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SYPOSIS Two large earthquakes struck Japan during only a 6 month period in 1993: Kushiro-oki on January 15 and Hokkaido Nansei-oki on July 12. Both caused a lot of damage to facilities, including installations such as farm roads, reclaimed farmland, channels, head works, drainage pump stations, pipelines and fill dams. In this paper, we present an outline of the damage to agricultural facilities and its features.

1. INTRODUCTION

In a half year period of 1993, two large earthquakes, Kushiro-oki on January 15 and Hokkaido Nansei-oki on July 12, occurred in Japan causing much damage. These earthquakes also damaged such agricultural facilities as farm roads, irrigation and drainage canals and pipelines. This paper describes the damage to agricultural facilities and the seismic activity at fill dams.

2. KUSHIRO-OKI EARTHQUAKE

The data of this earthquake is as follows:
Date and time: January 15, 1993, 08:06 p.m.
Epicenter: Lat. 42°48' N and Long. 144°24' E
Depth of the seismic center: 107 km
Magnitude: 7.8

The maximum seismic intensity in Kushiro was 6 on the Japanese scale. Fig.1 shows the epicenter of two earthquakes. The earthquake caused damage to agricultural facilities, including farm roads, reclaimed farmland, drainage canals (open channels), miscellaneous water facilities (small caliber pipelines and water purification facilities) and silos. The damage is outlined below.

GNERAL CONDITIONS AND FEATURES OF DAMAGE IN KUSHIRO-OKI EARTHQUAKE

The damaged sites of agricultural facilities are shown in Fig.2
(1) Farm roads: The main farm roads were damaged at 7 places, 5 of which were relatively lightly damaged including faulting resulting in 3- 5 cm differences in surface level and pavement cracks. The remaining 2 places in Isobunnai (town of Shibecha) were greatly damaged. The total length of damaged road was 180 m, faulting emerged, and the ground caved in 2 m at the maximum. Most of the damage on farm roads occurred in the boundary area between the cut and the bank over a ravine. Judging from the surrounding topography, the thicker the layer of soft ground, the greater the damage was.

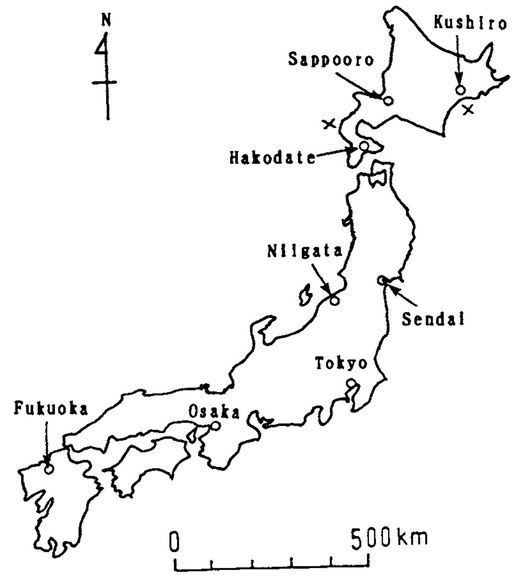

Fig.1. Epicenter of Two Earthquakes

(2) Miscellaneous water facilities (small caliber pipelines): Air valves were broken, water leakage occurred because joints dropped off, and holes appeared in the pipes. Both cast iron pipes (250 - 350 mm) and asbestos pipes were damaged. The damage was observed in crossings of the ravine and where there is a sudden topographical change, but a general distinct tendency of the damaged areas is not recognized.
(3) Silos: Three silos in the town of Bekkai were damaged. One was completely destroyed(Fig.3) and in the case of other two, panels on the side walls were damaged and anchor bolts fixing the silos were broken. It is presumed that acid silage had corroded the bolts.

THE SEISMIC ACTIVITY AT FILL DAMS DURING THE 1993 KUSHIRO-OKI EARTHQUAKE

The earthquake caused slight damage to one part of the earth dam in Hirotomi, in the town of Mombetsu, of mostly

