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CONSIDERATION OF EARTH DAM BEHAVIOR DURING THE 1995 HYOUGOKEN-NANBU EARTHQUAKE

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ABSTRACT

There are many samll-scall earth dams for irrigation called "TAMEIKE" in Japan. Most of them were constructed before modern soil enginnering were established on the basis of empirical techniques. Earthquakes in the past gave much damage to these earth dams. As a result of the 1995 Hyogoken-Nanbu Earthquake, about 1,200 relatively small-scale earth dams used for irrigation suffered some sort of damage. Using the results of damage and soil surveys obtained so far, this paper describes and characterizesthe damage of earth dams caused by the earthquake.

KEYWORDS

Earthquake damage; Hyogoken-Nanbu Earthquake; earth dam

INTRODUCTION

There are about two hundred thousand earth dams for irrigation called "TAMEIKE" in Japan. The first construction of the earth dam for irrigation in Japan was about 2030 years ago. These earth dams are generally small in scale. History of earthquake damage begins with history of earth dam construction.The first earthquake damage in history is the collapse of Sayamaike Dam (Oosaka Prefecture) due to liquefaction. Detailed damage survey was made after Oga-Earthquake(1939). Table 1 shows earthquake damages to earth dams. Fig. 1. shows the epicenter of each earthquake. Every heavy earthquake in the past may caused damages to earth dams.The first systematic survey on earthquake damage to earth dam was performed for Oga-Earthquake (1939). Detailed survey of earth dam damage is quite important for considering earthquake resistance of earth dams. Survey and study of earth dam damage is useful for considering earthquake resistance of similar soil structures such as large scale fill dams,reclamation dikes,river dikes,railway embankments etc.Recently,earthquake-resistance engineering is thought to have made a remarkabel progress by the progress in soil engineering and analysis by the finite element method, but the analysis method is still not enough for accurate prediction of actual earthquake damage. Detailed consideration of the actual earthquake damage, and the findings obtained here sould be coupled with the analysis.

The 1995 Hyogoken-Nanbu Earthquake struck the Kobe area on January 17, 1995. Registering amagnitude of 7.2, the earthquake was considered relatively small, but since it was a inland earthquake, it caused damage of enormous proportions. Even agricultural structures

Table 1. Earth dam damage caused by several earthquakes

Name of Earthquake	Origin Time	Magunitude (Riclte Scale)	Epicenter			Number of earth dams damaged
			East Longitude	North Latitude	Depth (km)	
Kita-Tango	Mar.7 ,1927	7.5	135°06´	35° 36′	10	90
Oga	May 1,1939	7.0	139°48´	40° 00′	0	74
Niigata	Jun. 16,1964	7.5	139°11´	38° 21′	40	146
Matsushiro	Aug. ,1965~ Dec. 1970	Max. 5.4	—	—	—	57
Tokachioki	May 16,1963	7.9	143°35´	40°44′	0	202
Miyagiken -Oki	Jun.12,1978	7.4	142°10´	38°09′	40	83
Nihonkai -Chubu	May 26,1983	7.7	139°06´	40°24′	14	238
Chibaken Toho-Oki	Dec.17,1987	6.7	140°29´	35°21′	58	9
Hotsukaido Nansei-Oki	July 12,1993	7.8	139°12′	42°47′	34	18
Notohanto-Oki	Feb.7, 1993	6.6	137°18′	37°41′	30	21
Hyogoken-Nanbu	Jan.17,1995	7.2	135°00′	34°36′	20	1222

