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Consideration of Earthquake Damage to Earth Dam for Irrigation in Japan

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SYNOPSIS: There are many samll earth dams for irrigation called "TAMEIKE" in Japan, Most of them were constructed before modern soil enginnering were established on the basis of empirical :echniques. Earthquakes in the past gave much damage to these earth dams. This paper surverys damage of earthquake for those remaining on records again, and as for Nipponkai-Chubu Earthquake, detaild .nvestigations such as in-situ test, laboratory test, analysis were made to clarify causes of the damage to earth dams. From the result of sruvey, the following matters were found; i.e., large damages occur at a high rate on earth dams whose foundation ground and embankment are consist of oose sand, and tha major cause of the damage is liquefaction. When the embankment and the foundation ground are made of cohesive soil, the degree of damage is relatively small.

INTRODUCTION:

There are about two hundred thousand earth dams for irrigation called "TAMEIKE" in Japan. The oldest one in history was constructed in B.C.40. Every heavy earthquake in the past may caused damages to earth dams. The first systematic survey on earthquake damage to earth dams was performed for Oga-Earthquake (1939). Detailed survey of earthquake damage to earth dams 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 structure 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 progress is still not enough for secure prediction of actual earthquake damage. Detailed discission of the actual earthquake damage, and coupling the findings obtained here sould be coupled with the analysis.

This paper reviewed libraies and damage records in the past regarding the earthquake damage on earth dams. Further, insitu test, laboratory test, and analysis were performed as for Nipponkai-Chubu-Earthquake to investigate the damage cause.

HISTORY OF EARTHQUAKE DAMAGE

The first construction of the earth dam for irrigation in Japan was about 2030 years ago. In 1978, a farmland of 560 thousand hectare was irrigated by earth dams and the storage capacity was 21billion m^3. These earth dams are generally small in scale. Table 1 classifies the scale of earth dams. The most famous old earth dam in Japan is Mannoh Dam (heighe 32m) constructed in about A.D.700. It is still in use with repeated repairs.

Table 2 shows earth dams of 15m or more height in Japan. Among 1577 earth dams, 438 were constructed before 1868. Most of them were constructed in the EDO period (1603-1868) indicating the high level of construction techniques at that time.

History of earthquake damage begins with history of earth dam construction. The first earthquake damage in history is the collapse of Mannoh Dam (Kohchi Pref.) was collapsed in Nohbi Earthquake (1891). Detailed damage survey was made after Kita-Tango Earthquake (1927). Table 3 shows earthquake damages of earth dams. Figure 1 shows the epicenter of each earthquake.

Table 1 Categorization of Earth Dam in Scale

Height	(m)	<5	5~10	10~15	>15
	(%)	33	49	13	5
Storage Capacity	($m^3 \times 10^3$)	<5	5~10	10~50	>50
	(%)	27	19	40	14

Table 2 Constructed Period of Fill Dam with Height of More Than 15 m

Constructed Period	Before 1867	1868 ~ 1945	1946 ~ 1982	Under Construction	Under Planing	Total Number
Numbers (%)	438 (23.4)	610 (32.6)	599 (32.0)	186 (9.9)	3.9 (2.1)	1872 (100)

Note:Number of earth Dam is 1506

As for Oga Earthquake (1939), the damage was surveyed in detail by Akiba. The result was fully quoted by H.B.SEED (1979, Rankine Lecture). The major conclusion is that a large damage occur to the earth dam whose embankment is made of sandy soil. This indicates that the cause of damage was liquefaction. Later, survey of earth dam damage was practiced for Niigata Earthquake (1964), Tokachi-Oki Earthquake (1968), Miyagiken-Oki Earthquake (1978), Nipponkai-Chubu Earthquake (1983), and Chiba-Toh.hoh-Oki Earthquake (1987).

This paper discussed tha past earthquake damage of earth dmas, particularly detailed damage survey and analysis of Nipponkai-Chubu Earthquake to clarify the cause of earth dam damage.

