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SOIL LIQUEFACTION AND DAMAGE TO SOIL STRUCTURE DURING THE EARTHQUAKE OFF MIYAGI PREFECTURE ON JUNE 12TH, 1978

by

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SYNOPSIS

The authors surveyed the area damaged by the earthquake of June 12, 1978 that occurred in the sea off Miyagi Prefecture in Northern Japan. It was reported from the Japanese Meteorological Agency that the estimated location of the epicenter was 28°09'N and 142°10'E, the depth was 40 km and the magnitude was 7.4. Reported herein are the results of this survey.

SOIL LIQUEFACTION

Sand boils or sand volcanoes due to soil liquefaction were observed at several sites in Miyagi Prefecture during the earthquake but soil liquefaction were not as severe and not as extensive as liquefaction during the Niigata Earthquake of 1964. The major sites where sand liquefaction was observed are shown in Fig. 1. Liquefaction occurred in reclaimed land between Sendai New Port and Ishinomaki Port, in old riverbeds, in existing riverbeds, along landward toes of alluvial bars parallel to river channels and along sand dunes parallel to the ocean.

ARAHAMA: At a National Recreational Area which is located behind a sand dune on the right bank at the mouth of Abukuma River, several cracks opened during the earthquake from which water spouted (see Photo. 1). The bottom face of a swimming pool was cracked by upward flow of excessive porepressure generated during the earthquake (see Photo. 2). Also, one side of a septic tank floated up 40 cm above the ground surface as shown in Photo. 3 and Fig. 2. Sand boils were observed only on the displaced side. Cone penetration tests were conducted at five points using a double tube cone penetrometer as illustrated in Fig. 2. At three locations, resistances

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increased rapidly with depth as in ordinary sandy deposits. But at two points, resistances did not increase with depth (to 2.5 m). This low resistance may be due to the formation of very loose layers in the ground as a result of dissipation of excess pore pressure.

In a trench subsequently dug to repair a sewer pipe damaged during the earthquake which was located 6 to 7 m away from the swimming pool, in situ densities of sand layers were measured using the sampling device illustrated in Fig. 4. A tube was pushed into the side wall of the trench carefully to a depth of around 20 cm. The maximum and minimum void ratios were measured by the Yoshimi-Tohno method (Yoshimi and Tohno (1972)). It was found that the relative density of the sand samples was around 30 to 40 per cent showing that the sand layer was in a very loose state. The ground-water surface was found at a depth of 1.45 m below the top of the trench and at a depth of 1 m in a nearby manhole. Using these data, a simple liquefaction analysis was performed following the method described in Iwasaki, Tatsuoka, Tokida and Yasuda (1978). The liquefaction resistance of the sand layer was obtained assuming D_r=35% and a stress ratio (R) calculated from the relationship:

$$R = 0.0042 \times D_r = 0.0042 \times 35 \doteqdot 0.15 \qquad (1)$$

The earthquake load parameter (L) was obtained using the relationship

$$L = \alpha_{s_{max}} \cdot \sigma_v \cdot \gamma_d \,/\, g \,/\, \sigma_v' \qquad (2)$$

in which $\alpha_{s_{max}}$ is the surface maximum acceleration, σ_v is the total overburden stress, σ_v' is the effective overburden stress, g is the acceleration of gravity equal to 980 cm/sec^2 and γ_d is the reduction factor that considers the elastic deformability of the ground. Taking γ_t as 1.95 t/m^3 and assuming that $\gamma_d=1-0.015\cdot Z$, $\alpha_{s_{max}}$ for R=L for the depth of 2~5 m became 100 to 125 gals. The results by the analyses described above show that for the maximum acceleration at the ground surface $\alpha_{s_{max}}$ larger than 100 to 125 gals the parameter representing loads L becomes larger than the parameter representing resistances R at the place analysed at Arahama and liquefaction can take place at the place. On the other hand, $\alpha_{s_{max}}$ at the place was estimated larger than 100 to 125 gals on the basis of the damage to nearby houses and acceleration records at several points surrounding Arahama. Therefore, it can be said that the simplified procedure for evaluating liquefaction potential described above gives reasonable results.