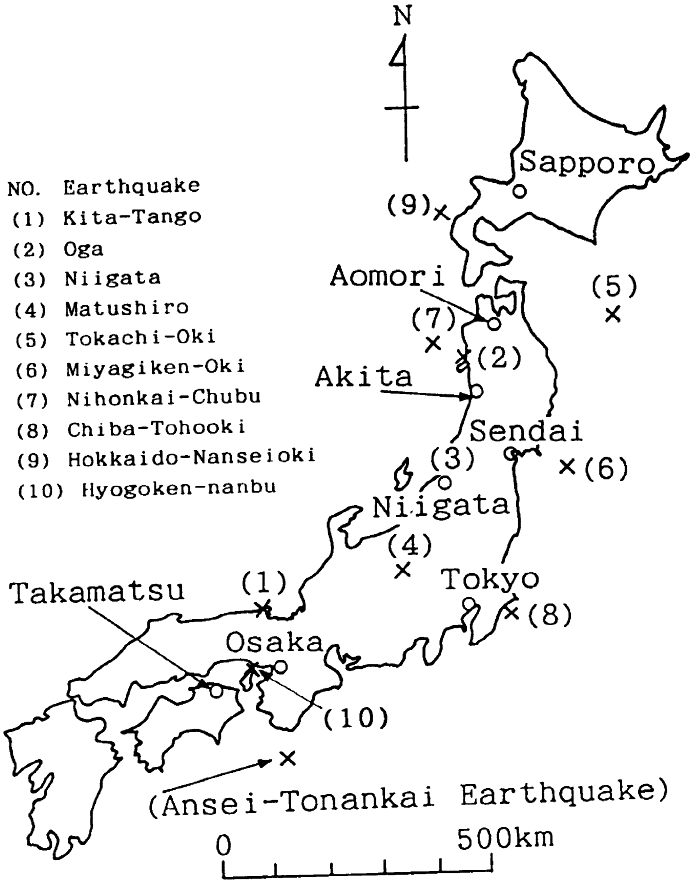

Fig. 1. Epicenter of several earthquakes

including earth dams, land reclamation embankments, farm roads, and pipelines were affected. Far large-scale fill dams designed using modern soil mechanics, only very slight damage was generatedeven by this earthquake. Earth dams for irrigation suffered heavy damage, including failure. This paper describes and characterizes the damage to earth dams, and reports on what is known so far on the geotechnical characteristics of the damage to earth dams.

GENERAL ASPECT OF DAMAGE

There are about 51,000 earth dams in Hyogo prefecture. From this earthquake, 1,222 earth dams were damaged and Fig. 2. shows the distribution of the earth dams damaged and faults in this area. Damage was especially severe in the northern part of Awaji Island, which was near the epicenter, but also occurred within a relatively narrow range of about 90km from the epicenter. The reason for this is that the earthquake was an inland type and thus caused strong shocks within a relatively narrow area.