Table 3 Earth Dam Damage Caused by Earthquake

Name of Earthquake	Date	Magnitudu M_J	Number of Earth Dam Damaged
Kita-Tango	Mar. 7, 1927	7.5	90
Oga	May 1, 1939	7.0	74
Niigata	Jun. 16, 1964	7.5	146
Matsushiro	Aug., 1965 ~ Dec., 1970	Maximum 5.4	57
Tokachi-Oki	May 16, 1968	7.9	202
Miyagiken-Oki	Jun. 12, 1978	7.4	83
Nipponkai -Chubu	May 26, 1983	7.7	238
Chibaken-Toh. hoh-Oki	Dec. 17, 1987	6.7	9

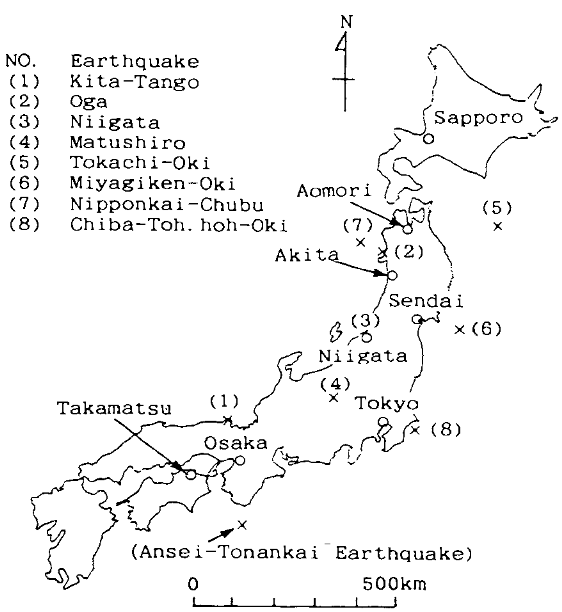

Fig.1 Epicenter of Several Earthquakes

ASPECT OF EARTH DAM DAMAGE

Genaral aspect

Figure 2 shows the earth dam damage distri butioned caused by Nipponkai-Chubu Earthquake. distance from epicenter was divided by every 2C to determine the damage rate (Total number of damaged earth dams divided by total number of earth dams) of earth dam in each area. Figure shows the relation between the distance from epicenter and the damage rate. The same relation was determined for other earthquakes to fi the distance from epicenter corresponding to 17 damage rate of earth dams (hereinafter referrec to as critical distance from epicenter). Figur 4 includes data of earth dams and analogous structures; river dikes and railway embankment. Rivers and earth dams have a similar relation. The relation between magnitude and critical distance from epicenter for earth dam was determined by the least squre method as shown below.

$$\log \Delta_d = 0.858\ M_J - 4.28 \qquad (1)$$

where M_J : Magnitude
Δ_d : Critical distance from epicenter (K

The value of equation (1) depends on property of earthquake, ground conditions, and ear Dam conditions. However, the approximate distance from epicenter at which a damage starts t occur can be determined by providing the distan from epicenter and the magnitude.

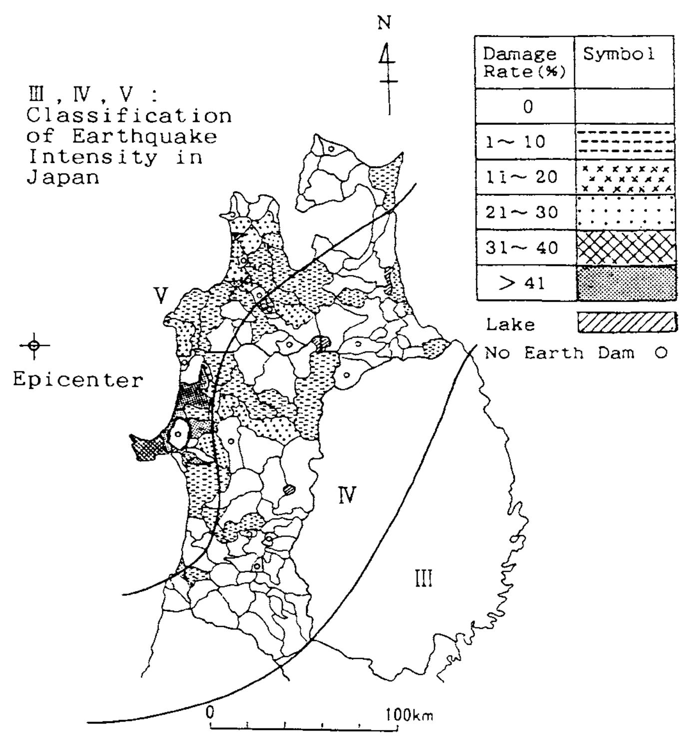

Fig.2 Distribution of Earth Dam Damage Caused by The Nipponkai-Chubu Earthquake

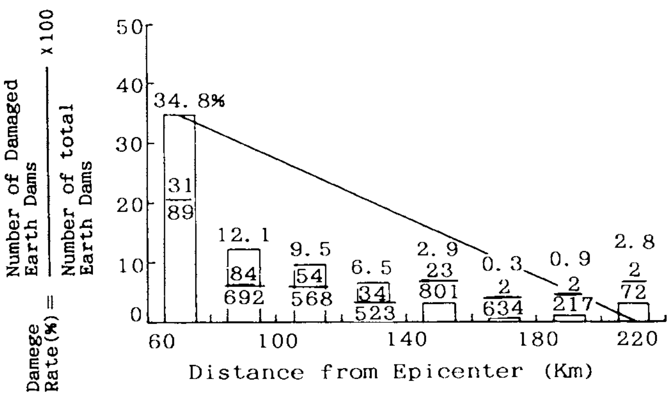

Fig.3 Damage Rate (%) versus Distance from Epiceter in The Case of The Nipponkai-Chubu Earthquake

