ASSET MANAGEMENT OF WATER SUPPLY SYSTEM CONSIDERING EARTHQUAKE RISK MANAGEMENT

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***ABSTRACT*:** This paper proposed the asset management method of the irrigation system considering the earthquake risk management and business continuity plan. It was difficult to decide the order of the maintenance of the facilities by the ordinal asset management considering only the degradation level, since it was very difficult to adjust the user's demands. The degradation level of each facility was gathered in GIS system, and the risk management and business continuity plan were constructed by using the map of seismic probability. By using the proposed method, we could set up the order from the point of view of seismic disaster, which would be acceptable for the users.

KEYWORDS: irrigation system, risk management , asset management

1. INTRODUCTION

The environment of the Japanese agriculture is very severe. The number of farmers decreased so much in last decades, and global competition becomes very active. While the food self-sufficiency is under 40%, the activity of the agriculture has not increased so much. Moreover, the irrigation facilities have degraded because much of them were constructed in high-speed growth era (1960-1980). So, the asset management of the agricultural facilities is very important while that is very difficult from the economic and business points of view. Furthermore, the natural disaster by earthquake and typhoon is frequent and so the risk management for the disaster has to be considered in the asset management.

Fig.1 shows the spending of the constructed irrigation facilities at each year and accumulated cost for renewal of facilities over economic life in Shiga prefecture in Japan. In this prefecture, most facilities have been constructed from 1972 to 1996. The economic life is set at 40 years.

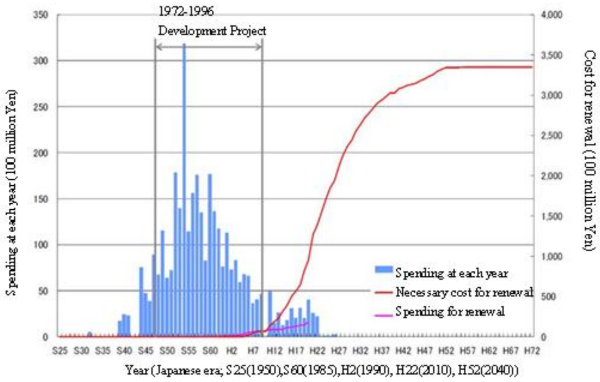

Fig.1 Necessary cost for renewal and spending of irrigation facilities for Shiga prefecture in Japan

The accumulated length of the irrigation channels over the economic life is 314 km at 2008 while the length of renewed channels is 74 km. The renewal project was not progressed according to the original plan because of poor economic condition. Moreover, the area has high probability of earthquake intensity of 5 upper and 6 lower in the next 30 years. The old facilities have to be maintained to avoid huge earthquake risk. When the facility is failed by earthquake, the loss of the agricultural activity also accrues in addition to the restoration cost. To continue the agricultural activity and minimize the loss, the business continuity plan (BCP) after earthquake is also very important.

In this paper, the method of asset management considering the earthquake risk and BCP is presented by using the actual data at a certain city of Shiga prefecture having the condition of the irrigation facilities shown in Fig.1. As mentioned above, since the economic condition is not so good in Shiga prefecture as well as the other prefectures in Japan, the even legitimate asset management of each facility is difficult to carry out. The order for the maintenance of the facilities has to be determined from another management. It is examined in this paper that the order of the maintenance is decided by the risk management and BCP.

2. FACILITIES AND AREA CONDITION

The data about the irrigation facilities in a certain city are applied to examine the asset management method. Fig.2 shows the schematic view of the facilities. The city is very near to a big lake. Water is pumped up from the lake and supplied through the pipeline system. At the mountain area, the dam was constructed and water is supplied through channel.

The number of main channels and pipelines is 340, and the number of the pumping station is 8. The location, specification and damage level of all facilities are gathered up in GIS system by the prefecture.

National Research Institute for Earthquake Science and Disaster Prevention (NIED) provides the prediction of earthquake intensity encountered in the next 30 years. In this area, the probability of the intensity 6 upper is very small, while the intensity 6 lower is presented as shown in Fig.3. The dark color shows the highest probability of 26-100%. The following probability classification is 6-26%, 3-6% and 0.1-3%. As mentioned above, the various data are gathered up in GIS system and so the risk of each facility can be calculated in detail. In particular, each section of the channel and pipeline, which has the long structure, can be examined.

