IRISK MANAGEMENT OF IRRIGATION SYSTEM IN AN EARTHQUAKE

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ABSTRACT: A risk analysis method of an irrigation system in an earthquake is proposed. The irrigation system consists of irrigation tanks and canals. The damage probability of the irrigation tanks and canals was obtained from both numerical simulation and actual disaster data from the Mid Niigata prefecture earthquake. The losses due to reduced crop yield, restoration and secondary disaster were considered in the risk assessment. The probability of annual peak ground acceleration was introduced from the earthquake records in Niigata prefecture. To reduce the damage probability, an enhanced foundation of canals on flat land and widening of the embankment were applied. It was found that the countermeasures for the irrigation tanks were more effective than those for the canals. In the case of a large secondary disaster of the irrigation system on flat land, the countermeasures for the irrigation system were very effective.

INTRODUCTION

In Japan, there are approximately 210,000 irrigation tanks, which have been important sources of water for farming since ancient times. Most of the irrigation tanks were constructed a long time ago and have greatly deteriorated. Kato (2005) reported that approximately 20,000 irrigation tanks need to be repaired. Major irrigation canals have also been in service for a long time. The major irrigation canals have a total length of 45,000 km. The total length of the irrigation canals, which include major and minor ones, is approximately 400,000 km. The deterioration of the system poses a serious problem for agricultural activity. However, under severe financial circumstances, any countermeasure to correct the great amount of deterioration is very difficult. Therefore, a strategy for repair and maintenance has been discussed as stock management. In the manual of stock management (Ministry of Agriculture, Forestry and Fisheries of Japan, 2007), risk management for earthquakes is included as a concept. However, a practical and effective method of risk management has not been developed.

In 2004, the Mid Niigata prefecture earthquake occurred. The earthquake damaged 561 irrigation tanks. The amount of damage to the irrigation tanks cost 7.6 hundred million yen. Also damaged were 4491 irrigation canals at a loss of 2.5 billion yen. Mohri et al. (2006) examined the damage of the irrigation tanks in detail. A few irrigation tanks failed and most of the damaged irrigation tanks had cracks or settlement in the embankment. The level of damage was similar to those in past seismic disasters. While these tanks did not constitute a serious disaster, reduction of agricultural activity was a real possibility. Approximately 900 ha in 2005 and 340 ha in 2006 became impossible to farm due to damaged irrigation facilities after the Mid Niigata prefecture earthquake, despite rapid rehabilitation (Misawa et al., 2007). Therefore, it is important to increase the earthquake protection of irrigation facilities for agricultural activity.

In this paper, a risk analysis method for seismic disaster is examined by using the data from the Mid Niigata prefecture earthquake. An event tree and event probability of the disaster for irrigation tank and canal are created by using the actual data and numerical simulation. The risk analysis method is examined by considering the losses due to the reduction of the crop yield, restoration and secondary disaster. Risk management is discussed by considering countermeasures for the irrigation system, and the effect of different geographic conditions is also discussed

RISK ASSESSMENT OF THE IRRIGATION TANKS

Event tree

The Mid Niigata prefecture earthquake occurred on October 23, 2004. Shortly afterward, 240 irrigation tanks were inspected for damage by the Niigata prefectural government. Table 1 shows the number of irrigation tanks classified according to the extent damage by the inspectors. The five conditions are unknown, undamaged, lightly damaged, heavily damaged and failed. The unknown condition means that the damage conditions could not be examined due to inaccessibility at the time of inspection. The heavily damaged condition means that the tank cannot be used any more. The lightly damaged condition means the tank can be used after the damage. According to the inspection results, the event tree in this study was created as shown in Figure 1. First, all tanks are classified into the damaged or undamaged condition. P_1 is the probability of the occurrence of damage. Then the damaged tanks are classified into the failed or unfailed condition. P_2 is the probability of failure among the damaged tanks. The failed condition leads to disaster in the downstream area, whereas the unfailed condition does not lead to another disaster. Unfailed tanks are classified into the heavily damaged or lightly damaged condition. P_3 is the probability of occurrence of heavy damage among the damaged but unfailed tanks. As mentioned above, the heavily damaged tanks cannot be used but the lightly damaged ones can continue to be used for irrigation.

As an example, the event probability of heavy damage P_B is calculated by multiplying the event probability of damage P_1 by that of non-failure (1- P_2) and that of heavy damage P_3. The event probabilities of failure P_A, light damage P_C and non-damage P_D are calculated in a similar way, as shown in Figure 1. The loss from each damage condition from C_A to C_D has to be examined for the risk assessment of the irrigation tanks. The risk for each damage condition is obtained by multiplying the event probability by the loss, as also shown in Figure 1.