Kuribayashi and Tatsuoka (1975) examined areas that liquefied during some 40 earthquakes in Japan between 1872 and 1968. For each earthquake, the maximum distance from the epicenter at which liquefaction were observed was determined. On the basis of these data, they established a relationship between the maximum epicentral distance R within which liquefaction was observed and the magnitude M

$$\log_{10}R = 0.77M - 3.6 \qquad (\text{for } M > 6) \tag{3}$$

in which R is in km. By making M=7.4 in Eq. (3), we get R=125 km. The actual epicentral distance of Arahama from the earthquake was estimated to be about 110 km. Thus liquefaction damage occurred within the expected zone of damage. Further, no liquefaction damage occurred at a distance greater than 110 km from the earthquake epicenter which is also expected based on the above calculation.

At several points along the lagoon named Torino-umi which is placed closely to the National Recreation Area, retaining walls facing to the lagoon tilted toward the lagoon and the pavements of road which is placed just behind the relating walls settled, the maximum settlement being 2 m (see Photo. 4). At the place where the maximum settlement of road surface was observed, some boiled sands were observed just behind the tilted retaining wall, at the cracks on the ground surface along the opposite side of the pavement to the lagoon and on the ground surface nearby the cracks. Therefore, it can be considered that soil liquefaction triggered the sliding and the tilting of the retaining wall.

YURIAGE BRIDGE: On the narrow flood plain between the right embankment and Natori River, many cracks opened from which much water sprouted around the pier foundations of Yuriage Bridge. This bridge is placed 1.5 km upper-reach from the rivermouth. Along these cracks, boiled coarse sands were observed (see Photo. 5). It seems that at this site soil liquefaction can not be simply related with the damage to structures. Firstly, no damage to nearby embankments was observed. Secondly, while horizontal small cracks on the RC piers appeared above the ground surface which were placed between the right embankment and the river channel, much severer cracks were observed on the RC piers which were placed between the left embankment and the river channel around which no cracks on the ground and no sand boils were observed.

A deep trench was subsequently dug using the well-point method around the pier which is placed nearest to the embankment on the right bank (see Fig. 5 and Photo. 6). This trench was dug to check whether the underground part of the pier was damaged or not. Any crack was not observed. In the trench, loose coarse sand layer of about 2 m thick was found. By the same method as done at Arahama, in situ density of the sand layer was measured in the trench as shown in Fig. 5. As shown in Fig. 5, measured relative densities was 36% and 38% which show a loosely packed state of the sand layer. By the results of the geotechnical survey which was conducted beforehand for the design of the bridge, this loose coarse sand layer was found to be underlain by a dense sandy gravel layer of about 3 m thick which is underlain by a very firm fine sand layer for which N-values were measured as 30 to 40. Also for this site, a simple liquefaction analysis was performed as done for a site at Arahama. Using, D_r of 37% and the depth of ground water level of 2 m, the maximum acceleration $\alpha_{s_{max}}$ at ground surface which causes liquefaction at the depth of 3 m making L equal to R was obtained as 130 gals. This seems to be a reasonable value because the actual maximum acceleration at this site during the earthquake can be considered larger than 130 gals.

Fig. 6 shows the grain size distributions of boiled sands several sites in Miyagi Prefecture. These sites are indicated in Fig. 1. The mean diameter D_{50} for these sands ranges from 0.2 to 0.4 mm and the coefficient of uniformity Uc is small. These grading characteristics are similar to sands in Niigata City liquefied during the Niigata Earthquake of 1964.

There were a few liquefied sites where sand liquefaction appeared to have caused damage to structures. The embankment on the right bank of Natori River at 2.2 km upper-reach from the rivermouth slid landward and around the toe of the slid embankment several sand boils were observed. At Ishinomaki Port, several harbors made of sheet piles slid toward sea. It was found that while the harbors made by excavating existing sand dunes were not damaged, the harbors made on reclaimed lands were damaged and boiled sand were found on the ground surfaces of the back fills of the damaged harbors.

DAMAGE TO SOIL STRUCTURES

MIDORIGAOKA RESIDENTIAL AREA AT SENDAI: This damaged place is a residential site made by filling volcanic soil into a small valley. This fill appeared to have slid during the earthquake motion. Therefore, the foundations of houses were forced to displace widening their foundations. It was found that the houses placed on the slid zone were severely damaged while houses outside of the slid zone were not or negligibly damaged. A gravity-type sabo dam which was constructed to prevent the slide of the fill moved downward, the maximum displacement being 50 cm.

EMBANKMENT AT MAKINOZU: This is placed on the left bank of Shin-kitagami River. The embankment was severely damaged continuously over 4 km. It seems that this damage was due to sliding both in the embankment and in the base ground. This embankment was made on an old river channel and underlain by very soft soil. It was found that the embankment on the right bank at the same area was not damaged and that this embankment was placed on a firm ground.