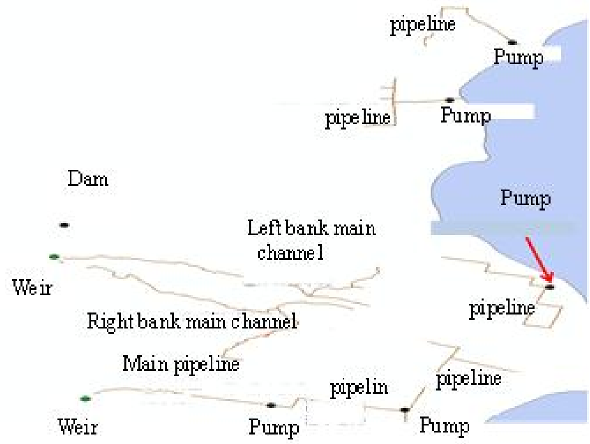

Fig.2 Irrigation system in a certain city

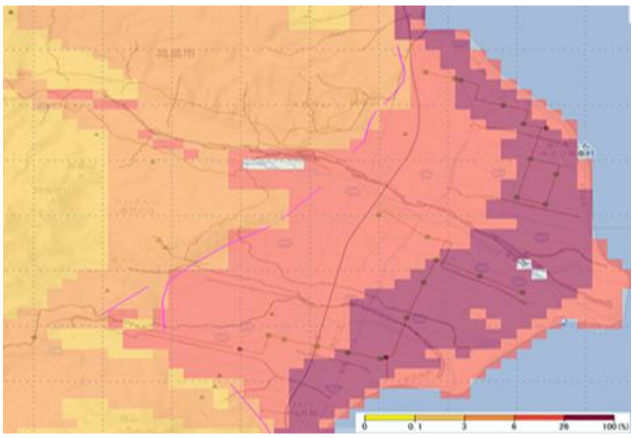

Fig.3 Example of distribution of probability of earthquake intensity 6 lower in the next 30 years

3. RISK MANAGEMENT

3.1 Failure probability by earthquake

While the earthquake is classified into the ocean-trench earthquake and inland one, the probability of earthquake intensity obtained for the largest one is used. Such information is presented as shown in Fig. 3 by NIED. By gathering up the information into GIS system, the probability of earthquake intensity at the location of the facility can be identified.

While it is preferable that the failure probability of each structure by earthquake is estimated by the detail individual examination, the simplified manner is adapted in this study. For the RC structure such as the pumping station, the earthquake damage curve obtained from the research result of Kobe earthquake in 1995 is used, which is the relation between failure probability and maximum ground surface velocity (Murao and Yamazaki, 2000). Since the damage curves are classified into the construction period, the old one before 1970 is applied to the most degraded level (in this study degradation level S-1 or 2), the damage curve between 1971 and 1980 is used for the degradation level S-3, and new one after 1981 is used for the degradation level S-4. Fig. 4 shows the earthquake damage curve for RC structure constructed before 1970. By using the data, the failure probability is estimated from the surface velocity corresponding to the earthquake intensity

On the other hand, for the buried structure like pipeline, the liquefaction is considered as the main factor of failure. The pipeline is put with sand base in the trench and covered by soil. The liquefaction in the trench has occurred in the past disaster. To estimate the FL value which means the resistivity for the liquefaction, N value of the sand base is assumed to be 10, and the average depth of the pipeline, i.e., 1.88 m is used. Moreover, the horizontal seismic coefficient is assumed to be 0.08 for earthquake intensity 5 lower, 0.16 for intensity 5 upper and 0.25 for intensity 6 lower, which is the highest acceleration at each earthquake intensity. From these assumptions, the FL value is estimated for each earthquake intensity. By using the variation coefficient of 0.5 for the strength of sand, the failure probability of pipeline by liquefaction is estimated. The results for RC structure and pipeline are shown in Table 1.

The earthquake risk is calculated by multiplying the failure probability by the restoration cost.