Table 1 The number of irrigation tanks for each damage condition

Damage condition	Un-known	Un-damaged	Lightly damaged	Heavily damaged	Failed
The number of irrigation tanks	33	86	57	59	5

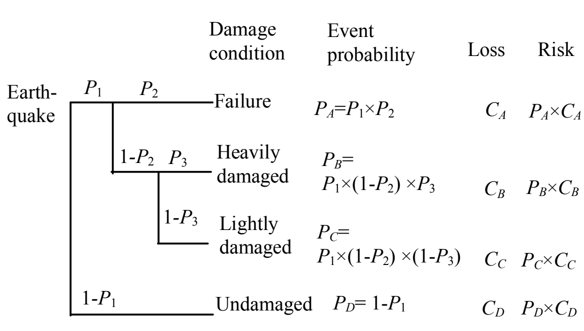

Figure1 Event tree of damage of irrigation tanks

Event probability

Kobayashi et al. (2010) introduced the average event probability of damage of inspected irrigation tanks after the Mid Niigata prefecture earthquake by using Monte Carlo simulation. The circular slice method (CSM), which considers the horizontal seismic coefficient, was applied for the devastated tanks. Moreover, the Δu method based on liquefaction was also applied according to the guideline of Ministry of Agriculture Forestry and Fisheries of Japan (2004). The methods are a so-called Swedish method developed by Fellenius (1927). Excess pore pressure was estimated from the ratio of the resistance to the load. Resistance was calculated from the assumed internal friction angle and fine grain fraction, and the load was estimated from the peak ground acceleration (PGA). The PGA at each tank is estimated from the distribution of PGA estimated by Suetomi et al. (2007), in which both geomorphologic and borehole data were used to estimate the distribution at a resolution of 250×250 m. To estimate the event probability of damage of each tank, safety factor F was calculated for each irrigation tank by Monte Carlo simulation approach using the average and variance of parameters introduced in the design manual (Ministry of Agriculture Forestry and Fisheries of Japan, 2006) and the shape of tanks estimated from the tanks in the same area as shown in Table 2. The gradient of upstream and downstream slopes of many tanks was not recorded, and so the estimation from the height was tried by using the available data in the same area. The event probability of damage, P_s, was calculated by Eq. (1) below. The number of trials was 1,000 for each tank. P_s was calculated for all of the 240 inspected tanks. Then, the average probability for each damage condition was obtained by averaging the P_s of the tanks classified in the damage condition.

$$P_s = \frac{\text{The number of times when } F_s \text{ is less than 1}}{\text{The number of trials}} \quad (1)$$

Kobayashi et al. (2010) presented the results shown in Table 3. As the damage condition becomes worse, the average event probability increases. The event probability of damage is consistent with the actual damage situation after the Mid Niigata prefecture earthquake. Although the parameters used in the calculation were not validated, the values might not be so far from the actual ones. In this study, the event probability of damage P_1 in Figure 1 is estimated for an irrigation tank by applying CSM on the downstream slope with the same statistical method.

It is difficult to find a significant difference among the lightly and heavily damaged and failed conditions from the CSM and Δu methods. In this study, the inspection result after the Mid Niigata prefecture earthquake is used to estimate the event probability of P_2 and P_3. Table 4 shows the actual number of tanks for each damage condition as a function of PGA. Even though one tank failed under 300 gal, most tanks were not damaged at this level, as shown in Table 4. By using the inspection result, the event probability is assumed as shown in Table 5. The value of P_2 is obtained from the average value of P_2 at all levels of acceleration, and the P_2 at 0~300 gal is assumed to be zero.

Risk analysis

The event probability of each damage condition for one irrigation tank in Mid Niigata prefecture is analyzed by using the above information. The damage probability, P_1, for slope failure at the downstream slope is calculated as a function of PGA by CSM. The parameters used in CSM are shown in Table 2, and the model for CSM is shown in Figure 2. The event probability for each damage condition is calculated by using Table 5. Figure 3 shows the obtained event probability of each damage level; the resulting curves are called fragility curves.

Restoration cost

The restoration cost of each tank assessed by Niigata prefecture is used to estimate the loss of the irrigation tanks. By arranging the assessment results, the average cost of restoration as a function of PGA is obtained as shown in Table 6. The cost reflects the unit volume of the tanks.

Table 2 Average value, probability distribution and standard deviation of parameters used for CSM

Parameter	Value	Standard deviation	Probability distribution
α: Gradient of upstream slope	1.26+0.06×H	0.46	Normal
β: Gradient of downstream slope	1.37+0.032×H+0.00034×TL	0.4	Normal
l: Reservoir water level (m)	1.0 m from the crest	0.3	Normal
γ: Unit weight of soil (kN/m^3)	18.0	1.0	Normal
c: Cohesion (kN/m^2)	27.5	17.5	Uniform (10~30)
ϕ: Internal friction angle (°)	25.9	8.37	Normal

*H: Height of embankment (m), TL: Length of embankment (m)

Table 3 Average event probability of each damage condition

Damage condition	Undamaged	Lightly damaged	Heavily damaged	Failed
CSM (up)	0.212	0.225	0.263	0.292
CSM (down)	0.081	0.110	0.121	0.143
Δu (up)	0.014	0.025	0.027	0.034