EMBANKMENT AT YAMAZAKI: The embankment on the right bank of Yoshida River settled over 5 km, the maximum settlement being 2 m. This embankment appeared to have slid due to the failure in the soft ground (Photo. 7). Cone resistances measured along the embankment were shown in Fig. 7. It can be seen from this figure that the ground underlaying the embankment is very soft to the depth of 3.5 m at least.

MIDORIGAOKA AT SHIROISHI: At this place, a fill made for residential houses slid fluidly. This fill was made in a small valley using volcanic loam and scoria. The gradings of soils sampled from the slid fill were shown in Fig. 8. It is reported that there used to be a small pond at the bottom of the existing fill. And it was observed at the site that the saturated soil of the fill becomes fluidy one when remolded.

CONCLUSIONS

The results of authors' survey about soil liquefaction and the damage to soil structures by the earthquake of June 12, 1978 which occurred in the sea off Miyagi Prefecture in Northern Japan have been presented. It was found that sand liquefaction occurred at several sites in Miyagi Prefecture. At a few places, soil liquefaction caused the damage to structures. Relative densities of liquefied sand layer were obtained at two sites and simple liquefaction analyses for these two sites were performed. Reasonable results were obtained from these analyses.

River embankments were damaged during the earthquake at several sites. The damage was mainly due to failures in soft base ground and at a few sites the damage was caused by soil liquefaction in base grounds.

ACKNOWLEDGEMENTS

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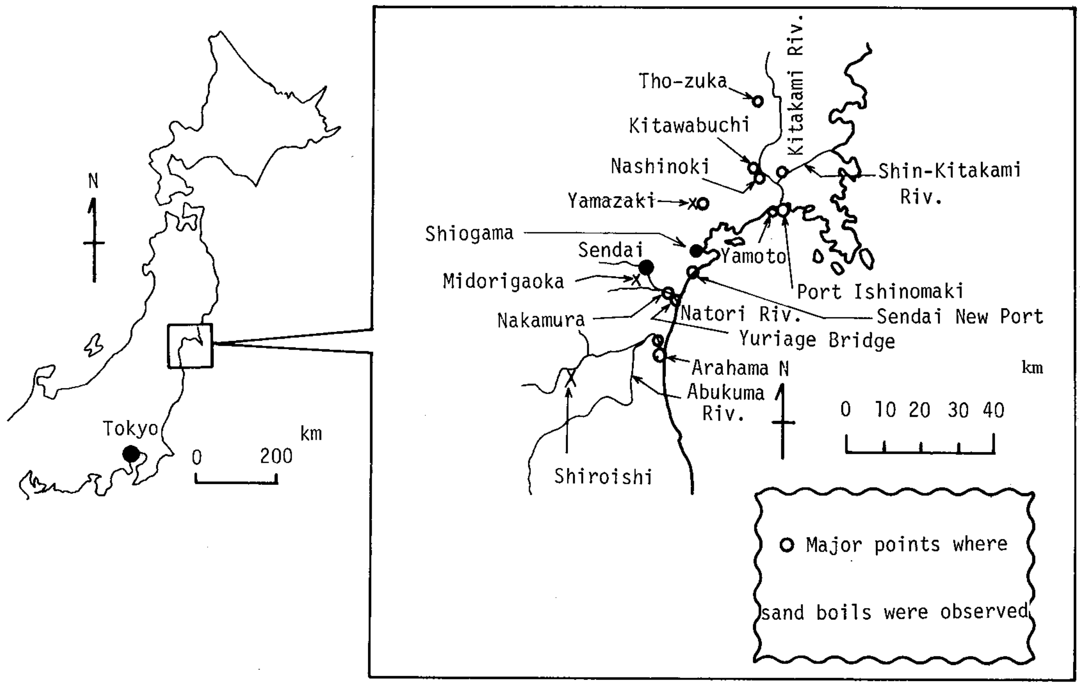