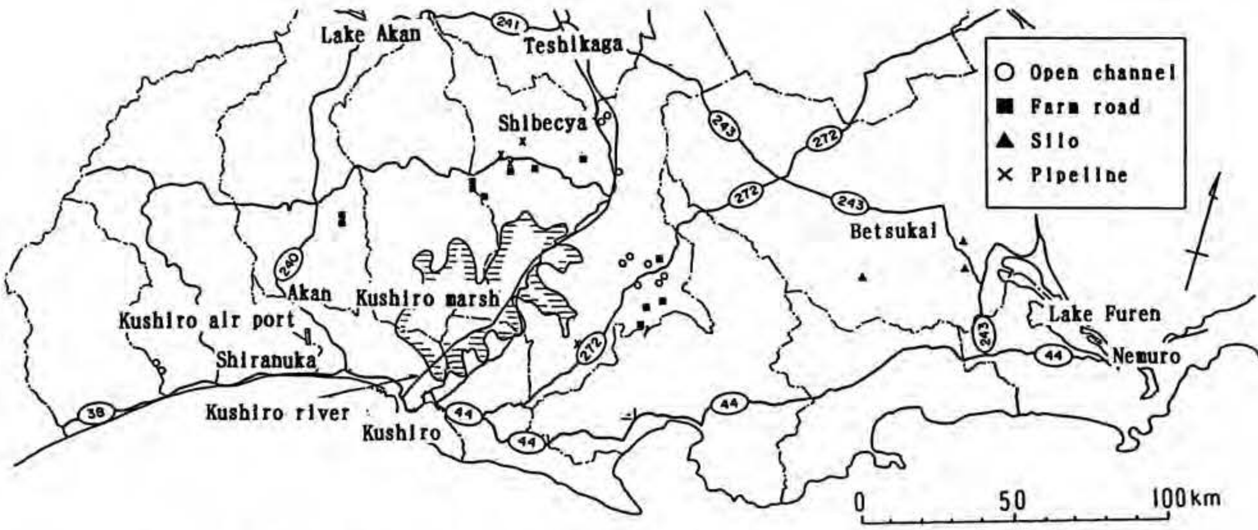

Fig. 2. Map of Damaged Agricultural Facilities caused by the 1993 Kushiro-Oki Earthquake.

Fig. 3. Collapse of Silo in Betsukai City.

cracks and sinking of the crown, but other fill dams were not affected. Mitsuishi Dam, in the town of Mitsuishi, is most closely located to the epicenter, about 100 km away, among allthe dams for agricultural use, but was not damaged by the earthquake. At this dam, seismic waves with the maximum inputacceleration of 58 gal was recorded. Table 1 shows the acceleration record. Other fill dams were not damaged either. Table 1 also contains the records of the earthquake at other dam sites in the vicinity.

TABLE 1. Maximum Accleration Record at Dam Sites in 1993 Kushiro-Oki Earthquake.

Name of dam	Nearest city	Year of comple.	Height (m)	Dist. from epicenter	Max. Acc. (gal)
Mitsuishi	Mitsuishi	1990	36	144 (km)	58
Shirogane	Biei	1990	64	153	4
Takami	Shizunai	1983	120	140	35
Nikatsupu	Nikatsupu	1974	103	125	39

HOKKAIDO NANSEI-OKI EARTHQUAKE

The data of this earthquake is as follows:
Date and time: July 12, 1993, 10:17 p.m.
Epicenter: Lat. 42°47'N and Long. 139°12'E
Depth of the seismic center: 34 km
Magnitude: 7.8

The maximum seismic intensity in Okushiri Island was estimated to be 6 on the Japanese scale. The earthquake caused extensive damage to such agricultural facilities as farm roads, reclaimed farmland, miscellaneous water facilities (water purification facilities), open channels, large caliber pipelines, head works and fill dams. The damage is outlined below.

GNERAL CONDITIONS AND FEATURES OF DAMAGE IN HOKKAIDO NANSEI-OKI EARTHQUAKE

The major damaged places and dam sites are shown in Fig. 4

(1) Reclaimed farmland: Slope collapse occurred in 6 districts. The bank of the reclaimed farmland in these districts was as high as 20 - 30 m in most cases and thus collapsed very intensively. The collapse of the slope caused cracks in the cultivated land, which extended several hundred meters from the top of the slope.
(2) Open channels (irrigation and drainage canals): In the western district of Mt. Komagatake, the base of the channel which is made of blocks on the three faces suffered upheaval extending up to 120 m. In the Ono district, damage was concentrated in a 1.7 km section of the 7.2 km channel. A past soil survey revealed that damage occurred in places where there was sandy ground and where L-shaped blocks were placed. The area with cast-in-place concrete was not affected. Judging from the fact that Kushiro-oki earthquake caused damage to precast inlet in the open channels but not to inlet made of cast-in-place concrete, it is presumed that cast-in-place concrete structures are resistant to earthquakes.
(3) Pipelines: The Makomanai first main pipeline in the Kitahiyama district was damaged. Fig. 5 shows the damage of Makomanai pipeline. Mostly, pipes were removed because thrust blocks moved, pipes came up to the surface and joints were dislocated. Large traces of sand boil were observed around