*up: upstream slope, down: downstream slope

Table 4 The number of tanks for each damage condition as a function of PGA

PGA (gal)	Lightly damaged	Heavily damaged	Failed
0～300	0	1	1
300～500	17	8	2
500～900	30	34	1
900～1,600	9	16	1

Table 5 Estimated event probability of P_2 and P_3

PGA (gal)	P_2	P_3
0～300	0	0
300～500	0.1	0.3
500～900	0.1	0.5
900～1,500	0.1	0.7

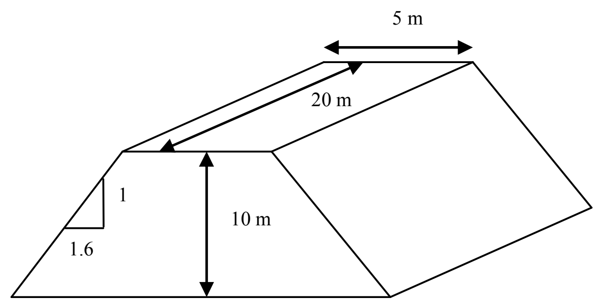

Figure 2 Model of irrigation tank for CSM

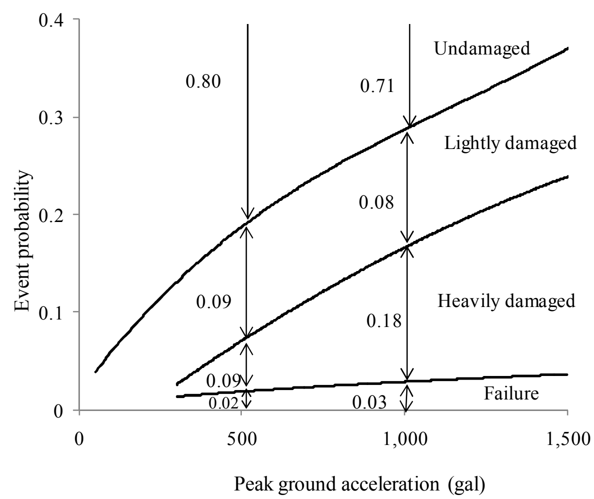

Figure 3 Example of fragility curves of irrigation tank

RISK ASSESSMENT OF THE IRRIGATION CANALS

Event tree

Asano et al. (2006) reported the disaster of the canals due to the Mid Niigata prefecture earthquake. Settlement and inclination of the canal and the influent sediment were the main problems. In the intermediate and mountainous area, the landslide caused the malfunction of the canals. On flat land, the horizontal ground movement caused disconnection of the canal. These kinds of damage by deformation of the ground could not be restored immediately.

The disaster of the canals due to deformation of the ground is considered in this study. The landslide in the mountainous area and the flat slide on the flat land are considered. As with the irrigation tanks, the damage condition of the canals was classified into lightly and heavily damaged conditions by the in-situ inspection, but the details of the deformation of the ground were not recorded, however. Therefore, it is difficult to estimate the difference between a landslide and a flat slide from the inspection results. In this study, the event probability of the heavily damaged condition is assumed to be the same for the landslide and flat slide.

From the above considerations, the event tree of the canal disaster is assumed as shown in Figure 4. First, the foundation is classified into whether liquefaction occurred. The event probability of liquefaction is P_5. A ground that experienced liquefaction caused severe damage to the canal. A ground saved from liquefaction is classified into the damaged or undamaged condition. The damaged ground is further classified into either landslide or flat slide. The event probability of the landslide among the damaged but not liquefied grounds is P_7. Similarly, the event probability of the flat slide is P_8. The damaged ground by both landslide and flat slide is classified into the heavily or lightly damaged condition. The heavily damaged canal requires time for restoration, but the lightly damaged canal can be repaired easily. However, both types of damaged canals cannot be used to run water after a disaster. The event probability of the heavily damaged condition P_9, which is the same for both landslide and flat slide, is assumed from the inspection results, as shown in Table 7.

Table 6 Restoration cost per unit volume (1,000 yen/m^3)

PGA (gal)	Lightly damaged	Heavily damaged	Failed
0~300	8.0	No expense	No expense
300~500	8.0	8.5	39.0
500~900	9.4	17.3	39.0
900~1,500	9.8	19.2	39.0

Table 7 Event probability of P_9 from the inspection results

PGA (gal)	Lightly damaged (1-P_9)	Heavily damaged (P_9)
0~300	1.0	0
300~500	0.7	0.3
500~900	0.5	0.5
600~1,500	0.3	0.7