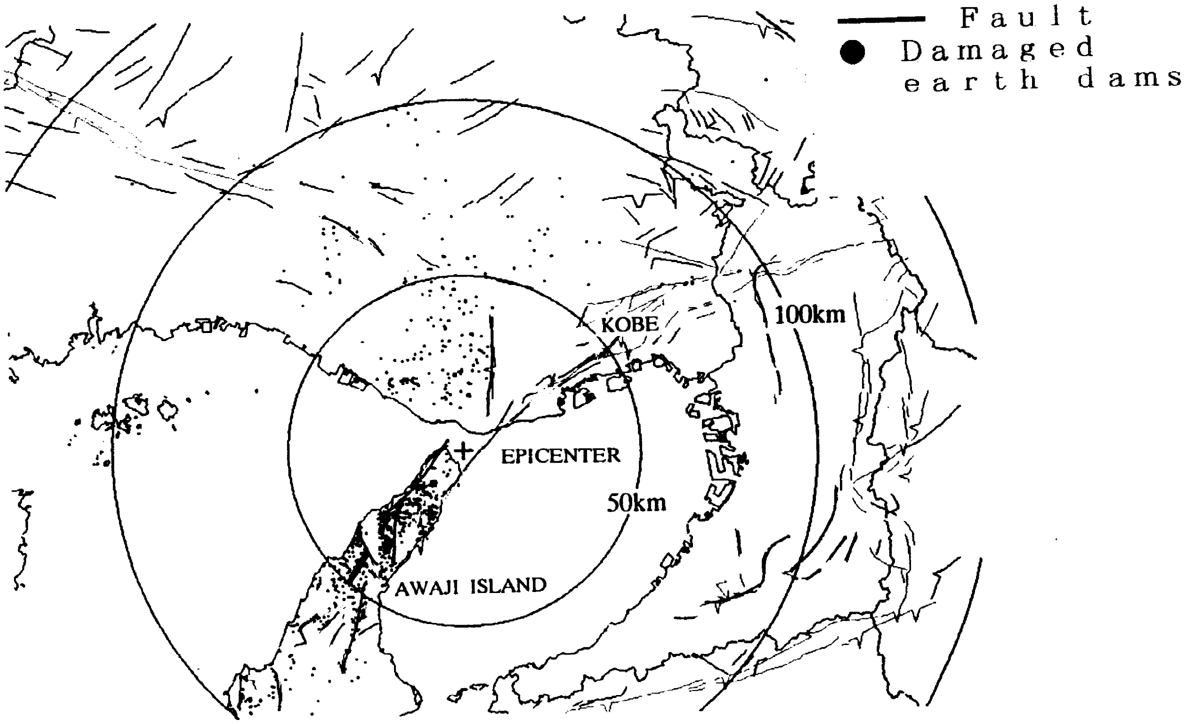

Fig. 2. Distribution of the damaged earth dams

Fig. 3 . shows the damage rate((number of damaged earth dams / total number of earth dams) X 100%) for earth dams in each affected district. In districts with a small number of earth dams, the ratio is very high even if damage occurred only in a relatively few earth dams. The damage rate therefore, is high even in districts far removed from the epicenter, although for the most part the damage rate was highest near the epicenter. Fig. 4. shows the relationship between earth dam damage rates and the average distance from the epicenter for each municipality. The solid line in fig. 4. is assumed to represent the maximum value for the relationship between damage rate and distance from epicenter. Although this relationship differs depending on the conditions of the foundation and embankments, the line in the figure is to represent the maximum values of distance from epicenter and the earth dam damage rate which was likely attributable to the earthquake. The example of the Nihonkai-Chubu Earthquake (M=7.7) shown in Fig. 5. is to express the relationship between damage rate and distance from the epicenter for different magnitudes.