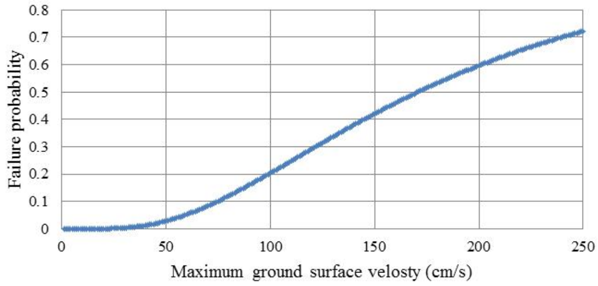

Fig.4 Earthquake damage curve for the RC structure constructed before 1970

Table 1 Failure probability of facility

Facility	Earthquake intensity	Failure probability at degradation level (S-No.)		
		S-4	S-3	S-2・S-1
Pumping station	5lower	0.00007	0.00003	0.00045
	5upper	0.0017	0.0022	0.0123
	6lower	0.008	0.016	0.053
Buried structure	5lower	0.068		
	5upper	0.159		
	6lower	0.345		

3.2 Business continuity plan

If the channel located upstream is failed, water cannot be transferred to the downstream farm and so agricultural activity is stopped at downstream farm. On the other hand, when the channel located downstream is failed, the loss is small. The loss on the agricultural business is estimated by multiplying the downstream area by the agricultural earning (Yen/m^2). Since the agricultural field more than 90 % is the rice paddy in this area, the price of the crop is set at 289 thousands yen/ton which is the average one in Japan. The average harvest in the prefecture is 525kg/10a (Ministry of Land, infrastructure, Transport and Tourism, 2005), and so the agricultural earning is estimated as 152 yen/m^2. The loss risk is calculated by multiplying the loss by the failure probability.

To consider the business continuity plan (BCP) for the agricultural activity, the BCP cost is estimated. When the main channel is failed, water has to be transferred from the alternate water resource to continue the business at downstream area. The irrigation tank, the lake and the river existing within a 500m distance from the failed facility are selected as the alternate water resource. Water pumped up at the alternate water resource is transferred by PVC pipe. The pump can be lent as the emergency operation by the administrative institution (Kinki Agricultural Administration Office, 2009). The number of pumps is calculated by the discharge rate of the pump and the irrigation area. The cost is estimated with the price of PCV pipes and pipe fittings (Kinki Agricultural Administration Office, 2008). By considering BCP, the loss at downstream area can be neglected. When BCP treatment can be carried out, the agricultural activity can be continued and so the damage by the disaster can be decreased.

4. ASSET MANAGEMENT

4.1 Degradation curve

The degradation of each structure has to be predicted. The irrigation facilities consist of dam, weir, open channel, pipeline (RC, FRP, Cast iron), water pipe bridge, and pumping station. In this study, the large facility such as dam and weir is assumed not to deteriorate because the structures have a large effect on the assessment and the degradation process is not understood so well. Actually, those structures have sound function without trouble for over 40 years.

The prefecture investigated the degradation condition of the other facilities at once. Therefore, it is impossible to examine the deterioration of the specific facility with time. The degradation is estimated for each structure by aggregating the degradation condition at different service time in this study. For example, Fig. 5 shows the degradation level as a function of service time for open channel. The number at each mark means the number of facilities. For instance, 34 open channels serviced for 52 years are judged as the degradation level of S-3. 6 ones serviced for 32 years are also judged as the degradation level of S-3. From these investigation results, the average year and the standard deviation of each degradation level can be obtained. When the data are not obtained for a degradation level, the average and standard deviation at the level is estimated from the vicinity. The average degradation curve is estimated by connecting the average year for each degradation level. The early degradation curve is obtained by the year subtracted the standard deviation from average year at each level. For example, the degradation curves for open channel are shown in Fig. 6. We examine the life cycle cost by using the both degradation curves.

Figs. 7-9 show the degradation curves for each facility. In some facilities, deterioration progresses rapidly by skipping a degradation level such as the degradation level S-3 of pipeline. This result comes from the data showing the similar probability density distribution at each degradation level. This means that the condition of the facility varies widely. The sudden collapse might occur for this kind of facility.