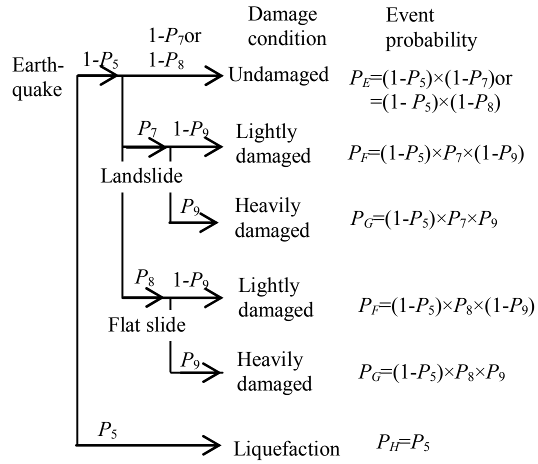

Figure 4 Event tree of the disaster of the canals

Event probability

The inclination of the foundation is estimated from the topography. Then, the event probability of the landslide and flat slide is calculated. To estimate the foundation inclination, the canal is divided into cells of size 5×5 m, as shown in Figure 5. The average inclination of each cell is calculated from the topographic data. Then, the canal is classified according to three locations: mountainous area, intermediate and mountainous area and flat land area, by grouping the cells having the same range of gradient. We selected one canal damaged by the Mid Niigata prefecture earthquake to estimate the event probability.

The event probability of the landslide is calculated by CSM. The cohesion coefficient is assumed to be zero and the unit weight and internal friction angle are assumed as shown in Table 8. The fragility curves of the concerned canal for the landslide are obtained as shown in Figure 6.

The event probability of the flat slide is calculated by the model shown in Figure 7 with the design standard of the canals (Ministry of Agriculture Forestry and Fisheries of Japan, 2001). The safety factor F_s is calculated by

$$F_s = \frac{P_{RF}}{P_{AE} + P_{SF} - P_{PE}}, \; P_{RF} = V \tan\left(\frac{2}{3}\phi\right) \quad (2)$$

where V is the weight of the canal.

The parameters of the foundation are the same as those used for the landslide. The fragility curves for the flat slide are obtained as shown in Figure 8.

Restoration cost

The cost for restoration of the canals is also estimated from the inspection result after the Mid Niigata prefecture earthquake. For the canals, the geography of the location had an effect on the restoration cost. The canals in the mountainous area had a high cost. Table 9 shows the restoration costs as a function of location and damage condition. It was difficult to define the difference between the landslide and the flat slide from the inspection data. Table 9 shows the restoration cost per damage case.

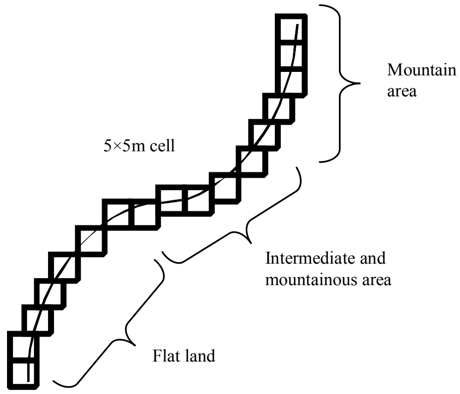

Figure 5 Divisions of the canal

Table 8 Parameters used for the event probability of a landslide

Parameters	Average	St. Dev.	Distribution
Unit weight (kN/m^3)	18.0	1.0	Normal
Internal friction angle (°)	25.0	1.0	Normal

Table 9 Restoration cost of canals for both landslide and horizontal slide (1,000 yen)

Location	Lightly damaged	Heavily damaged
Mountainous	5,000	7,000
Intermediate and mountainous	3,000	5,000
Flat	1,000	3,000

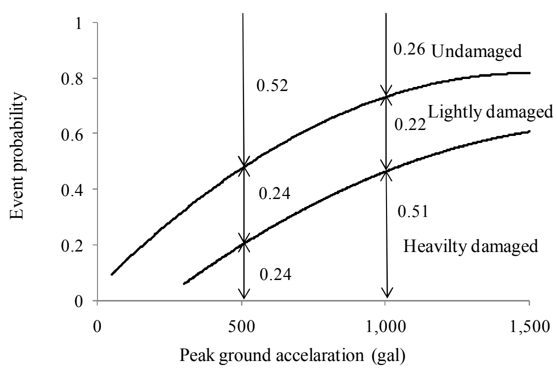

Figure 6 Fragility curves of canals for a landslide

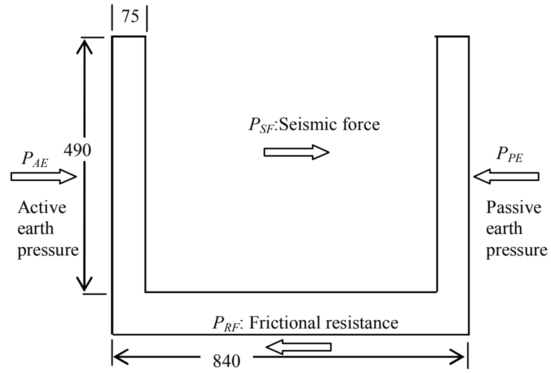

Figure 7 Model of canal for a flat slide (mm)