Fig.1. Locations of the Sites

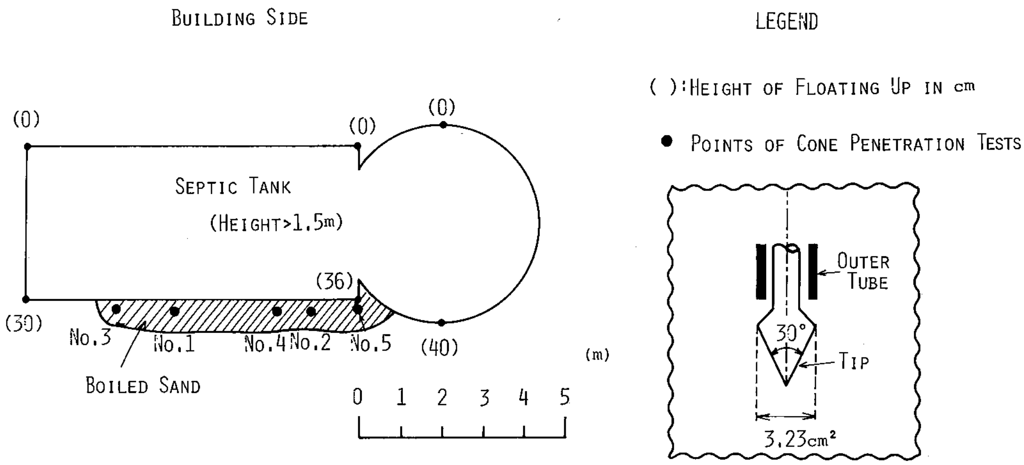

Fig.2. Floated up Septic Tank at Arahama, on the Right Bank at the Rivermouth of Abukuma River

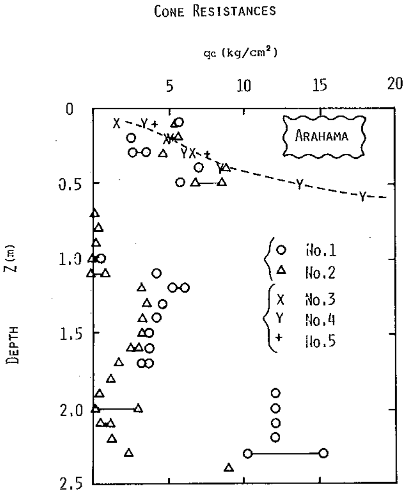

Fig.3. Results by Cone Penetration Tests along the Floated up Septic Tank

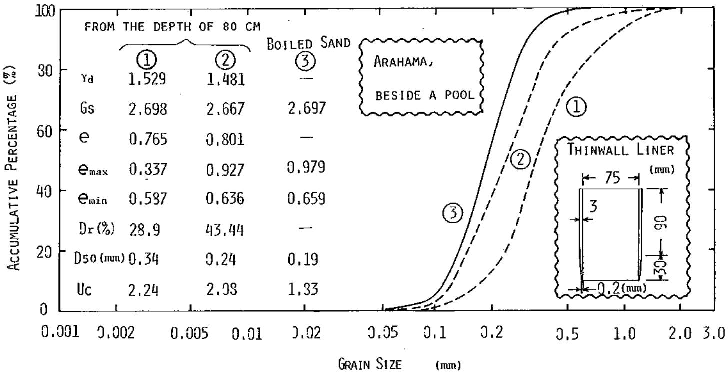

Fig.4. Gradings and Physical Properties of Sands from Arahama

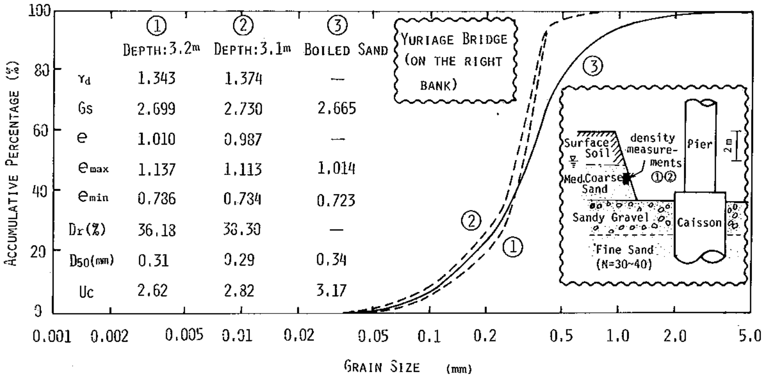

Fig.5. Gradings and Physical Properties of Sands from the High Water Channel of Natori River at Yuriage Bridge