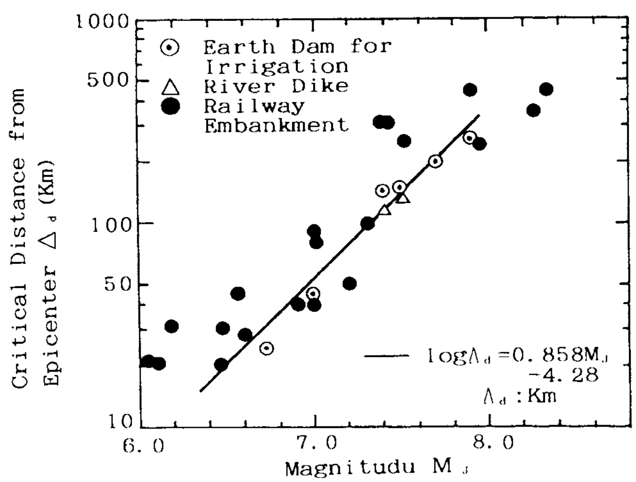

Fig.4 Magnitudu versus Critical Distance from Epicenter

Table 4 summarizes the outline of earth dam damage caused by five past earthquakes. The damage can be divided as the dam body damage and dam facilities (spilway, outlet works). Further, dam body damage can be classified into functional defects (crack, settlement, slip) and failure which makes water storage impossible. These damages may occur at the same time; e.g., settlement occurs accompanying slip, or on the contrary settlement and crack may occur independently. Table 4 lists, in the event of plural damages, all of them.

As for cracks, most of them are longitudinal cracks in parallel with the dam body axis. They are frequently generated in upper slopes and crests of dam. The reason for this may be the difference in stability between upper and lower slopes. Lateral cracks im the direction perpendicular to the dam axis can be coupled with a large damage because of a possiblility of water leak from dam bodies although such cracks occur only by a small rate. Most lateral cracks cross the dam body.

In Nipponkai-Chubu Earthquake, lateral cracks are generated on the border between aboutment and dam body, and near lutlet works at a rate near 50%. The same thing is pointed out in the survey result of Oga Earthquake. These tendency may be based on the behavior difference between aboutment and dam body, and between dam body and outlet works.

In any earthquake, slip and slope swelling occur upstream about twice as frequent as downstream. There are some cases where three-dimensional slope slip is clearly recognized among slips.

TYPE OF DAMAGE

For rough grouping the type of damge in Nipponkai-Chubu Earthquake, classification was carried out on the basis of major causes of damage, making reference to the damage classification for river diked and railway embankment.

Table 4 Outline of Earth Dam Damage

Name of Earthquake	Number of Surveyed Earth Dam	Damage of Dam Body								Dam Facilities	
		Damage on Function of Dam							Failure	Outlet Works	Spilway
		Crack			Slip			Settle-ment			
		Late-ral	Longi-tudinal	Both	Upper Slope	Lower Slope	Both				
Oga	58(6)	43	0	5	17	6	6	42	12	9	6
Niigata	123(37)	87	3	8	34	16	1	30	7	38	7
Tokachi-Oki	93(8)	24			25	10	4	8	10	24	
Miyagiken -Oki	83(5)	49			17			7	0	6	
Nipponkai -Chubu	218(15)	138	3	16	32	21	10	79	10	50	28

Note: ( ) is number of earth Dam with height of more than 10m

Table 5 shows classified types of damage. Type I and III occupy 30% respectively, and followed by types II, IV and other types. Type V was only 1.8%. Type I (crack) almost keeps the shape of dam body with a little settlement, and cracks alone are generated. The feature of this type is that many dam bodies are made of clay on good foundation ground. There were three examples of cracks generated along the line grouted in the past. Type II (settlement) was produced keeping the shape of dam body with accompanying cracks. This type occurs frequently on a weak ground, and its major cause is thought to be the settlement of foundation ground.