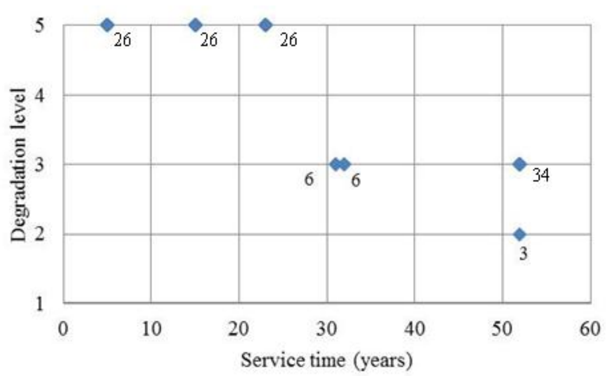

Fig.5 Degradation level of open channels

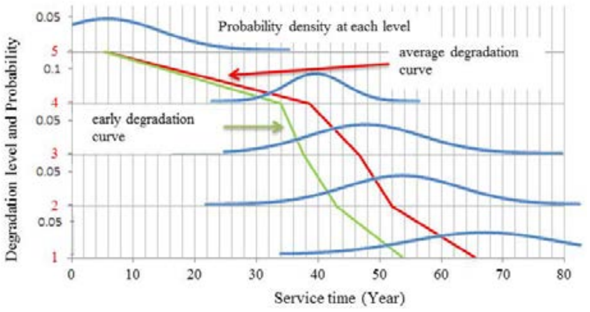

Fig.6 Degradation curve for open channel

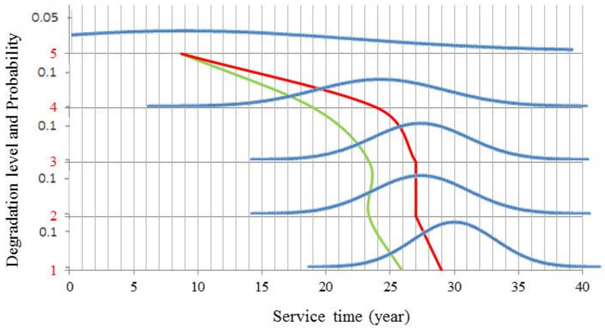

Fig.7 Degradation curve for pipeline

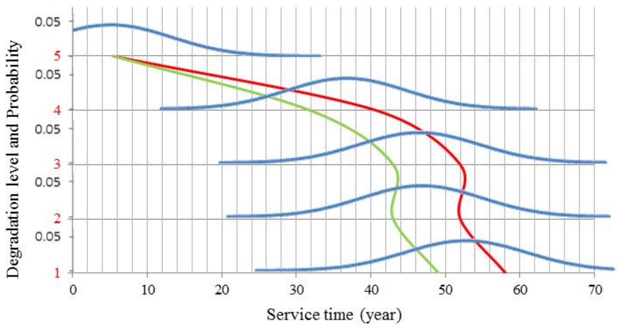

Fig.8 Degradation curve for water pipe bridge

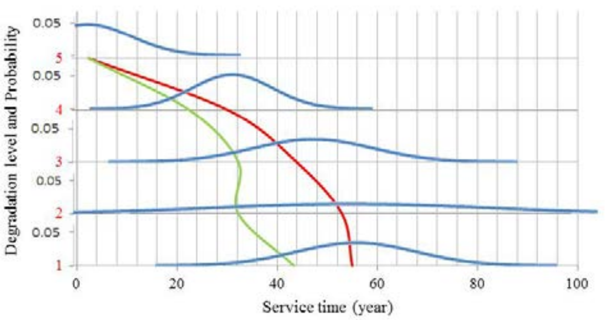

Fig.9 Degradation curve for control facility

4.2 Maintenance plan

The prefecture considers three cases of maintenance plan. Case 1 is that maintenance is carried out when the degradation level of the facility becomes S-3. In this case, some maintenance methods can be selected and the cost is small. After the maintenance method is carried out twice, the facility is used until the degradation level of S-1 and then renewal is carried out. Case 2 is that the maintenance is carried out at the degradation level of S-2. The mechanical strength of the facility has to be increased and options of repair method are less. Case 3 is that the facility is renewed at the degradation level of S-1. The construction cost is the largest while the facility is used longest.

Table 2 shows the example of the maintenance cost for pipeline. The service life after maintenance is also investigated. In this study, the maintenance cost and service life after maintenance for all facilities are set up as shown in Table 2. When the service life after maintenance terminates, the degradation level takes bake to the former level and the degradation advances along the degradation curve.