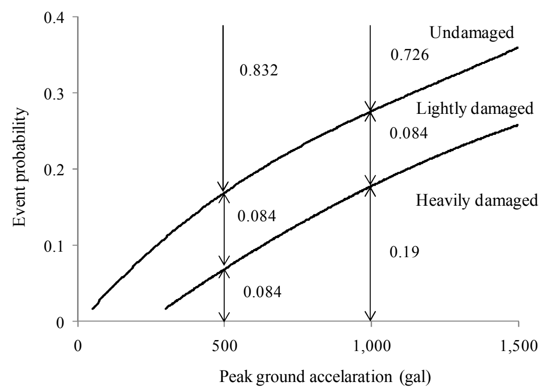

Figure 8 Fragility curves of canals for a flat slide

RISK MANAGEMENT OF THE IRRIGATION SYSTEM

Irrigation system

To estimate the risk, the irrigation system shown in Figures 9 and 10 are used. The irrigation system shown in Figure 9 is an actual system in Niigata prefecture. The water is supplied from an irrigation tank in the mountainous area to the farmland through the canals. Since the area of farmland and the number of farms related to the system are unknown, they are assumed as shown in Figure 10. The upper stream of the canal, of which length is 752m, exists at the mountain area where a single farmer works and there is no rice field. In the intermediate and mountainous area at which length of the canal is 835m, two formers work and they have totally 1ha of rice field. The downstream canal existing at the flat land is 906m long, around where 10 farmers work and they have 4ha of rice field. The PGA inferred at the location is used to estimate the event probability of the damage.

Other losses

To calculate the risk for disaster of the irrigation system, the losses except for the restoration have to be estimated. In this study, the losses by reduction of the crop yield and secondary disaster are considered. The loss by reduction of crop yield is estimated by assuming the reduction in the rice yield for one year after the disaster. The rice yield is assumed to be zero in the cases of the failed and heavily damaged irrigation tanks and lightly and heavily damaged canals. The loss by reduction of the crop yield, C_1, is obtained by

$$C_1 = (\text{Area where water is supplied}) \times (\text{crop yield per area}) \times (\text{price per weight}) \quad (3)$$

The area where water is supplied is assumed in the model shown in Figure 10. The amount of the crop is given as 5460 kg/ha, which is the average value of this region. The price per unit weight is assumed to be 316 yen/kg. The flood from the irrigation tank and canal is considered to cause a secondary disaster. Even though a flood did not occur in the actual Mid-Niigata disaster, it is assumed in this study that the flood above the floor level of houses happens by the failure of the irrigation tank, and the flood under the floor level of houses happens by the heavy damage of the canals. The cost for the disaster is estimated from the manual of the Ministry of Land, Infrastructure, Transport and Tourism (2005).The cost by the flood above the floor level of houses is 32,480 thousand yen per house, in which the damage of the house and household articles, and the compensation for cleaning are included, and that by the flood under the floor level of houses is 1,542 thousand yen per house.

Table 10 shows the damage conditions causing the various losses. As shown in the table, the loss is dependent on the damage level and PGA. The loss by the reduction of crop yield occurs in the case when the irrigation tank is heavily damaged or failed, or else the canal is rightly or heavily damaged. The restoration cost is incurred in the case when any damage occurs at the irrigation tank or canal. The secondary disaster causes the loss when the irrigation tank or canal is heavily damaged. Although the values of Table 10 are assumed in this study, the loss has to be examined thoroughly on the basis of the actual disaster data.

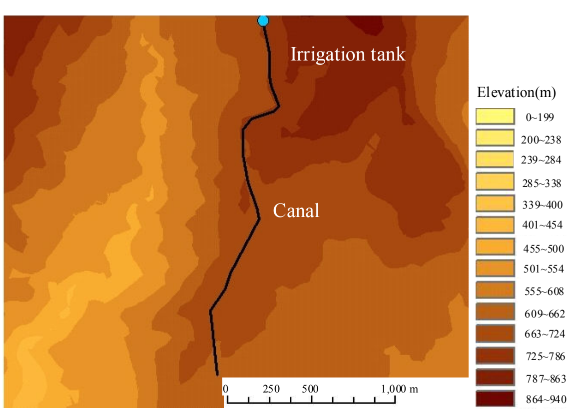

Figure 9 Location of irrigation system

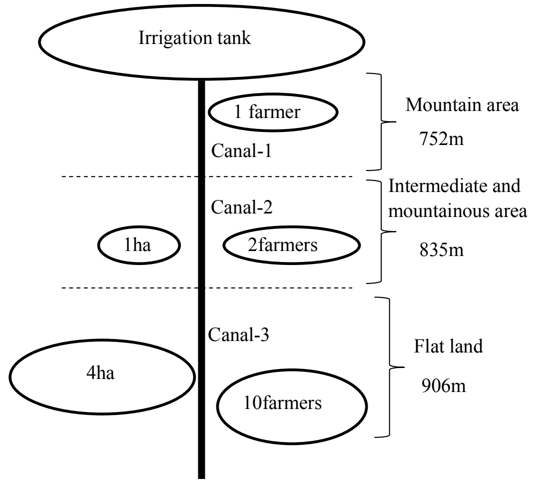

Figure 10 Irrigation system examined in this study

Table 10 Damage condition of facilities for each loss

	Facility	Irrigation tank			Canal	
	Damage	Light	Heavy	Failure	Light	Heavy
Loss	Reduced crop yield	−	○	○	○	○
	Restoration	Table 6			Table 9	
	Secondary disaster	−	−	○	−	○