Type III (failure of slope) and type IV (slip) are basically of the same type of damage, but type III is more slight in damage than type IV. Most part of the dam body remains sound and a large damage is not reached in type III. An evident slip is recognized in type IV, though this type is only few in the number of damages. But most part of the dam body is settled by slip in type IV, frequently causing large damage such as failure.

A clear slip surface is recognized in the dam body of two earth dams, Unoki and Ichinisawa failed in Nipponkai-Chubu Earthquake, though this slip surface is not definite within the ground. Fugure 6 shows the slip line confirmed by excavation of dam body after the earthquake in Unoki. (Akita pref.) The slip line not clearly seen at the lower part, but it can be estimated that the slip line passes through the shallow part of the silty clay layer directly under the dam body. This applies also to the case of Ichinosawa (Akita Pref.) It is estimated that liquefaction has occurred in the counterweight fill and the sand bed.

Table 5 Relationship between Type of Damage and Soil in The Case of The Nipponkai-Chubu Earthquake

Type of Damage		I Crack	II Settle-ment	III Failure of Slope	IV Slip	V Failure	Dam Facilities
Number of Damage		69	47	62	13	4	23
Material of Dam Body	Sandy Soil	4	11	8	2	3	5
	Clay Soil	57	30	48	11	1	17
	Others	8	6	6	0	0	1
Rate (%)		31.6	21.6	28.4	6.0	1.8	10.6

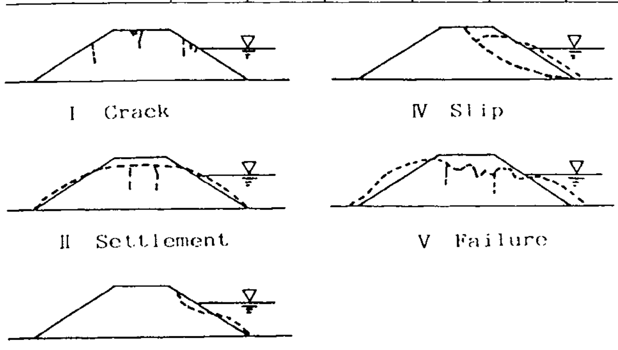

Fig.5 Classification of Damage Type

In type V, the dam body and the foundatior ground are broken. Though the number of damag is very few, the earth dam failure occurs in many cases like type III. The estimated cause are liquefaction of dam body and foundation ground. Besides these, outlet works, spilway, abutment break, and damage to only covering block occupy about 10% of all.

Earth dam failure frequently occur near th center of dam body. According to boring surve at several earth dams, the failure point was at the deepest portion of valley. In many cases, a weak layer is deposited to a maximun thickne in this portion, sometimes causing a large settlement by consolidation etc. Pipes for outlet works are frequently burried in this position, and it is estimated that deterioration of these pipes leading to weakening of dam. Frequent earth dam fauilure near its center may be due to the above composite function.

The survey report of Oga Earthquake and Niigata Earthquake says that most failures occu several hours or more than one day after the earthquake. H.B.SEED points out that this is due to re-distribution of pore water pressure, or piping (1979). Table 6 shows the time peric after the earthquake till the earth dam failure for Nipponkai-Chubu Earthquake. In this result only one example of Aomori pref. applies to the conclusion of Oga, and Niigata Earthquakes, anc most dams are estimated to have failed within a short period (30 minutes) immediately after the earthquake.

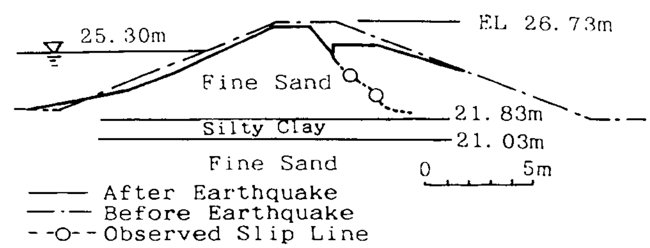

Fig.6 Observed Slip Line of Unoki Dam Caused by The Nipponkai-Chubu Earthquake

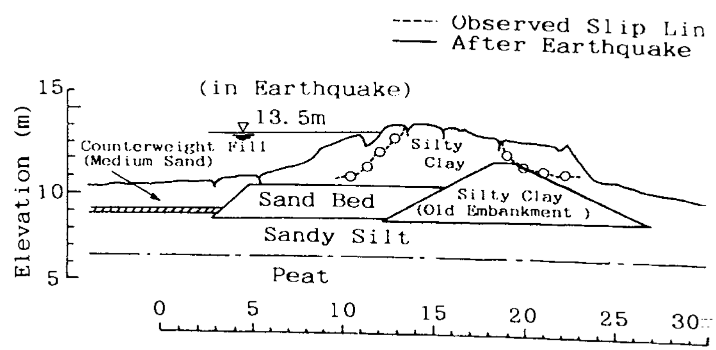

Fig.7 Observed Slip Line of Ichinosawa Dam Caused by The Nipponkai-Chubu Earthquake