Table 2 Example of maintenance method, cost and service life after maintenance

Facility	Degradation level	Method No.	Mainetenance method	Cost (Yen)	Service life (Years)
Pipeline	S-3	Method 1	joint repair	68,242	10
	S-2	Method 2	rehabilitation (φ500)	60,000	30
	S-2	Method 2	rehabilitation(φ700)	90,000	30
	S-2	Method 2	rehabilitation(φ800)	100,000	30
	S-2	Method 2	rehabilitation(over φ1000)	160,000	30
	S-1	Method 3	renewal(φ500)	107,500	40
	S-1	Mrthod 3	renewal(φ700)	168,900	40
	S-1	Method 3	renewal (φ800)	206,700	40
	S-1	Method 3	renewal(φ1500)	521,300	40
	S-1	Method 3	renewal(φ1800)	714,200	40

4.3 Asset management

As the helm of the government, the life cycle is calculated by adding the construction period with 40 years. In this prefecture, the function tests of the all facilities were finished in 2008. It is assumed in this study that the life cycle is 40 years from 2008. The cost is converted to the present value at 2008 by using the social discount rate of 4 %, which is used for the all infrastructures in Japan.

Table 3 shows the example of the life cycle cost of the pipeline at left and right banks in the case that the degradation progresses according to the average degradation curve. The surviving value is calculated from the surviving service life after maintenance and the maintenance cost. When the service life of the maintenance method is terminated, the surviving value becomes zero. The life cycle cost is obtained by subtracting the surviving value from the present maintenance cost. In Case 1, the maintenance is carried out for the pipeline with the degradation level of S-3. The pipeline with the degradation level of S-5 in 2008 is repaired by the method described in Table 2 at the maintenance period from 2008. The maintenance period is dependent on the service period until 2008. Since the maintenance method 1 has the service life of 10 years after maintenance, the same method is carried out at 10 years after the first maintenance. After the same maintenance method is carried out twice, the facility is used until the degradation level of S-1. The facility degraded more than S-3 in 2008 is used until the degradation level of S-1. As shown in Table 3, Case2 gives the minimum life cycle cost for the pipeline.

Table 3 Example of life cycle cost according to average degradation

Maintenance case	Facility	Degradation level	Serviced life (Years)	Quantity (m)	Maintenance peiod (year)	Maintenance method	Maintenance cost (thousands Yen)	Present value (thousands Yen)	Serviving value (thousands Yen)	Life cycle cost (thousands Yen)
Case 1	Pipeline	S-2	52	1,486	6th	Method 3	508,163	401,606	15,877	385,729
		S-5	23	55	8th	Method 1	1,513	1,106	0	
					18th	Method 1	1,513	747	0	1,853
		S-5	15	42	16th	Method 1	1,155	617	0	
					26th	Method 1	1,155	417	0	1,034
						Total	513,499	404,493	15,877	388,616
Case 2	Pipeline	S-2	52	1,486	1st	Method 2	142,284	136,812	0	
					37th	Method 3	508,163	119,063	97,907	157,968
		S-5	23	55	29th	Method 2	8,784	2,817	960	1,857
		S-5	15	42	37th	Method 2	15,552	3,644	2,996	648
						Total	674,783	262,336	101,863	160,473
Case 3	Pipeline	S-2	52	1,486	6th	Method 3	508,163	401,606	15,877	385,729
		S-5	23	55	35th	Method 3	28,619	7,253	5,216	2,037
						Total	536,782	408,859	21,093	387,766