○: the loss is considered in the case of the damage

− : the loss is not considered

Risk for peak ground acceleration

As shown in Table 10, each loss depends on the damage condition of the facility. To calculate the risk of each loss, the event probability of the damage condition related to the loss is multiplied by the loss, and the products are summed. The event probability of each damage condition of the irrigation tank is the function of PGA, as shown in the fragility curve, and the loss is also the function of PGA, as shown in Table 6. In the case of the canal, the loss is the function of the damage condition and the location. Therefore, the risk of each loss, R_n, is the function of PGA, where n=1 is the loss by the reduced crop yield, n=2 is the loss by restoration, and n=3 is the loss by the secondary disaster. $R_n(A)$ is given by

$$R_n(A) = \sum_J P_n^J(A) \times C_n^J \quad (4)$$

where P_n^J is the event probability of damage condition J related to loss n. C_n^J is the loss by n for the damage condition J, and A is PGA. $R_n(A)$ can be calculated for the irrigation system shown in Figure 10 by using the above examination results. Figure 11 shows the resultant risk as a function of PGA. It is found that restoration has the largest risk. This is because the loss by restoration becomes large with PGA. In contrast, the loss by reduced crop yield does not increase as much with PGA, since the event probability of the damage condition related to the reduction is low. Furthermore, the loss by the secondary disaster is small for the same reason found for the reduced crop yield.

The risk shown in Figure 11 is the expected loss due to PGA. For example, the expected loss at 500 gal is 18,900 thousand yen. However, the event probability of such a large PGA is very small. The annual risk for each loss is small, as is discussed next.

Annual risk

The statistical method with past records is used to estimate the event probability of PGA at the site of the irrigation system (Kobayashi et al., 2010). The annual probability density function of PGA at the site is estimated by using the observation results from 1926 to 2008, as shown in Figure 12. The annual risk, RY_n, is calculated by the following equation:

$$RY_n = \int_0^\infty R_n(A) \times F(A)dA \tag{5}$$

where $F(A)$ is the probability density function shown in Figure 12. Table 11 indicates the results of the annual risk. The loss by reduced crop yield cannot be divided into the loss of irrigation tanks and the loss of canals, because water is supplied only when both facilities are operational. It is found that the annual risk becomes very small when considering the annual event probability of the earthquake. The restoration risk of the irrigation tank is larger than that of the canal. This is because the restoration cost of irrigation tanks is larger than that of canals. The risk of the secondary disaster is very small in comparison with the other losses. This is due to the difference of the conditions for losses, shown in Table 10.

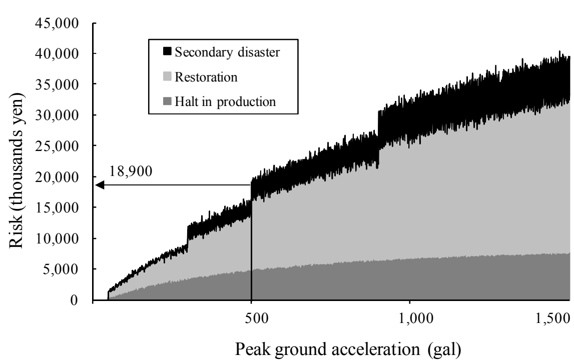

Figure 11 Risk as a function of PGA

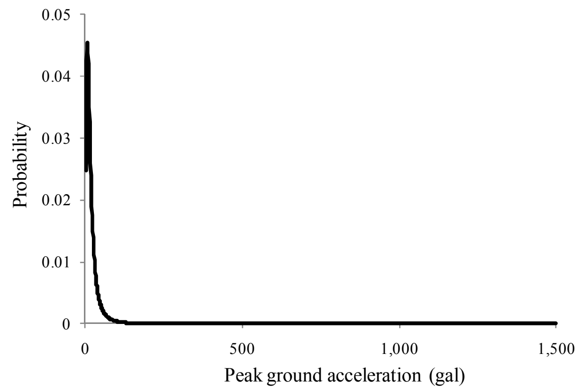

Figure 12 Annual probability of PGA at the site

Table 11 Annual risk of the irrigation system (1,000 yen)

Loss	Reduced crop yield	Restoration		Secondary disaster		Total
Risk	134	176	Tank 107 Canal 69	7	Tank 2 Canal 5	318

Cumulative risk

For management of the life cycle cost of the facilities, the cumulative risk has to be estimated. The cumulative risk for N years can be estimated by

$$RN_n = \sum_{i=1}^{N} RY_n \times (1 - PY_n)^{i-1} \times \left(\frac{1}{1+\rho} \right)^{i-1} \tag{6}$$

where

$$PY_n = \int_0^\infty \sum_J P_n^J(A) \times F(A)dA \tag{7}$$

and ρ is the social discount rate (=0.04). The results for 100 years are shown in Table 12.

