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QUANTITATIVE EVALUATION OF EARTHQUAKE DAMAGE OF SMALL EARTH DAMS FOR IRRIGATION

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SUMMARY

The statistical analysis was carried out on earthquake damages of small earth dams for irrigation. The data for this analysis were obtained from the questionnaire in Aomori and Akita prefectures hit by the 1983 Nihonkai-chubu earthquake and the Type II quantification analysis, one of multivariate analyses, was used in this study. As the results of analysis, 8 items were selected from 27 items as the factors greatly affecting the earthquake damage of a small earth dam. Weighting factors were given to items so as to discriminate the heavy-damaged group from the undamaged group including light-damaged dams as clearly as possible.

INTRODUCTION

There are about 250,000 small earth dams for irrigation in Japan. If these dams suffer damage due to an earthquake, the surroundings will be seriously affected by their damage. Measures for earthquake disaster mitigation of small earth dams for irrigation need to examine.

In order to prevent earthquake disaster of small earth dams smoothly on the basis of the earthquake engineering, first of all, what kind of dams are susceptible to damage must be investigated. Conventionally, the way to clarify damage factors has been taken by particular investigation of damaged dams. Moreover, static and dynamic analysis have been carried out individually for each dam to examine its earthquake-resistant capacity. However, the former method can not explain factors of undamaged dams, that is to say, what kind of dams are not damageable and the latter method has a difficult point to spend much time and cost in such a case as earthquake resistance for a lot of small earth dams is examined. Therefore, it is considered to be an effective method to make a complete survey of the state of pre-earthquake on dams in an area hit by a large-scale earthquake and to analyze damage factors from significant differences between damaged and undamaged dams.

From the point of view mentioned above, the complete survey was made on damaged and undamaged dams due to the 1983 Nihonkai-chubu earthquake and the factors analysis was carried out on the basis of the data. As shown in Fig. 1, the range of survey is within a radius of about 150 km from the epicenter in Aomori and Akita prefectures and corresponds roughly to the region of JMA Intensity Scale V. The present paper deals with the method, procedure and results of the factors analysis.

FACTORS ANALYSIS

Earthquake damage occurs generally caused by many factors that are complicatedly entangled together. Therefore, it is difficult to grasp the relation between an earthquake damage and each factor even if relevant factors are individually analyzed. Moreover, the contents of complete survey include qualitative data as well as quantitative data and such qualitative data whether there is any damage or whether damage is serious are applied to the outside criterion of the analysis. In such a case, among some of multivariate analyses called as the prediction model, the "Type II quantification analysis" (Ref. 1,2) which aims at the discrimination of the outside criterion is considered to be useful.

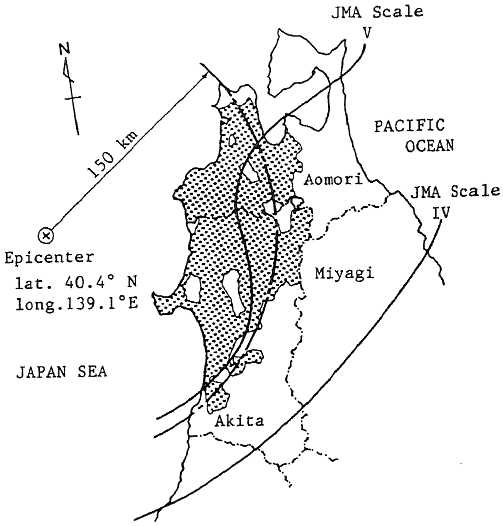

Fig. 1 Range of Complete Survey

In the analysis, the factor affecting the outside criterion is called "item" and an item is classified into some "categories". There are 36 items in the distributed questionnaire to collect the data of small earth dams for irrigation regarding to the 1983 Nihonkai-chubu earthquake. 26 items among them were selected as the items of the factors analysis. Moreover, the epicentral distance was added to the group of items as an index which indicates indirectly the intensity of earthquake motion striking a dam. After all, the analysis was carried out using a total of 27 items.

The degree of damage was classified into three ranks as follows.

rank A : failure or its equivalent damage (heavy damage)
rank B : damage not to develop into rank A (light damage)
rank C : no damage

Furthermore, the damage equivalent to failure was defined as follows.