Table 4 Example of life cycle cost according to early degradation curve

Maintenance case	Facility	Degradation level	Serviced life (Years)	Quantity (m)	Maintenance peiod (year)	Maintenance method	Maintenance cost (thousands Yen)	Present value (thousands Yen)	Serviving value (thousands Yen)	Life cycle cost (thousands Yen)
Case 1	Pipeline	S-2	52	1,486	2nd	Method 3	508,163	469,827	5,292	464,535
		S-5	23	55	4th	Method 1	1,513	1,293	0	
					14th	Method 1	1,513	874	0	2,167
		S-5	15	42	12th	Method 1	1,155	721	0	
					22th	Method 1	1,155	487	0	1,208
						Total	513,499	473,202	5,292	467,910
Case 2	Pipeline	S-2	52	1,486	1st	Method 2	142,284	136,812	0	
					37th	Method 3	508,163	119,062	97,907	157,967
		S-5	23	55	25th	Method 2	8,784	5,706	0	5,706
		S-5	15	42	33th	Method 2	15,552	7,382	972	6,410
						Total	674,783	268,962	98,879	170,083
Case 3	Pipeline	S-2	52	1,486	2nd	Method 3	508,163	469,827	5,292	464,535
		S-5	23	55	31th	Method 3	28,619	8,484	4,620	3,864
		S-5	15	42	39th	Method 3	69,420	15,038	14,098	940
						Total	606,202	493,349	24,010	469,339

Table 5 Total cost for repair of the facilities at right bank (Yen)

Eary degradation	Average degradation	Eary degradation /average degradation
274,001,000	189,118,000	1.45

Table 4 shows the result according to the early degradation curve. While Case 2 shows the minimum life cycle cost as well as the result with the average degradation curve, the cost increases a little. The life cycle cost is dependent on the degradation curve. Table 5 shows the total cost by average degradation and early degradation cases of the facilities at right bank. In the case of early degradation curve, the cost increases 45% than average degradation case.

5. ORDER OF REPAIR

By the asset management mentioned above, the maintenance method and period are determined. However, since the annual budget is decreasing year by year, we need to select the repair project of that year. As it stands now, it is very difficult to decide the order of repair with satisfaction of all users. Therefore, the method to objectively decide the order of repair is proposed by using the risk analysis results mentioned above.

The risk management is carried out to minimize the damage by the accident such as earthquake. In this study, the earthquake risk R_e is estimated by the following equation;

$$R_e = \sum_i (P_i \times F_i) \times (C_r + C_d) \qquad (1)$$

where P_i is the event probability of earthquake intensity i, F_i is the failure probability for the earthquake intensity i, C_r is the restoration cost, C_d is the loss caused by not supplying water and i is the index of the earthquake intensity. In this study, the possible earthquake intensity is 6 lower, 5 upper and 5 lower.

The risk considering BCP, R_B, is examined by the following equation;

$$R_B = \sum_i (P_i \times F_i) \times (C_r + C_{BCP}) \qquad (2)$$

where C_{BCP} is the cost used for BCP. By considering BCP, the loss at downstream area can be avoided while the cost for pipes transferring water from the alternate water resource is needed. The facility where cannot have the alternate water resource within 500 m cannot avoid the loss by BCP. By managing to minimize R_B, the economical BCP can be carried out.

As an example, the facility on the right bank is sorted in descending order of earthquake risk in Tables 5 and 6. Table 5 shows the facilities at high order while Table 6 is the results at low order. The facility number is numbered from the upstream, and therefore small number means the upstream facility. It is found that Table 5 has a relatively small facility number. While some of the facility number of 110s and 120s has the high earthquake risk, the risk with BCP becomes small (Orange lines). This means that the priority of the repair for those facilities becomes small by considering BCP. Those facilities have large loss risk which is larger than restoration risk, and so the risk becomes small by considering BCP.

When BCP is considered, the total risk becomes small and management becomes economical. Therefore, it is preferable that the risk considering BCP is used to manage to reduce the earthquake disaster. Table 7 shows the total earthquake risk and total risk with BCP of the facilities at right bank. The risk with BCP is about 68 % of the earthquake risk.

It is found that Table 6 has the results of relatively large facility number. Thus, the downstream facility has the low priority for the repair. Those facilities have small loss and high restoration risk and so BCP does not work so well.

Table 5 Facilities having high earthquake risk at right bank (Yen)

