to communication lines	437
Boats	
sunk	255
washed away	451
damaged	1187

Fig. 3 Typical Rice Paddies

TABLE II

Recent Earthquakes in Japan Causing Liquefaction of Sand Deposits

Earthquake	Date	M	Epi-center	Focal depth, km
Niigata	'64.6.16	7.5	38.4°N 139.2°E	40
Tokachi-Oki	'68.5.16	7.9	40.7°N 143.6°E	0
Nemuro-Hanto-Oki	'73.6.17	7.4	42.9°N 146.0°E	40
Miyagi-ken-oki	'78.6.12	7.4	38.2°N 142.2°E	30
Nihonkai-Chubu	'83.5.26	7.7	40.4°N 138.9°E	14

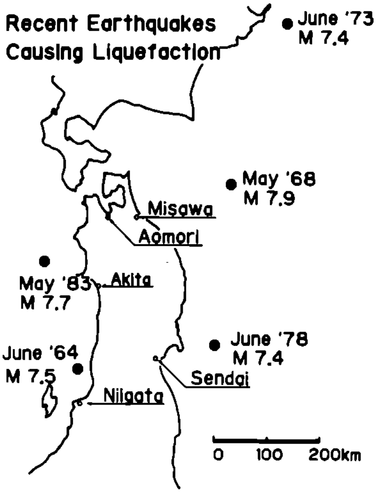

Fig. 4 Earthquakes Since 1964 Causing Liquefaction in Sand Deposits (Circles Show Epicenters)

Since the famous Niigata earthquake of 1964, five earthquakes of magnitude 7.4 or greater have occurred in northern Honshu, four or five years apart, as shown in Fig. 4 and TABLE II. With a margin of error of 25 percent, the earthquakes have occurred as regularly as the International Conference on SMFE! It might be pointed out in passing that every one of these earthquakes occurred either in the last half of May or the first half of June.

The dark areas on the map of Fig. 2 represent lowlands where there are extensive alluvial deposits of sand, including fluvial deposits along several rivers, and Hachirogata polder that was reclaimed for farming (just northeast of the peninsula shown near the bottom of the map). The maximum horizontal accelerations of about

0.25 g along the sea coast were more than enough to cause liquefaction in loose deposits of saturated sands.

According to a review of the past earthquake records for the last 120 years, the engineers at the Public Works Research Institute of the Ministry of Construction, Japan, showed that the epicentral distance to the farthest place of liquefaction increased nearly exponentially with an increase in the magnitude (Kuribayashi and Tatsuoka, 1975). In reference to Fig. 5, if this relationship is considered in the case of the main shock and the largest aftershock in 1983, it could be assumed that soil liquefaction would be likely to have occurred within the solid arcs, whereas it would not be considered likely that soil liquefaction would have occurred outside the dashed arcs. Numerous cases of liquefaction were indeed observed within the solid arc of radius 158 km during the main shock. It is noteworthy that soil liquefaction was observed in the area marked B during the largest aftershock although the area was clearly outside the dashed arc. The observation of the liquefaction phenomena during the aftershock was made by geotechnical engineers who happened to be there for performing soil investigations related to the main shock.

The above experience might encourage the advocates of rapid deployment of field instruments in the hope of getting measurements during strong aftershocks. It might be feasible if one could predict where the strong aftershock might occur, or else if one could afford to deploy instruments at a number of places.

Fig. 6 shows a sand boil caught in action. Many eyewitnesses reported that the soil liquefaction during this earthquake occurred either during the ground shaking period or immediately afterwards. In contrast, the liquefaction during the Niigata earthquake of 1964 is believed to have occurred at some depth, and its effects did not become visible until some time after the ground shaking had ceased. Another feature of the 1983 earthquake in comparison with the Niigata earthquake is that the damaged areas were predominantly rural. Numerous sand boils occurred in rice paddies, often uprooting the rice seedlings. The rice paddy of Fig. 7 was drained because the buried plastic membrane that had contained the water was broken as a result of the liquefaction of the sand below.