(1) sliding of slope
(2) longitudinal crack more than 5 cm wide
(3) transverse crack
(4) crest settlement more than 30 cm
(5) leakage of water

Total number of samples on the object to the analysis is 1129 and rank A, rank B and rank C are 145, 32, 952 respectively. Because the number of rank B is less than that of rank A or rank C, two categorization, rank A and (rank B plus rank C), are applied to the outside criterion of the factors analysis.

One of the aims of this study is to make the prediction model of earthquake damage for small earth dams on the results of the factors analysis. It is generally considered that the more the number of analyzed items is, the better the precision of analysis becomes in spite of the causal relation between added items and damage. However, taking account of the ease of investigation, it is to be desired that the number of items essential to the prediction of damage is as few as possible. Therefore, four stages of analysis were given and several items correlating relatively high to the outside criterion were selected in principle.

RESULTS OF ANALYSIS

As a result of the analysis mentioned above, eight items finally remained. In this case, the correlation ratio, which is the ratio of between-variance to total-variance, is 0.2243 and the good-hit rate of judgement is 75 percent.

Table 1 shows the result of fourth-stage of analysis. Category score in this table means that the smaller the value in an item, the greater the category contributes to the damage of a small earth dam. Range is the absolute value of difference between the maximum and the minimum value among category scores in each item. The larger the range of an item, the more the item varies a sample score calculated as sum of the score of each category to which the sample is applicable.

The number of samples belonging to each category for every damage rank is tabulated in Table 2. The ratio of A to (A+B+C), called the damage ratio in this paper, is also put on the Table 2. Comparing Table 1 with Table 2, the result of analysis for each item is examined as follows.

(1) Crest width

The wider the crest width, the smaller the category score is , so an embankment with wide crest is relatively susceptible to damage.

(2) Crest width / Height of dam

This item seems to be a scale indicating the stability of embankment in a sense. According to Table 1, The category of 0.6 - 1.0 is damageable.

(3) Upstream slope

The range and the partial correlation coefficient of this item are relatively large. The upstream slope is the item greatly affecting the earthquake damage of a small earth dam. According to Table 1, the gentler the slope, the more the embankment is dangerous. The damage ratios A/(A+B+C) of the item shown in Table 2 have also the same tendency. This is contradictory to the conventional knowledge of engineering. That is a reason why the embankment under worse conditions such as a bad foundation or bad materials used to be constructed with a slow grade. Therefore, it seems that the embankment with a gentle upstream slope is substantially the more deficient in the earthquake-resistant strength and the category scores in this item are consequently expressed containing such bad conditions.

(4) Geological age of substratum

The embankment on the Diluvial deposits is damageable and that on the Tertiary deposits is not.

(5) Soil of substratum

The embankment on sand deposits is susceptible to damage and that on rock is unlikely to damage.

(6) Crest settlement before earthquake

The embankment with crest settlement before earthquake is more damageable than that without crest settlement.

(7) Epicentral distance

As shown in Table 1, the partial correlation coefficient of this item is secondly large next to that of the upstream slope, so the epicentral distance has a great influence on the earthquake damage of a small earth dam. Comparing with category scores in this item, the category of 100-120 is damageable and it does not necessarily follow that a dam is susceptible to damage due to an earthquake because the dam is near to the epicenter. This result agrees with that of the damage ratio shown in Table 2 and seems to reflect that the seismic intensity felt by a dam greatly depends on the ground condition and the configuration along with the epicentral distance.

(8) Water level (Ratio of depth of water to height of dam)

The smaller the ratio, the more the embankment is consequently damageable. This also reflects the order of the damage ratio shown in Table 2.

CONCLUSIONS

On the basis of the data from the complete survey on the 1983 Nihonkai-chubu earthquake, the factors analysis of the earthquake damage of small earth dams for irrigation was carried out by using the Type II quantification analysis. The results obtained from this study are summarized as follows.

(1) For analyzing the relevant factors to predict whether a dam is liable to serious damage, the Type II quantification analysis is an effective method.

(2) As the factors greatly affecting the earthquake damage of a small earth dam, 8 items were selected from 27 relevant items by this study. They are the followings.

> crest width, crest width / height of dam, upstream slope, geological age of substratum, soil of substratum, crest settlement before earthquake, epicentral distance, water level(ratio of depth of water to height of dam)

(3) Category scores to be used for the prediction of earthquake damage of a small earth dam reflect the damage ratio A/(A+B+C) which is calculated from the data of the complete survey.