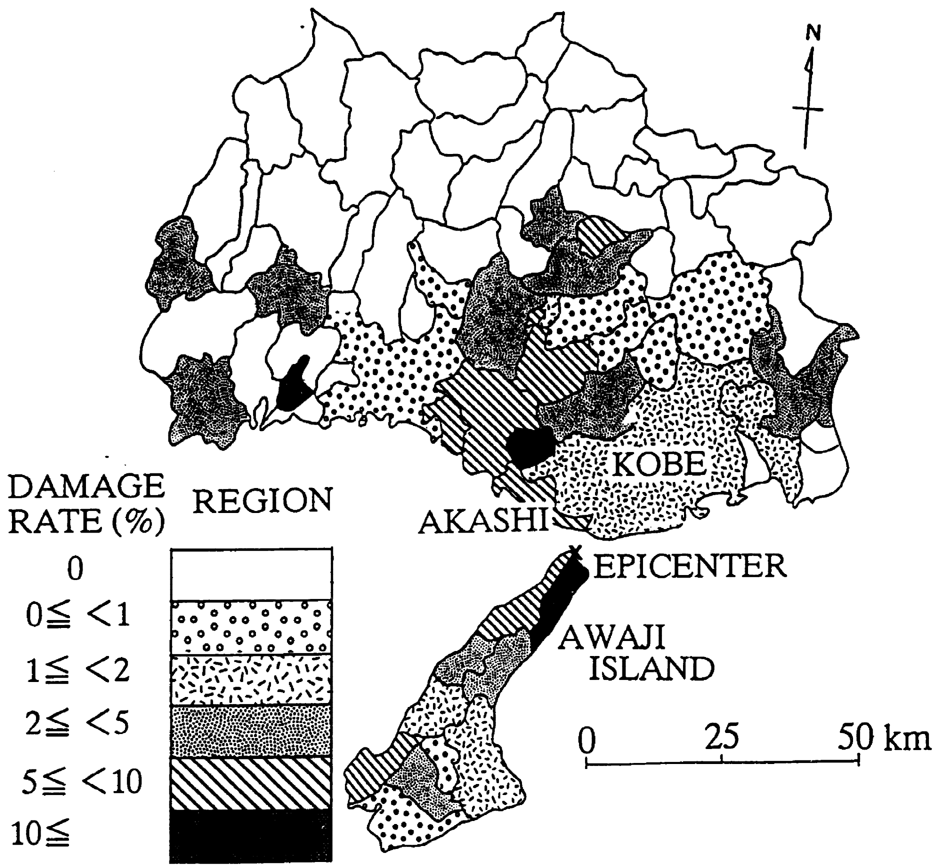

Fig. 3. Distribution of damage rates of these earth dams

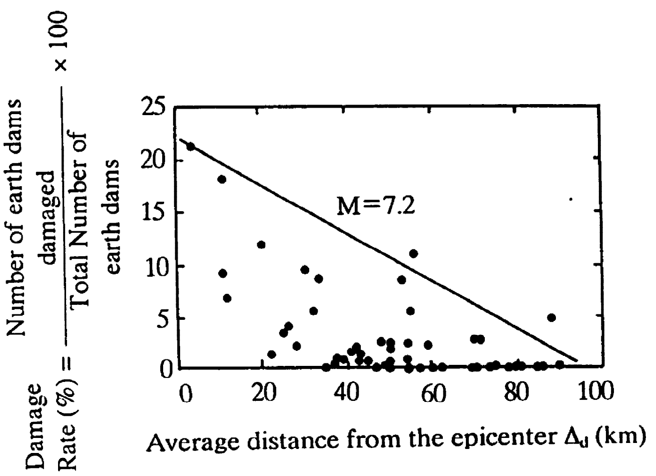

Fig. 4. Relationship between damage rate and average distance the from epicenter for the Hyogoken Nanbu Earthquake

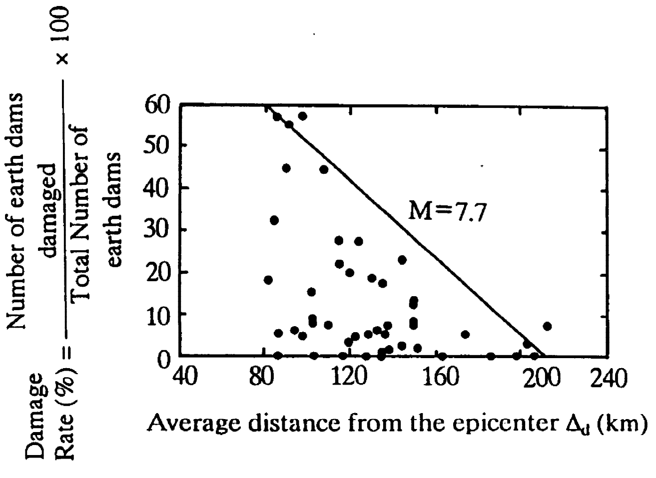

Fig. 5. Relationship between damage rate and average distance from the epicenter for the Nihonkai-Chubu Earthquake

Fig. 6 . depicts the relationship between average distance from epicenter and estimated maximum damage rate as a function of magnitude for the Tokachi-oki, Niigata, Japan Sea, and the 1995 Hyogoken-Nanbu earthquakes shown in Table 1. Since the degree of damage and subsoil and embankment conditions were not taken into account, these are merely conservative estimates. Fig. 7 . shows the relationship between earthquake magnitude (M) and epicenter distance for the earth dams farthest from the epicenter which was damaged by the earthquake (hereafter called "critical distance from epicenter"). Using past data, the relationship between M and critical distance from epicenter can be expressed as

$$\log \Delta d = 0.858M - 4.28 \qquad (1)$$

where Δd= critical distance from epicenter and M= magnitude. This relationship is shown by the solid line in the figure, which also delineates the boundary of the damage area. The upper area sustained no damage, and the damage rate the lower area is where damage most likely occurred. The damage rate therefore increases in a downward direction as can be seen in this figure. It should be noted that the critical distance from the epicenter signifies the distance from the epicenter in Fig. 5. at which the damage rate decreased to zero.

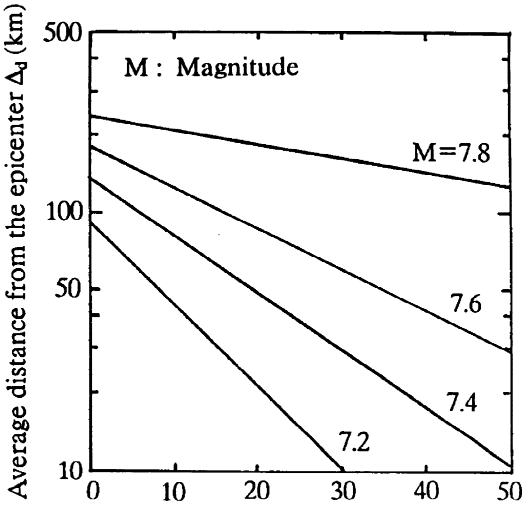

Fig. 6. Relationship between average distance from epicenter and damage rate based on past earthquake data