Fig. 8 shows one of the largest sand craters found after the 1983 quake, about 7 m across. The groundwater kept flowing for a few days. Fig. 9 shows a cross-section perpendicular to the coastline. Strong wind from the sea blew the dune sand to form so-called "blowout depressions" that were partly surrounded by parabolic dunes down wind (Kuwabara et al., 1985), as shown in Fig. 10. The blowout depressions became swampy, and then were filled by windblown dune sand in a very loose condition. That is where the giant sand boils were formed. Fig. 11 shows a cross-section of one of the giant sand boils.

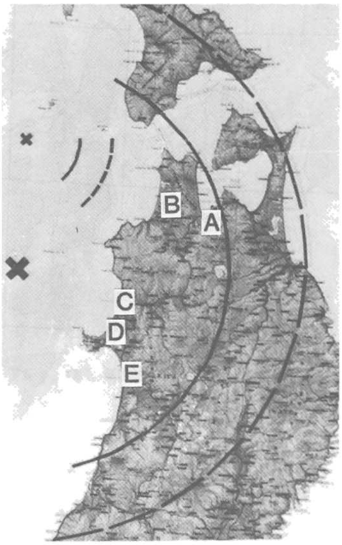

Fig. 5 Arcs Around Epicenters of Main Shock and Largest Aftershock Showing Likelihood of Liquefaction

Fig. 6 Sand Boil in Noshiro City, Akita Prefecture (Courtesy of Mr. Matsumori)

Fig. 7 Sand Boils in Drained Paddy in Wakami Town, Akita Prefecture

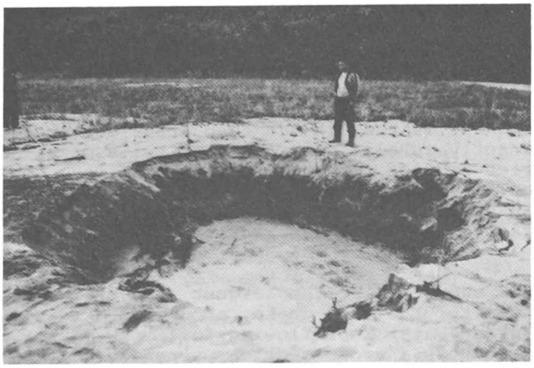

Fig. 8 Giant Sand Boil in Shariki Village, Aomori Prefecture (Courtesy of Dr. I. Tohno)

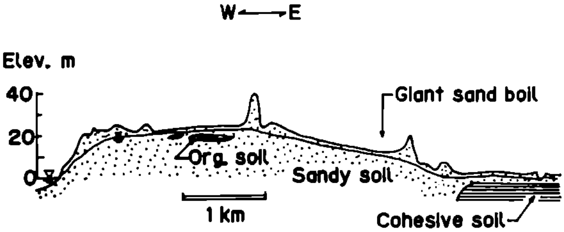

Fig. 9 Cross-Section Through Shariki Village (Courtesy of Dr. I. Tohno)

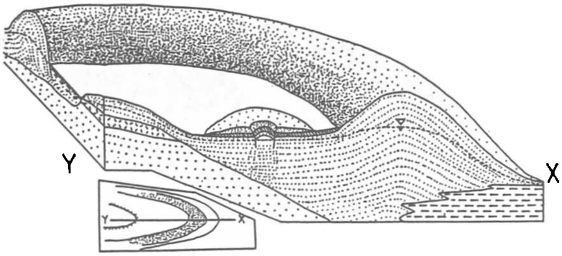

Fig. 10 Schematic Illustration of Blowout Depression and Parabolic Dune (Courtesy of Dr. I. Tohno)

Unlike the Niigata earthquake of 1964 where small houses were seldom damaged, the 1983 earthquake caused extensive damage to light structures such as wooden houses (Fig. 12), or low concrete block walls (Fig. 13), probably because the surface soil liquefied during the ground shaking period.