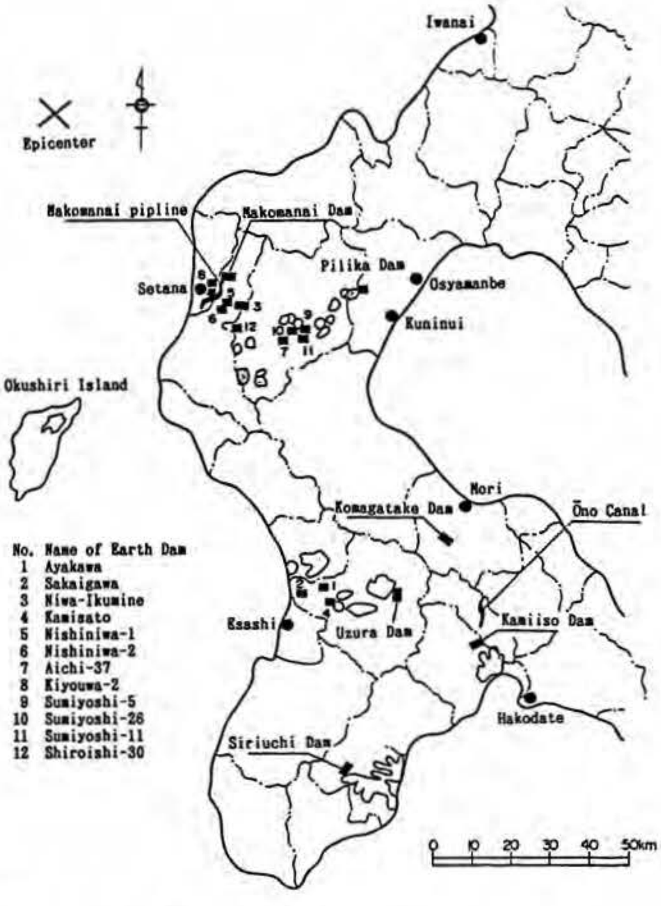

Fig. 4. Map of The North Hokkaido Showing Dam Sites.

Fig. 5. Damage of Makomanai pipeline.

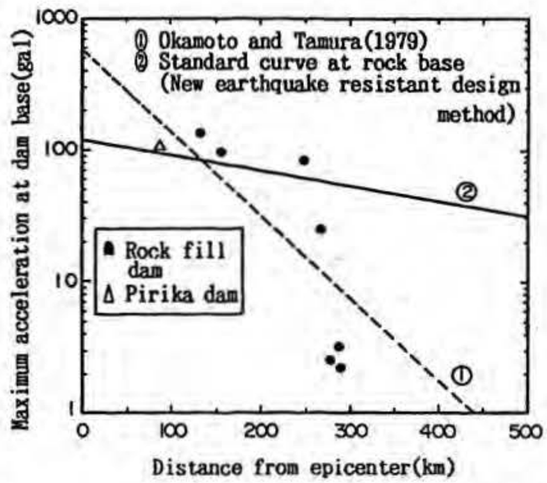

Fig. 6. Maximum Accelation Records at Dam Base.

the damaged places. The sand boil seems to have been caused by ground and back-filling sand. Additionally, sand boil occurred when pipes were removed due to high pressure applied to the pipelines. The main cause of damage can be attributed to liquefaction and the accompanying excessive thrust forces working on the blocks, because large damage was observed in the place near the thrust blocks where topographic features suddenly changed.

The damage and the seismic activity at fill dams for agricultural use are described in the following section. Fill dams are structures of particular importance, and an examination of their activity at the time of earthquakes is significant when we consider future earthquake-proof design.

THE SEISMIC ACTIVITY AT FILL DAMS DURING THE 1993 HOKKAIDO NANSEI-OKI EARTHQUAKE

There are two dams within a 100 km radius of the epicenter: Makomanai Dam and Niwa-ikumine Dam. Makomanai Dam is a rock-fill dam, with a dam height of 34 m, and is located about 66 km away from the epicenter. The earth-quake affected the dam very lightly, only the concrete frame on the slope in the upper stream was slightly distorted. In natural ground, blocks on the right bank were distorted, shotcrete on the natural ground of the left bank slid down slightly, and a small collapse occurred on the natural slope around the reservoir. Fig. 6 shows the relationship between the distance from the epicenter and the maximum input acceleration, based upon the data obtain ed at the fill dams in the vicinity. The result in Fig. 6 adheres closely to the relationship suggested by Okamoto and Tamura. Judging from the data, the maximum acceleration at Makomanai Dam is estimated at about 180～250 gal.

Niwa-ikumine Dam is an earth dam, with the height of the dam being 10 m, and is located about 71 km away from the epicenter. The dam suffered heavy damage, and almost the full length of the crest in the upper stream suffered faulting, which resulted in a 1-1.5 m difference of levels in the direction of the axis of the dam. In addition, a swelling was observed in the bottom part of the slope in the upper stream. This dam was built by settlers at the end of the Taisho era and collapsed once in the beginning of the Showa era and was repaired. A detailed survey of the dam and base ground was conducted after the earthquake. Fig. 7 shows a rough cross section of the dam and base as well as the composition of soil. Although it is basically an earth dam with a core, the composition of soil in the random zone in the down stream and upper stream is complicated. The bank is composed of a mixtureof gravel and silt, while the base is composed mostly of fine sand and silty sand with N-values of less than 5. Sandstone with an N-value of more than 40 appears in the layer of -17 m from the crest.