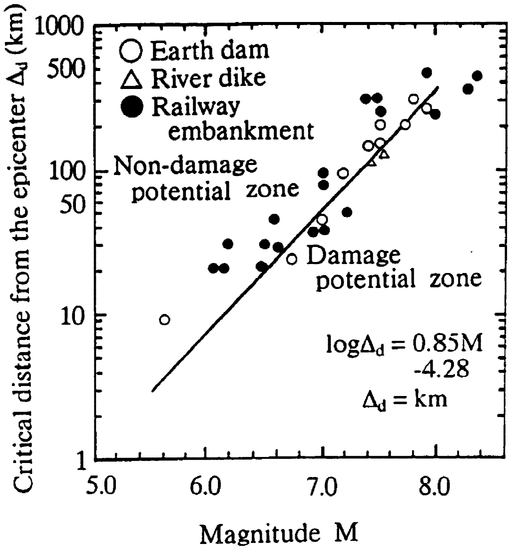

Fig. 7. Relationship between magnitude and critical distance from epicenter

GEOLOGICAL CONDITION OF DAMAGED EARTH DAMS

Table 2 shows the relationship between the geologic type of foundation and earth dam damage, based on data which are currently available. In the upper and middle layers of the Osaka group, there are numerous incidents of damage in the terrace and alluvial deposits, but these decline as one moves from the bedrock to the lower layers of the Osaka group. Generally speaking, most damage occurred in the Quaternary layers. It is necessary to thoroughly investigate data for all earth dams, including those which have not yet sustained damage, at the time such data are obtained. Despite the fact that there are numerous reservoirs in the upper bedrock layers in northern Awaji Island, there were a considerable number of damaged areas, probably because 1) this is where much of the seismic activity occurred, and 2) earth dams are dependent on the local subsoil conditions immediately below the embankments.

Table 2 Relationship between geological classification and damage on earth dam

	Number of total earth dams	Damage rate (%)	Geological classification				
			Surface geology			Base rocks	
			Quaternary			Neogene	Cretceous
			Recent alluvial deposits	Terrace deposits	Osaka group (Upper, lower part)	Osaka group (Lowermost part)	Base rocks
Total	51,679	2. 4	9 4	1 5 6	1 5 1	1 2 0	2 5 4
			4 0 1				

CLASIFICATIONS OF DAMAGE TYPES AND SOIL PROFILES OF DAMAGED EARTH DAMS

The types of damage to earth dams caused by the 1995 Hyogoken-Nanbu Earthquake have been classified as follows

Level I: Failure of embankments, sliding, dam facilities completely destroyed, crack width of more than 5cm

Level II: Small-scale sliding, leakage in the embankment, damage to dam facilities, crack width of 5 cm or less

Level III: slight damage to dam facilities and embankments

Level I indicates the greatest extent of damage, followed by Levels II and III, in that order. A report on all types of damage sustained by a typical Level I earth dam is present ed as follows. The locations of all earth dams are shown in Fig. 8 ., while Table 5 . lists their respective data.