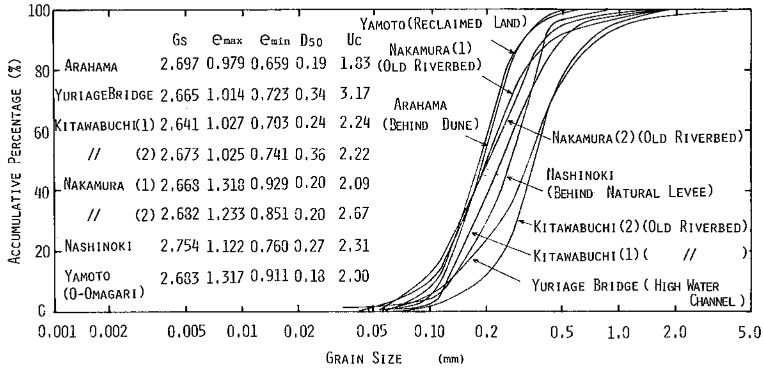

Fig.6. Gradings and Physical Properties of Boiled Sands

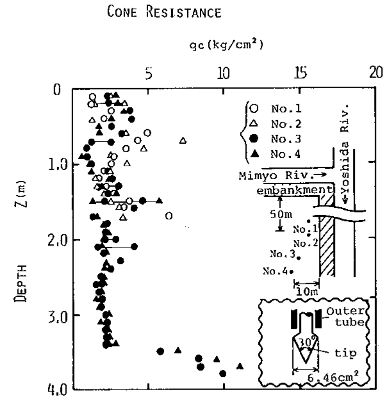

Fig.7. Cone Resistances along Yamazaki Embankment of Yoshida River

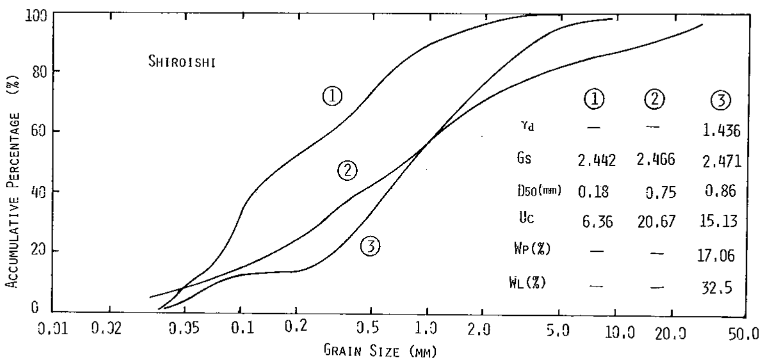

Fig.8. Gradings and Physical Properties of Materials Sampled from Slipped Embankment at Shiroishi