Risk management

The above discussion is related to the risk analysis of the facilities, shown in Figure 10. The goal of risk management is to seek a strategy for reducing the risk. Kobayashi et al. (2010) carried out a sensitivity analysis for the seismic resistance of irrigation tanks and showed that widening the tank was effective. By widening the downstream slope from the gradient of 1.69 to 2.5, the fragility curve changes, as shown in Figure 13. The slope gradient is the ratio of horizontal length to vertical length. In comparison with Figure 3, the event probability of damage then becomes small. For the canal in the mountainous area, the countermeasure is difficult and expensive because of the severe topography and bad accessibility. In contrast, the canals on flat land are relatively easily improved. In this study, the resistance for a flat slide is intensified by improving the foundation as shown in Figure 14.

The improvement is as follows: a short pile is placed under the base of the canal. The fragility curves after this improvement are shown in Figure 15. By comparing Figure 15 with Figure 8, the damage probability becomes small.

By improving the irrigation tanks and canals as mentioned above, the annual risk changes, as shown in Table 13. By comparing Table 13 with the annual risk before the improvement shown in Table 11, it is found that the risk due to a reduced crop yield only slightly changes by improving the irrigation tank. This is because the reduced crop yield occurs by the failure or heavy damage of the irrigation tank. However, since the lightly damaged canal causes the reduced crop yield, the risk becomes low by improving the canal. The restoration risk becomes low by improving the tank because the restoration risk of the lightly damaged condition is improved greatly. Since the risk of the secondary disaster is small in the case without improvement, the effect of the improvement is small.

Table 14 shows the cumulative risk after the improvement. It is found by comparing this table with Table 12 that the improvement of the irrigation tank lowers the cumulative risk after 50 years by about 2,000 thousand yen. However, it is difficult to improve the irrigation tank by a cost smaller than the reduction of the cumulative risk, although the cost of the countermeasure depends on the method. This is because the annual probability of PGA is very small, as shown in Figure 12.

Table 12 Cumulative risk for 100 years (1,000 yen)

N (years)	1	5	10	30	50	80	100
Cumulative risk	318	1,440	2,558	5,044	5,965	6,394	6,476

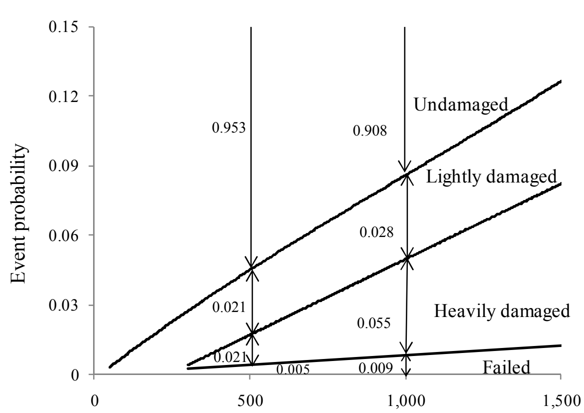

Figure 13 Fragility curves of irrigation tank after

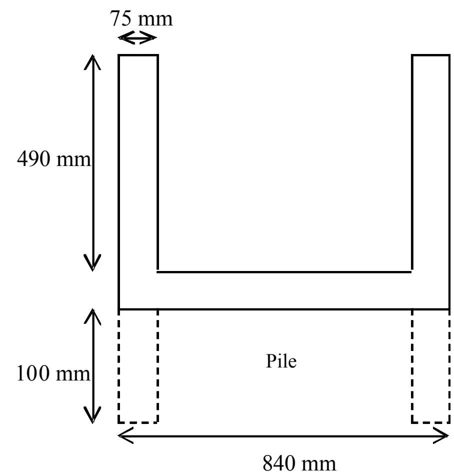

Figure 14 Improvement method for canals

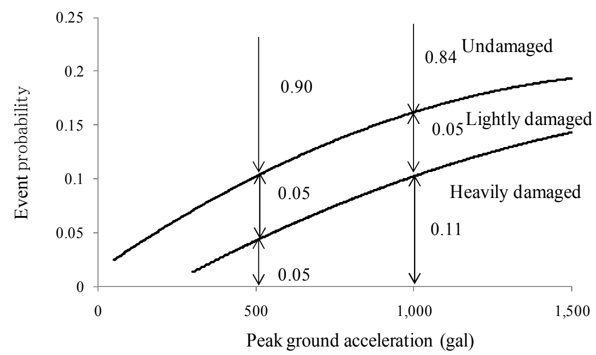

Figure 15 Fragility curves of improved canals for a flat slide

Table 13 Annual risk after improvement (1,000 yen)

Risk	Reduced crop yield	Restoration		Secondary disaster		Total
Improvement of tank	134	87	Tank 18 Canal 69	6	Tank 1 Canal 5	245
Improvement of canal	114	167	Tank 107 Canal 60	5	Tank 2 Canal 3	286

Table 14 Cumulative risk for 100 years after improvement (1,000 yen)