Underground facilities are quite vulnerable to soil liquefaction because the pore water pressure on the bottom increases at least 90 percent or so, while the side wall friction becomes zero. With respect to the example shown in Fig.

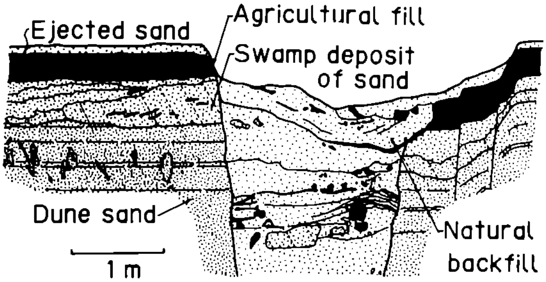

Fig. 11 Cross-Section of Sand Boil of Fig. 8 (Courtesy of Dr. I. Tohno)

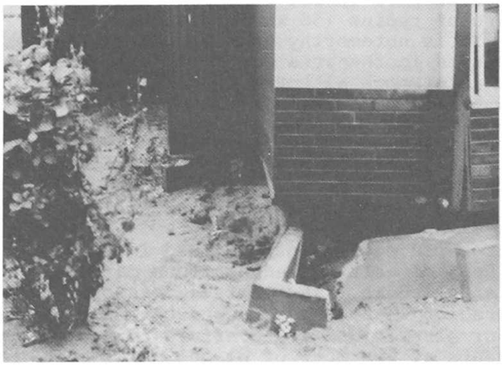

Fig. 12 Foundation of Wooden House Damaged due to Liquefaction

Fig. 13 Concrete Block Wall Damaged due to Liquefaction

14, where d_w is about equal to d/3, the uplift pressure, p_1, becomes about 3 times the initial hydrostatic pressure, p_o. According to the Public Works Research Institute, about 20 underground liquid storage tanks were damaged due to the uplift pressure. Fig. 15 shows a 60-percent full gasoline tank that rose about 76 cm during the ground shaking. Fig. 16 shows a case in-

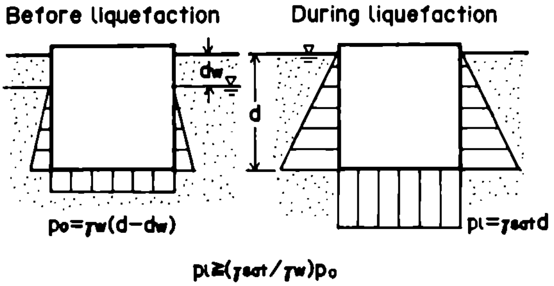

Fig. 14 Pore Water Pressure on Underground Object Before and During Liquefaction

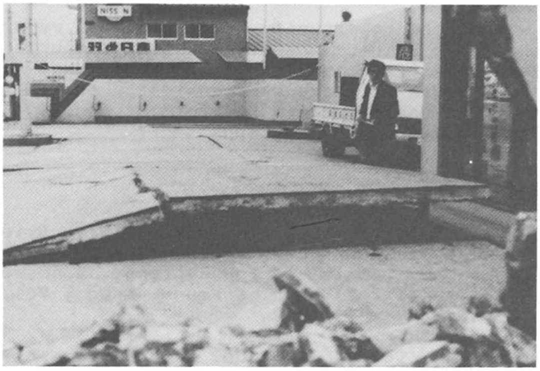

Fig. 15 Damage Caused by Uplift of 60-% Full Gasoline Tank

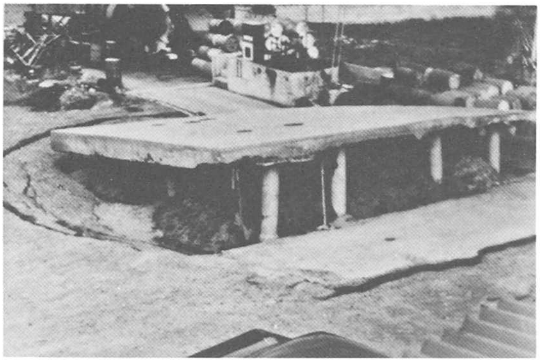

Fig. 16 Damage Caused by Uplift of Empty Kerosene Tank (Courtesy of Dr. E. Taniguchi)