Twenty seven earth dams were randomly sampled for Nipponkai-Chubu Earthquake to investigate the presence of temporary restoration. According to the result, the cracks were covered with sheets or sandbagged within two days for eight dams. To stop water leaks generated around the dam body or outlet works, some emergency measures such as watre level dropping were made for about 30% of the whole 27 samples. Many earth dams for irrigation out of all damaged ones are thought to be subjected to emergency measures. Here is an example of "delayed failure" in Aomori pref. The failure occurred by piping one day after the earthquake with out emergency measures. Above described examples show that emergency restration is effective to prevent delayed failure by piping. As a general result, appropriate emergency measures after damage occurrence can prevent the secondary damage although delayed failure may be possible as a symptom.

Table 6 Time Taken to Cause Failure of Earth Dam after Earthquake in The Case of The Nipponkai-Chubu Earthquake

Time (min)	0～20	21～30	31～60	After 1 day	Unknown
Case	3	2	2	1 (Piping)	2

DAMAGE FACTOR

This section studies those factors that affect earth dam damages. Only the data of Nipponkai-Chubu Earthquake are exhibited in this article since a sufficient space is not left. The relation between the dam height and the damage rate is shown in Table 7. Generically, for dams of height not more than 20m (30m), the damage rate increases as the height increases. No damage occurs in 30m or higher dams. The same tendency was observed in Oga and Niigata Earthquakes though the data are not included in Table 7. Most failures occurred in 5-10m high dams. Only Hayagake dam (height 12.0m) among those above 10m height failed in Tokachi-oki Earthquake. This tendency may be caused by the fact that the earthquake magnification increases generally as the dam height increases. No particular relation was observed between crest length and damage occurrence. The relation between shape factor (crest-lengh/height) and damage in Nipponkai-Chubu Earthquake is shown in Table 8. The damage rate is almost constant above 5 of shape factor, while the damage rate is reduced below 5 of shape factor, in particular, damage does not occur below 2.5. This trened may be caused by the constraint effect of abutment. Also in other earthquakes, no damage occurred below 2.5 of shape factor.

Table 9 shows the number of damage and damage rate for each dam body soil obtained from questionnairing for 218 damaged earth dams and 1834 non-damaged earth dmas in Nipponkai-Chubu Earthquake. The number of damage of clay and gravelly clay occupies as high as 80% in comparison with sandy soil. On the other hand, the damage rate of sandy soil. On the other hand, the damage rate of sandy soil against all earth dams including non-damaged earth dams is as high as nearly 20%. This is nearly twice the rate of clay and gravelly clay. This tendency is more obvious with the damage rate of largely damaged earth dams. Dam body soil was sampled at 39 places of a damaged earth dam and at 18 places of a non-damaged earth dam, and subjected to physical tests. As for the non-damaged earth dam, the one which belongs to the similar region, geography and height was selected as far as possible. Figure 8 shows grain sizes of the damaged and non-damaged earth dams in the triangular diagram. Many data of damaged earth dams are located at left bottom of the triangular diagram. These grain sizes are roughly classified into coarse grain soil and fine grain soil according to the unified soil classification system as shown in Table 10.
The tendecy that many damaged earth dams consist of coarse grain soil is found from Table 10. Those earth dams with particularly large damage mostly consist of coarse grain soil. Similarly in the survey of Oga Earthquake, many damaged dams were of coarse grain soil, and it was pointed out that this tendency was remarkable among failed earth dams.

Table 7 Relationship between Dam Height and Damage on Earth Dam

Earthqauake	Tokachi-Oki			Miyagiken-Oki			Nipponkai-Chubu		
Height	①	②	③	①	②	③	①	②	③
0～4.9	932	138	14.8	3990	27	0.6	1235	123	10.0
5.0～9.9	241	55	22.8	2645	45	1.7	481	81	16.8
10.0～14.9	25	5	20.0	255	6	2.4	79	9	11.4
15.0～19.9	9	2	44.8	88	5	5.7	28	5	17.9
20.0～29.9		2					9	0	0
> 30	1	0	0	29	0	0	2	0	0
Total	1208	202	16.7	7007	83	1.2	1834	218	12.1