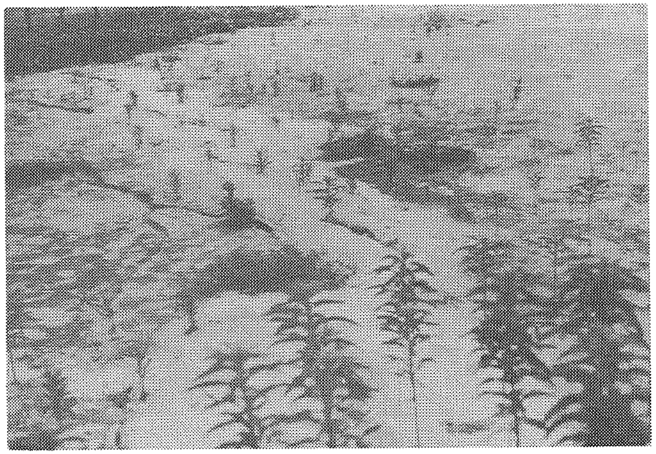

Photo. 1 Boiled Sand at Arahama

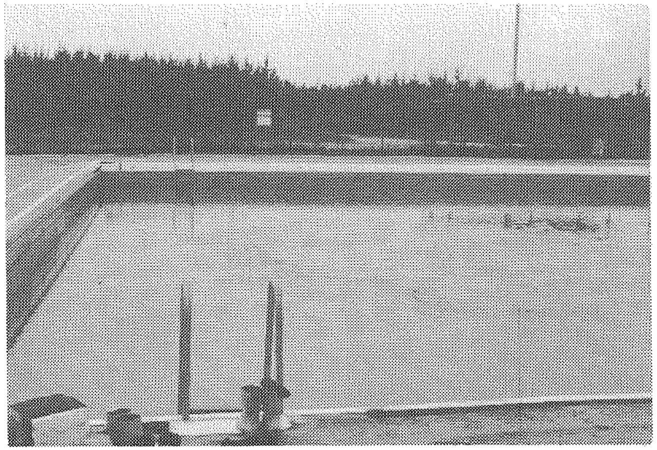

Photo. 2 A Swimming Pool Damaged by Soil Liquefaction at Arahama

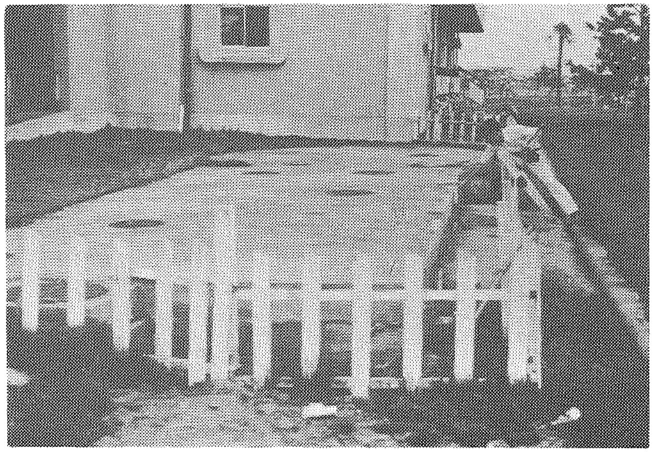

Photo. 3 A Floated Up Septic Tank at Arahama

Photo. 4 Tilted Retaining Walls and Settle Road Faces Along Torino Umi

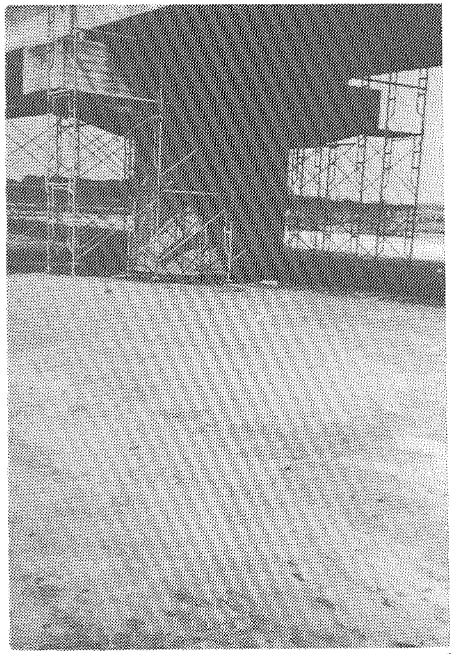

Photo. 5 Boiled Sand Around Yuriage Bridge

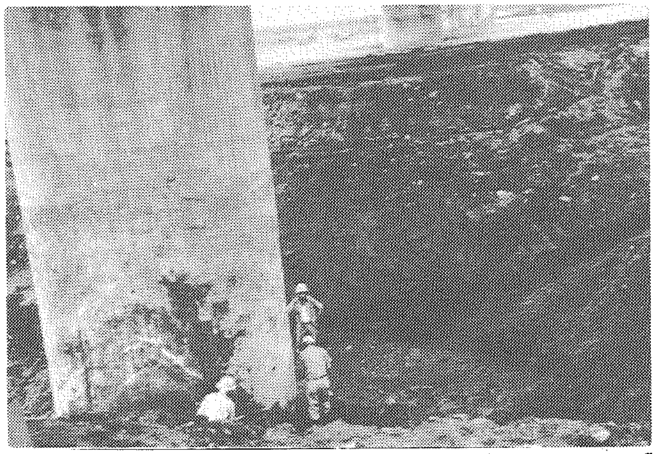

Photo. 6 A Trench Dug Around A Pier of Yuriage Bridge

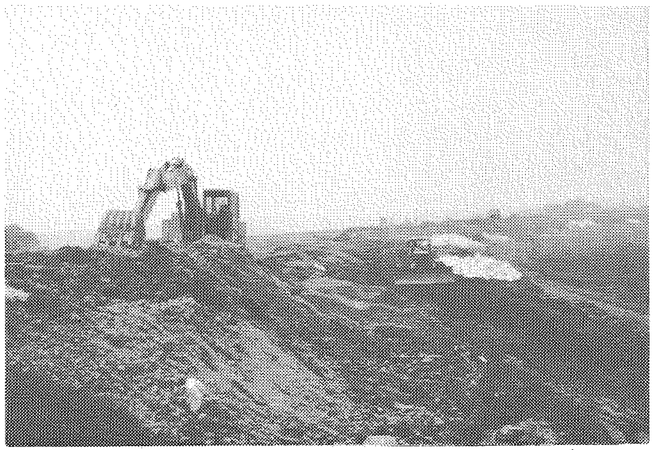

Photo. 7 Damaged Embankments Under Repairing at Yamazaki