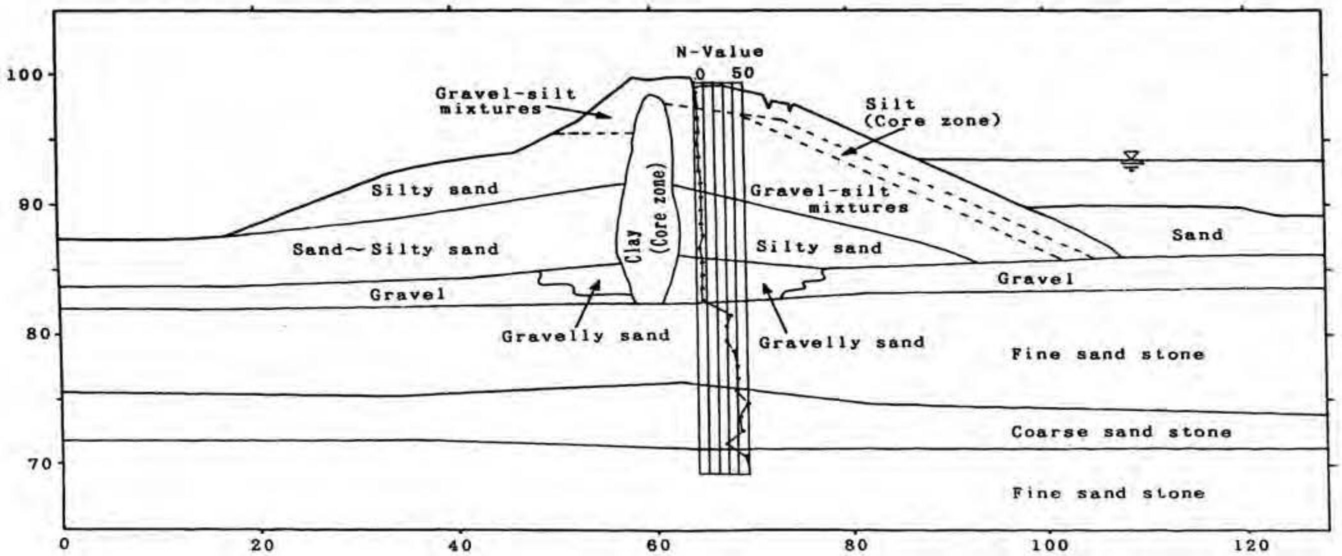

Fig. 7. Cross-section through Niwa-Ikumine Dam Damaged by the 1993 Hokkaido-Nannsei Oki Earthquake.

Fig. 8. Damage of Niwa-Ikumine Dam.

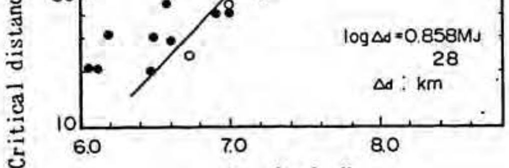

Fig. 9. Relationship between Magnitude and Critical Distance from Epicenter.

According to soil test results, it was confirmed that excessive water pressure in the base ground soil easily increases. It is therefore concluded that the major cause of the damage to Niwa-ikumine Dam was the collapse of bank which was brought on by the decrease in the bearing capacity of the ground as excess pore pressure in the ground increased. Analytic study of the cause is now under way. With regard to small earth dam damage, two in Kitahiyama collapsed. 12 other earth dam suffered slight damage, including cracks and sinking. The locations of these earth dam are shown in Fig. 4 with numbers. Most of the damage is concentrated in the town of Setana near the epicenter.

Fig. 9 shows the relationship between magnitude and critical distance, the greatest distance from the epicenter when any earth dams are damaged by the earthquake. The line in the figure was drawn based upon the data of earthquakes in the past and the area below the straight line shows affected areas. ☆ indicates the data of Hokkaido Nannsei-Oki earthquake, which appears to relate closely with tendencies of past earthquake result data.

CONCLUSION

Agricultural facilities suffered extensive damage in Kushiro-oki and Hokkaido Nansei-oki earthquakes. Fill dams are particularly important structures, and thus examination of the seismic activity is extremely significant in considering earthquake-proof design of fill dams.

Although no fill dams suffered destructive damage by earthqakes in the past, except for hydraulic fill dams, some small earth dam for irrigation were destroyed. Elucidation of the cause of their collapse is necessary to understand the ability to resist earthquakes of fill dams