Note: ① Total Number of Earth Dam
② Number of Earth Dam Damaged
③ Damage Rate (%)=② / ①

Table 8 Relationship between Ratio (Lenght/Height) and Damage on Earth Dam

Earthquake / Length of Dam Crest / Height of Dam	Nipponkai-Chubu: Total of Earth Dams	Number of Damaged Earth Dams	Damage Rate (%)
0～2.49	8	0	0.0
2.5～4.99	72	2	2.8
5～7.49	193	26	13.5
7.5～9.9	182	19	10.4
10～19.9	639	77	12.1
20～29.9	316	35	11.1
> 30	403	59	14.6
Total	1834	218	11.9

Table 9 Relationship between Soil Type of Dam Body and Damage on Earth Dam in The Case of The Nipponkai-Chubu Earthquake

Soil type	Total Number	Number of Damage	* Number of Heavy Damage	Rate (Total) (%)	Rate (Heavy Damage) (%)
Sandy Soil	215	43	10	20.0	4.7
Clay Soil	1258	130	5	10.3	0.4
Gravel Clay Soil	287	40	1	13.9	1.4
Others	74	5	0	6.8	0
Total	1834	218	16	11.9	0.9

* Note : Heavy Damage Means Failure or More than 1.0m Settlement

Table 10 Relationship between Soil Classification and Damage on Earth Dam in The Case of The Nipponkai-Chubu Earthquake

Soil Classification	Not Damaged	Damaged
Coarse-grained soils (More than half of materials is larger than 75μm sieve size)	10	25(8)
Fine-grained soils (More than half of materials is smaller than 75μm sieve size)	8	14(2)

Note: ( ) is Number of Heavy Damage

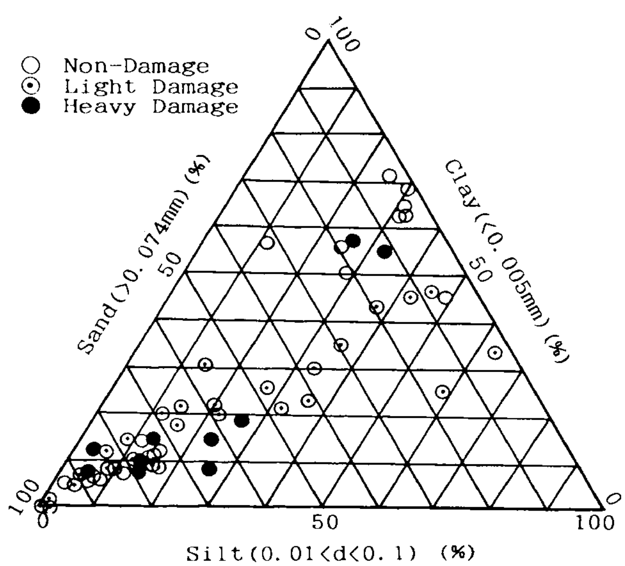

Fig.8 Grain Distribution of Earth Dam Materials Surved in The Case of The Nipponkai-Chubu Earthquake

The relation between the mean diameter of grain (D_{50}) and damage will be examined next. D50 values of dam body soil of damaged and nondamaged earth dams are plotted in Fig.9. The range of D_{50} that can cause liquefaction ($0.02<D_{50}\leq 2$mm) is indicated in Fig.9. As for a non damaged earth dam, only 7 places (39%) out of 18 places are in this range, while 27 places (69%) out of 39 places are within the range for a damaged earth dam. This tendency is particularly strong with largely damaged earth dams.

Table 11 shows the relation between the age of dam construction and the damage rate for Nipponkai-Chubu Earthquake. It is found that those dams within ten years after constructed exhibit a large damage rate. When those dams are divided into two groups; i.e., dams. constructed within three past years and others, the damage rate of the former is particularly high. This may be explained that the dam body stability is improved by aging and accompanying natural consolidation after constructed.

Similarly in Oga, Niigata, Tokachi-Oki, and Miyagiken-Oki Earthquakes, those dam bodies within 10 years after construction exhibited a large damage rate. As mentioned above, the tendency that those dam bodies within about ten years after construction are subjected to heavy damage. In the survey of railway embankment for Tokachi-Oki Earthquake, the damage rate of new embankments (within three years after constructed) was as large as about six times of older embankments.

For most of the above mentioned earth dams, the damage of each dam was relatively slight. Therefore, damaged earth dams of relatively recent construction are limited to small scale ones which are not covered by the design standard. The same conclusion applies to examples of failure.