volving two kerosene tanks buried side by side, one about 1/3 full and the other nearly empty. The empty tank rose about 2 m. Fig. 17 shows a typical cross-section of an underground tank. In most damaged tanks, the steel straps were broken or the anchors were pulled out of the concrete base.

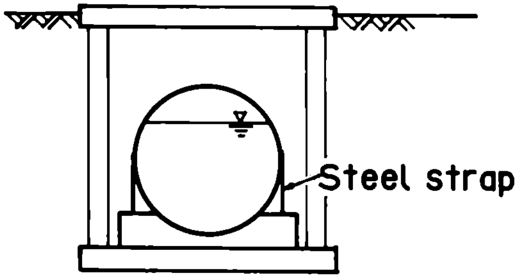

Fig. 17 Typical Cross-Section of Underground Fuel Tank

Fig. 18 Damage at Akita Harbor due to Failed Quaywall

Quaywalls are also quite vulnerable to soil liquefaction because the earth pressure increases while the lateral resistance decreases at the same time. Fig. 18 shows a typical damage at Akita Harbor caused by a failed quaywall, and Fig. 19 shows a more detailed description (Nakata and Terauchi, 1984).

The roads were damaged at numerous places as a result of soil liquefaction (Fig. 20). Approach embankments to bridges were damaged at numerous places (Fig. 21), the damage rate being about 60 percent in the polder area.

In summary, the 1983 Nihonkai-Chubu earthquake caused extensive damage in primarily rural areas in Aomori and Akita prefectures in northern Honshu. The damage was mainly caused by liquefaction of alluvial and reclaimed sands. The following features may be pointed out concerning the liquefaction phenomena and damage types: the liquefaction occurred in unusually widespread areas, light structures such as the foundations of wooden houses were severely damaged, huge sand craters several meters across were observed, and liquefaction was observed during an aftershock. It must be emphasized that every new earthquake presents something new in damage features as well as ground motion characteristics. One must therefore be careful not to draw hasty conclusions from one's observations of a few earthquakes, no matter how thorough they may be.

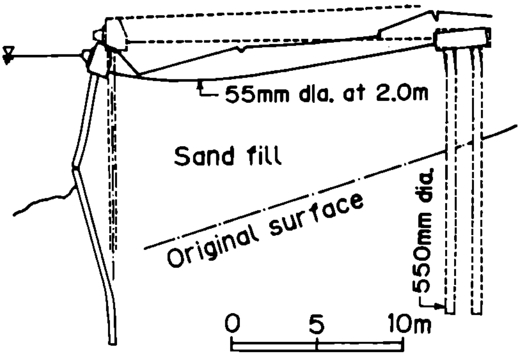

Fig. 19 Damaged Quaywall at Akita Harbor (Nakata and Terauchi, 1984)

Fig. 20 Pavement Damaged due to Liquefaction

Some of the damage could have been mitigated or prevented if the facilities had been adequately designed and constructed based on available knowledge, although economic considerations could have precluded the use of elaborate mitigation measures. There may be such a thing as an "appropriate technology" for liquefaction mitigation for rural facilities.

Fig. 21 Approach Embankment to Bridge at Hachirogata Polder

The writer is grateful to Professor H. B. Seed, Chairman of the Organizing Committee, for giving the writer the opportunity to present his report in the Fifth Plenary Session entitled "Reports on Recent Failures and Near Failures." Many thanks are due to those who generously provided him with valuable data in the form of unpublished reports and photographs.

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