Including the detailed preliminary investigation, in order to repair enormous small earth dams for irrigation to the number of 250,000 by turns, the priority order of repair is one of the most important problems. Therefore, first of all, it is necessary to select dams which are relatively dangerous so as to promote the repairs smoothly. As the first-stage of selection like this, it can be considered that the method by the Type II quantification analysis mentioned in this paper is remarkably effective. It is expected that significant data are accumulated still more hereafter and they are analyzed so that the precision of prediction will be improved.

ACKNOWLEDGEMENTS

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Table 1 Discrimination between A and (B+C)

ITEM [SYMBOL]	CATEGORY	CATEGORY SCORE	RANGE	PARTIAL CORR. COEFFICIENT
Crest Width (m) [WI]	0-3 3-4 4-	0.2833 -0.0569 -0.2714	0.5547	0.1159
Crest Width / Height of Dam [WI/HE]	0.0-0.6 0.6-1.0 1.0-	-0.0277 -0.2284 0.3041	0.5324	0.1103
Upstream Slope (Ratio of Horizontal to Vertical) [SL]	0.0-1.5 1.5-2.0 2.0-	0.4540 0.0765 -0.5179	0.9718	0.2066
Geological Age of Substratum [GA]	Tertiary Diluvial Alluvial	0.1898 -0.3522 0.1110	0.5420	0.1230
Soil of Substratum [SS]	Rock Sand Clay	0.4506 -0.4855 -0.1802	0.9361	0.1735
Crest Settlement before Earthquake [SE]	Yes No	-0.9718 0.1028	1.0746	0.1642
Epicentral Distance (km) [EP]	0-100 100-120 120-140 140-	-0.2483 -0.2825 0.5523 -0.2039	0.8348	0.1957
Water Level (Depth of Water / Height of Dam) [WL]	0.0-0.4 0.4-0.7 0.7-	-0.8666 -0.2165 0.3107	1.1774	0.1824

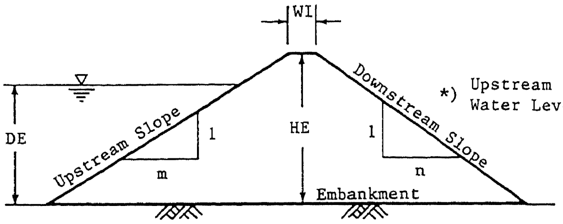
[Discrimination]

If $f \leqq x$, then A

If $f > x$, then (B+C)

where f = Sum of Category Scores

x = Dividing Point (= -0.78)



*) Upstream Slope [SL] = m
Water Level [WL] = [DE] / [HE]

Table 2 Number of Sample in Each Category

ITEM [SYMBOL]	CATEGORY	TOTAL A+B+C	DAMAGE LEVEL			RATIO (%)
			HEAVY A	LIGHT B	UNDAMAGED C	$\frac{A}{A+B+C}$
Crest Width (m) [WI]	0-3	412	26	4	382	6.3
	3-4	363	58	14	291	16.0
	4-	354	61	14	279	17.2
$\frac{\text{Crest Width}}{\text{Height of Dam}}$ [WI/HE]	0.0-0.6	388	34	8	346	8.8
	0.6-1.0	403	71	12	320	17.6
	1.0-	338	40	12	286	11.8
Upstream Slope (Ratio of Horizontal to Vertical) [SL]	0.0-1.5	390	17	5	368	4.4
	1.5-2.0	346	35	7	304	10.1
	2.0-	393	93	20	280	23.7
Geological Age of Substratum [GA]	Tertiary	461	29	5	427	6.3
	Diluvial	349	76	14	259	21.8
	Alluvial	319	40	13	266	12.5
Soil of Substratum [SS]	Rock	385	15	3	367	3.9
	Sand	129	35	15	79	27.1
	Clay	615	95	14	506	15.4
Crest Settlement before Earthquake [SE]	Yes	108	37	8	63	34.3
	No	1021	108	24	889	10.6
Epicentral Distance (km) [EP]	0-100	257	52	15	190	20.2
	100-120	351	63	2	286	17.9
	120-140	356	14	15	327	3.9
	140-	165	16	0	149	9.7
Water Level (Depth of Water / Height of Dam) [WL]	0.0-0.4	83	27	8	48	32.5
	0.4-0.7	480	79	20	381	16.5
	0.7-	566	39	4	523	6.9
TOTAL		1129	145	32	952	12.8