The relation between the direction of focus and the damage was investigated for Oga, Niigata Miyagiken-Oki and Nipponkai-Chubu Earthquakes without finding any definite tendency.
The relation between the water level and the damage rate exhibited indefinite tendency for each earthquake with no steady tendency.

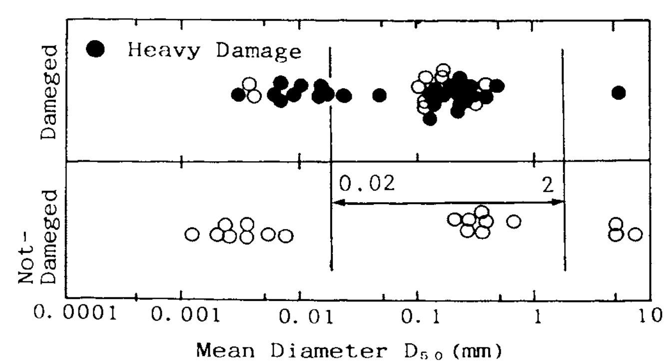

Fig.9 Mean Diameter of Earth Dam Materials Surved in The Case of The Nipponkai-Chubu Earthquake

For only 10 examples of failure by Nipponkai-Chubu Earthquake, seven out of ten failed dams have a water storage rate above 0.75 indicating that a high storage rate is readily coupled with a large damage. In Nipponkai-Chubu Earthquake, for those earth dams repaired in the past by grouting, cracks occurred in the vicinity of grouted places. The probable cause for this crack generation at the above places may be insufficient familiarity and the large regidity difference between the dam body and the grout. This indicates that grouting ingredients familiar enough with dam body have to be selected.

Table 11 Relationship between Constructed Period and Damage on Earth Dam in The Case of The Nipponkai-Chubu Earthquake

Coustructed Period	Number of Earth Dam	Damage	
		Number of Earth Dam Damageed	Rate (%)
1973～1983 (1981～1983) (1973～1980)	11 (4) (7)	4 (2) (2)	36.4 (50.0) (28.6)
1963～1972	2	3	13.6
1943～1962	112	23	20.5
1923～1942	127	20	15.7
Before 1923	342	36	10.5
Unknown	1220	132	10.8
Total	1834	218	11.9

CASE STUDY OF EARTH DAM DAMAGE

In Nipponkai-Chubu Earthquake, Kansuke dam (height 5.4m) in Aomori pref. was damaged obviously by liquefaction. Detailed study and investigation were made for this earth dam using boring survey, sampling by insitu freezing method. soil tests, and dynamic response analysis to determine damage causes. There was a subsidence of about 1.8m at the center of the dam body which may lead to failure. The subsidence was repaired by banking at the center. Figure 10 shows the emergency repair after the earthquake. In the body of this earth dam, a trace of sand boil from the bottom of dam body is confirmed. Figure 11 shows the boring date of the dam body and the foundation graound. The dam body and the foundation ground are loose sand. (N<15) down to-17m). The dynamic response analysis was perfomed (1987) for this earth dam by the finite element method considering the excessive pore water pressure. The earthquake wave observed in the vicinity was adjusted to 119 gal of maximum the acceleration and used as the input wave. Figure 12 shows the liquefaction region after 6 seconds. This analysis result proves the damage was caused by liquefaction.

EARTHQUAKE DAMAGE TO LARGE DAM

Earth dam damages due to earthquakes in the past are summarized as shown above. But these damaged earth dams were not designed on the conception of modern soil mechanics. Those fill dams designed in conformity with standards are amall in the number of damaged dams, and slight in the degree of damage.