Table 3. Outline of damaged earth dams

Damage type	Level I	Ⅱ	Ⅲ	Total
Numbers (%)	349 (37.2)	480 (51.3)	108 (11.5)	937

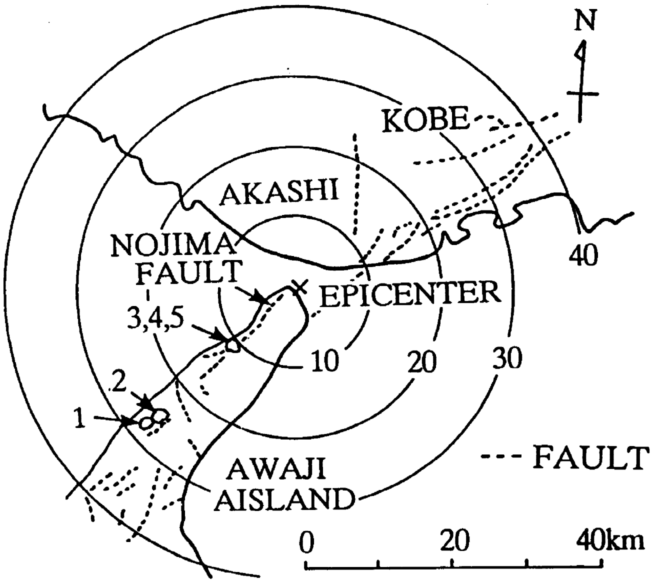

Fig. 8, Location of the damaged earth dams

Table 4. Data from the damaged earth dams

Site No.	Name of Dam	Height (m)	Unified Classifi-cation	Details of Damage
1	Ideno -shiri	6.0	SM	Failure due to liquefaction
2	Koujin	5.0	SM	Longitudinal 20cm wide cracks on the crest
3	Mukumoto	5.8	SM	Failure of spillway
4	Izuminaka	7.3	SM	Sliding of upper slope
5	Izumi	6.0	——	Cracks on the upper slope

Fig. 9. outline the damage to Idenoshiri Dam, where the central part of the embankment failed. Sand boil due to liquefaction was observed within the water storage area. The grain size distribution indicates this to be fine sand. Soil profile obtained from a post-earthquake boring. The embankment section has an N-valueof less than 5 and is composed of fine sand. The results of cyclic triaxial tests indicate that liquefaction strength was not veryhigh. These results suggest that liquefaction caused damage to the embankments and foundations of this earth dam. Fig. 10. shows the locations of the three earth dams close to 'the Nojima Fault'. The example of Mukumoto Dam illustrates complete failure of dam facilities. Fig. 11 shows the failure to the spillway on the left side of the crest. Almost no damage was seen in the embankment section itself. The embankment consists of a mixture of silt and fine sand with an N-value of ≒ 5. Near this dam are two other earth dams (Izuminaka and Izumi), where the Nojima Fault runs parallel to the longitudinal axis of these dams for several meters.

Fig. 11. shows the extent of damage sustained at Izuminaka Dam immediately after the earthquake. Sliding was detected on the down stream slope of the dam and leakage was found on the downstream slope of the dam. The results from a boring made after the earthquake are shows that the N-values and soil types were similar to those of Mukumoto Dam, Izuminaka Dam suffered extensive damage. Only a few minor cracks developed on the upstream slope of Izumi Dam. Even though the Nojima Fault is in the immediate vicinity, the embankment suffered only minor damage. No boring surveys were conducted at this dam. Despite having with stood severe shocks from the earthquake, the embankment suffered only minor damage. The reason for this could be because the Nojima Fault runs parallel to the embankment, although detailed analytical investigations will have to be conducted to determine the exact causes.