N (years)	1	5	10	30	50	80	100
Improvement of tank	227	1,021	1,803	3,487	4,075	4,329	4,374
Improvement of canal	286	1,300	2,320	4,629	5,511	5,934	6,017

Case of flat land

In recent years, the flat land in the rural area has become much more urbanized, and the population around the agricultural facilities has become high. The risk management for such a region is more important. The hypothetical facilities system on flat land is examined to see the effect of the improvement of the facilities in comparison with the case of the intermediate and mountainous area shown in Figure 10. Figure 16 shows the hypothetical system. All agricultural fields exist at flat land. The canal is divided into three parts and each part has one disaster. In each part, there are 10 houses and they have 4 ha of rice field. The canal is assumed to be damaged by a flat slide. The same risk analysis method mentioned in the previous section is used for the system shown in Figure 16, and the annual and cumulative risks are calculated as shown in Tables 15 and 16.

In comparison with Table 13, Table 15 shows high annual risks by the reduced crop yield and secondary disaster before the improvement. This is because of the large area of farmland and many houses on the flat land.

In contrast, the restoration risk is reduced because the damage probability of the flat slide is smaller than that of the landslide. After improving the irrigation tanks, it is found by comparing Table 15 with Table 13 that the risks by restoration and secondary disaster become small, and the effect of improving the irrigation tank becomes very high. The cumulative risk after 50 years in Table 16 becomes small in comparison with the risk in Table 14. The effectiveness by the improvement increases on flat land.

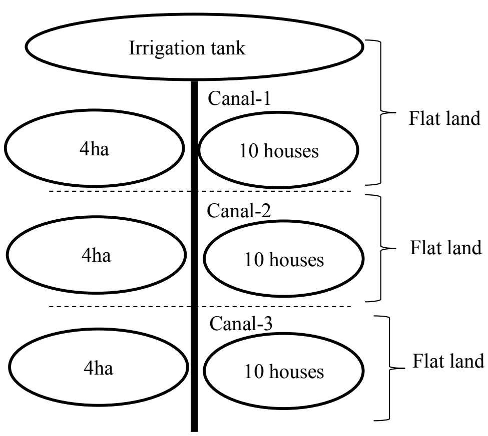

Figure 16 Hypothetical agricultural system on flat land

Table 15 Annual risk of system on flat land (1,000 yen)

Risk	Reduced crop yield	Restoration		Secondary disaster		Total
Before improvement	206	118	Tank 107 Canal 11	32	Tank 23 Canal 9	355
Improvement of tank	205	29	Tank 18 Canal 11	14	Tank 5 Canal 9	248
Improvement of canal	174	115	Tank 107 Canal 8	28	Tank 23 Canal 5	317

Table 16 Cumulative risk of system on flat land (1,000 yen)

N (years)	1	5	10	30	50	80	100
Before improvement	355	1,614	2,875	5,717	6,797	7,314	7,417
Improvement of tank	248	1,120	1,983	3,868	4,544	4,846	4,901
Improvement of canal	317	1,444	2,581	5,187	6,204	6,703	6,805

CONCLUSIONS

A risk management method was examined by using the data from the Mid Niigata prefecture earthquake. After carrying out the risk analysis of the irrigation facilities system, the effect of countermeasures were examined by the same analysis method. Then, the case in which the system existed on flat land was examined. The conclusions are summarized as follows.

(1) The event tree was made on the basis of the data inspected by Niigata prefecture. Although the event probability of the undamaged situation was estimated by numerical simulation, the event probability of different damage levels was estimated from the inspection data. This is because the difference between damage levels is not clear in the numerical results. To evaluate the event probability of the different damage levels, the accuracy of the deformation analysis for the earthquake has to be increased.

(2) Fragility curves were obtained by using the numerical simulation and inspection data. The fragility curve of the canals was examined for the mountainous area and flat land. This was because the mechanism of damage was different at both locations. It is very important to analyze the mechanism of damage on the basis of actual events because the fragility curve is very important for the risk analysis.

(3) The restoration cost was estimated from the assessment results. However, those are not the true costs for the actual restoration. The reduced crop yield and secondary disaster by flood were assumed as the other losses. Since the value of the agricultural activity is assessed from multiple aspects, multiple estimations of the losses by each disaster have to be carried out. It is important to realize the actual loss by a disaster because the loss has a great influence on the result of the risk analysis.

(4) The risk analysis for the irrigation system (shown in Figure 10) was carried out. The annual and cumulative risks were examined. Since the estimated event probability of PGA had a very small value for the large acceleration, the risks were relatively small

(5) in comparison with the ordinary improvement costs. Even though the event probability of PGA is dependent on the region, the handling of a huge earthquake has to be discussed from the losses and social effect. The discussion related to the accountability of the administration is also expected. For this discussion, the method introduced in this paper is helpful for examining risk management.

(6) Some countermeasures were examined with the risk analysis method. Moreover, the effect of the countermeasures was examined for different land conditions. It was found that the effect of a countermeasure was dependent on the geographic condition, and so the risk analysis shown in this paper was important to quantitatively understand the effect.

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