Fig.10 Kansuke Dam after Emergency Repair

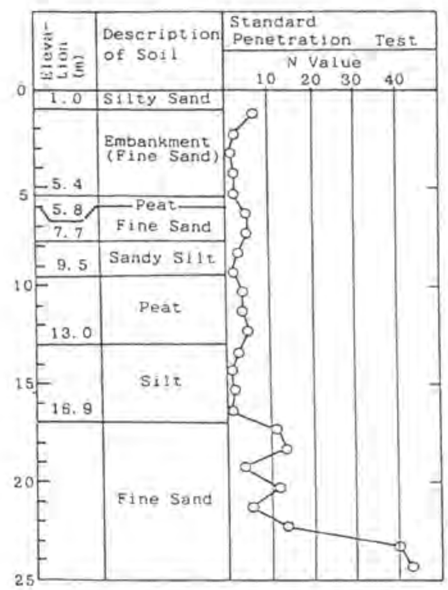

Fig.11 Soil Profile of Kansuke Dam Surved after The Nipponkai-Chubu Earthquake

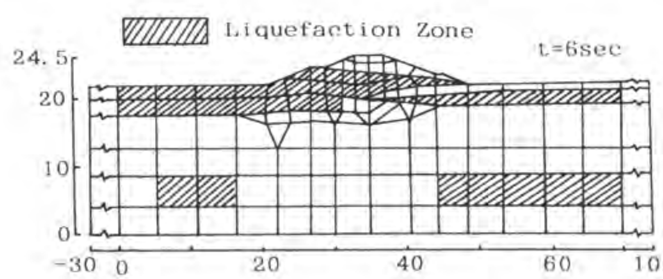

Fig.12 Liquefaction Zone of Kansuke Dam Calculated by Seismic Response Analysis (1987,Yasunaka,M,T.Tanaka,S.Tani)

Here are some examples of several large scale fill dams. In Akitaken-Namtohbu Earthquake (1970, M_J=6.5), a damage was generated at Ainono dam. This uniform type dam was established in 1961, and has a height of 41m. The distance from its epicenter is 13km. Major damages were only several longitudinal cracks generated on the crest of dam with a width of 5-25cm along a length of 40m.

In Naganoken-Seibu Earthquake (1984, M_J=6.9 Makio dam located very near the epicenter was damaged. This center core type rock fill dam of 105m high was completed in 1961. A strong motion seismograph with an upper limit of 300 gal was installed in this dam, but the magnitude of the earthquake exceeded the limit. On the dounsteam crest, the dam body material slipped down along the slope in a range of 20-25cm in width and 10-50cm in height with no relatively large damage. In designing the dam, K_h=0.15 was adopted and the minimum safety factor was cluculated as 1.37.

In Chiba-Toh,ho-Oki Earthquake (1988, M_J=6.7 damage occurred at Nagara dam. This zone type earth dam of 52m high dompleted in 1985. The distance from epicenter was 29km. The maximum acceletation observed in the upstream and downstream, directions observed on the ground was 262 gal, and the record at the crest was 369 gal. Settlement at the crest was about 2cm with only cracks on the crest.

For fill dams designed on the modern soil mechanics, only very slight damage was generated even by earthquakes exceeding the design intensity.

CONCLUSION

From the result of the above investigation, the followings can be concluded.
(1) Based on data of five earthquakes, the didtance from epicenter at which earth dam damage occurs is experessed using magnitude as follows;

$$\log \Delta_d = 0.858M_J \quad 4.28 \quad (\Delta_d : \mathrm{Km})$$

(2) Most cracks generated on dam bodies are longitudinal cracks in parallel with the dam body Lateral cracks perpendicular to the dam body are few in number, their places of occurrence are frequently on the border to the abutment and near outlet works.
(3) Slope slip occurrence upstream is twice as frequent as downstreams.
(4) Types of damage were classified into I through V addording to main causes of damage. Types IV and V are related with heavy damages.
(5) In the survey of Oga Earthquake, it is pointed out that most failures are categorized as dalayed failure. For Nipponkai-Chubu Earthquake, unlike Oga Earthquake, many failures occurred within ashort time ofter earthquake (immediately after 1-hour) with only one failure which occurred after one day. The probable cause of this is the reduction of the secondary damage due to piping by appropriate emergency measures after damage occurrence.

The following damage causes can be citied
(1) Damage rate is generally high as the dam height increases for dams of height below 20m (30m). This is probably because the ground guak is laegely amplified as the dam height increases except that large damage such as failures are mostly occur for 10m or lower dams. The damage is small with a shape factor (crest-lengh/height of 5 or less, and not much changed above 5. Thi is probably the three dimensional effect by constraint due to abutment.
(2) As for physical properties of dam body, the number of damages is large with sandy soil dam in the triangular diagram classification, particularly in examples of failure. From the view point of mean diameter D_{50}, the material of many earth dams are within the liquefiable size range This relation is reversed for non-damaged dams. It is estimated that liquefaction was the major cause of damage for many damaged dams.
(3) The damage rate is high for dam bodies withi 10 years after constructed. Further, in example of damages of Nipponkai-Chubu Earthquake and railway embankment, it can be pointed out that the damage rate of soil structures constructed within past three years is particularly high. This is probably because of increase in strength obtained by natural consolidation.

The typical case of damage due to liquefac tion was studied and analyzed in detail for kansuke Dam. According to toe result, liquefaction occurrence is analytically shown.

Damage of earth dam dur to earthquake was summarized as above particularly from existing libraries, materials and survey at site. Howeve these damaged earth dams are mostly small scall ones to which design standards are not applied. Damaged dams designed on design standards are few in number, and slight in the extent of damage

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