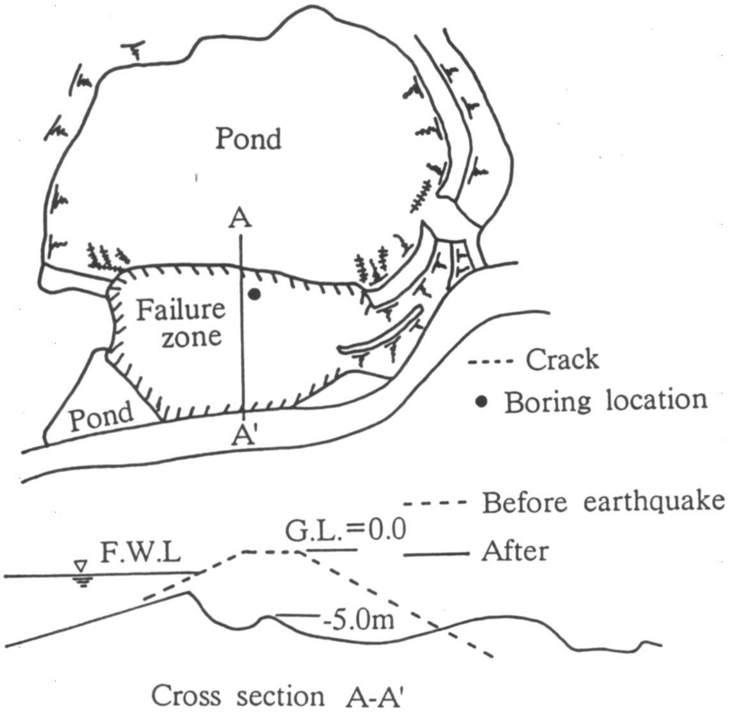

Fig. 9. General condition of the Idenoshiri Dam after earthquake

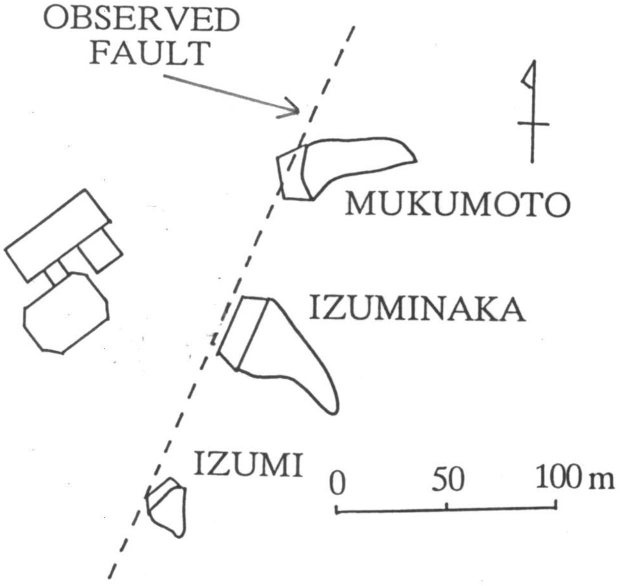

Fig. 10. Location of the earth dams close to the Nojima Fault

Fig. 11. Damage to the spillway on Mukumoto Dam close to Nojima Fault

Fig. 12 Damage to Izuminaka Dam close to Nojima Fault

The greatest number of damaged areas were of the Level II category. Since only moderate damage occurred at this level, repairs to damaged sections could restore the water storage capacity of the affected dams. Since Level III represents only slight damage to embankment and dam facilities, it is possible to store water for this type of damage. Other than the above damage, no invisible types of damage were detected, although there were about 100 reservoirs which leaked or were otherwise unable to hold water when the water level was raised. Although it is believed that leakage originated from the dam or its foundation, the exact cause is still unknown. Since the 1995 Hyogoken-Nanbu Earthquake occurred in January, most of the reservoirs held little water. In past damage surveys 2), the higher the water level, the greater the damage that occurred. Previous reservoir-damaging earthquakes had occurred in May, June, and July, when the water level was high. Since the 1995 Hyogoken-Nanbu Earthquake occurred in winter, most of the reservoirs were at 30% or less of storage capacity. Had the water level been higher therefore, even greater damage might have occurred.

CONCLUSION

The 1995 Hyogoken-Nanbu Earthquake caused damage to many agricultural small-scale earth dams. Large-scale fill dams, which were built with modern technology, sustained only minor damage. About 1,222 earth dams sustained some sort of damage, a higher number than in past erthquakes. Since the magnitude of this earthquake was 7.2 and it was small in scale, damage was also limited to a relatively narrow area within a radius of about 90 km from the epicenter. Survey results obtained so far on the damage and the soil conditions can be summarized as follows:

(1) Damage surveys from the 1995 Hyogoken-Nanbu and previous earthquakes indicated that a constant relationship exists between the average distance of a region from the epicenter and the damage rate of earth dams. Using these results, we were able to derive a relationship between magnitude as a function of the average distance from epicenter and the estimated maximum damage rate of earth dams.
(2) Based on the classification of Levels I, II, and III ; Level I damage in Hyogo Prefectur e accounted for 37% of all damaged types. Based on this, it can be said that the damage caused by the 1995 Hyogoken Nanbu Earthquake was much more extensive than from past earthquakes.
(3)Boring surveys was conducted at Idenoshiri Dam to provide a case study for Level I damage. The results of these surveys indicated that liquefaction in the embankment and foundation may have caused them to fail.
(4) Three earth dams which are located in the immediate vicinity of the Nojima Fault were also surveyed. Although the fault line is only a few meters away from the downstream slope, the embankment section of two of these earth dams sustained only minor damage, whereas the third dam suffered moderate damage. Since boring surveys showed little difference among the soil characteristics of the dam bodies and foundations of the three dams, it will be necessary to clarify the reasons why there was variation in the extent of the damage.

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