Facility No.	Facilitiy	Earthquake restoration risk	Loss risk	BCrisk	Eathquake risk	risk with BCP	Risk reduction by BCP(%)
104	Pipeline	779,370	296,385,488	0	297,164,858	297,164,858	0.0
129	Open channel	24,261,196	267,715,129	18,415,860	291,976,325	42,677,056	85.4
130	Open channel	3,458,558	267,715,129	14,732,688	271,173,686	18,191,246	93.3
131	Diversion aqueduct	618,172	267,715,129	0	268,333,301	268,333,301	0.0
103	Open channel	24,750,975	240,725,646	0	265,476,621	265,476,621	0.0
109	Open channel	12,180,025	237,070,972	0	249,250,997	249,250,997	0.0
95	Open channel	5,794,450	242,101,653	0	247,896,103	247,896,103	0.0
97	Open channel	5,562,672	242,101,653	0	247,664,325	247,664,325	0.0
98	Open channel	3,631,188	242,101,653	0	245,732,842	245,732,842	0.0
102	Open channel	3,090,373	242,101,653	0	245,192,027	245,192,027	0.0
105	Open channel	6,746,474	237,070,972	0	243,817,445	243,817,445	0.0
96	Open channel	193,148	242,101,653	0	242,294,802	242,294,802	0.0
114	Open channel	12,381,203	229,541,212	9,408,425	241,922,414	21,789,628	91.0
132	Open channel	9,926,642	231,659,639	0	241,586,282	241,586,282	0.0
111	Open channel	5,830,786	234,722,004	0	240,552,789	240,552,789	0.0
110	Open channel	3,108,900	237,070,972	0	240,179,872	240,179,872	0.0
116	Open channel	10,622,040	229,541,212	12,544,567	240,163,252	23,166,607	90.4
107	Open channel	2,409,717	237,070,972	0	239,480,689	239,480,689	0.0
112	Pipeline	4,496,313	234,722,004	16,631,055	239,218,317	21,127,368	91.2
117	Pipeline	10,428,494	228,545,933	12,544,567	238,974,427	22,973,061	90.4
133	Open channel	6,789,193	231,659,639	0	238,448,832	238,448,832	0.0
106	Open channel	1,375,689	237,070,972	0	238,446,661	238,446,661	0.0
108	Open channel	1,369,158	237,070,972	0	238,440,129	238,440,129	0.0
118	Open channel	7,757,167	228,545,933	15,680,709	236,303,101	23,437,876	90.1
113	Open channel	1,460,435	234,722,004	13,304,844	236,182,439	14,765,279	93.7
121	Open channel	9,585,114	225,067,178	9,265,874	234,652,292	18,850,988	92.0
115	Open channel	4,986,873	229,541,212	9,408,425	234,528,085	14,395,299	93.9
122	Open channel	3,844,840	225,067,178	9,265,874	228,912,018	13,110,714	94.3
120	Open channel	2,947,414	225,067,178	9,265,874	228,014,592	12,213,288	94.6
119	Open channel	1,075,245	225,067,178	12,354,498	226,142,423	13,429,743	94.1
128	Open channel	10,148,386	214,138,304	0	224,286,690	224,286,690	0.0
123	Open channel	6,469,120	214,138,304	11,784,290	220,607,424	18,253,410	91.7
127	Open channel	5,421,459	214,138,304	0	219,559,763	219,559,763	0.0
125	Open channel	2,766,410	214,138,304	14,730,363	216,904,714	17,496,773	91.9
124	Open channel	1,648,417	214,138,304	11,784,290	215,786,721	13,432,707	93.8

Fig. 10 shows the rough schematic view of the risk condition of the facilities at right bank. The facilities located at upstream have high priority for repair and difficulty for BCP, and so the repair project has to start immediately. The facilities located intermediately can be reduced the priority for repair by considering BCP. It is preferable that the facility which can be treated with BCP is repaired later. The facilities located at downstream are repaired at the last time.

6. CONCLUSIONS

In this paper, the asset management for irrigation facilities is introduced. Since the economic environment of agricultural activity is very bad, the maintenance project of irrigation facilities is very difficult to conduct. Therefore, the repair project of each facility has to be prioritized. In this paper, the earthquake risk and risk considering BCP are tried to prioritize the order. The earthquake risk includes the restoration cost and the loss. The risk considering BCP consists of the restoration cost and the cost for business continuity. By considering the BCP, the loss can be neglected.

The method is applied to the actual irrigation facilities in Japan. The degradation level at present is investigated and registered into the GIS system. The obtained conclusions can be summarized as follows:

Table 6 Facilities having low earthquake rick at right bank (Yen)

Facility No.	Facility	Earthquake restoration risk	Loss risk	BCrisk	Eathquake risk	risk with BCP	Risk reduction by BCP(%)
126	Open channel	149,456	214,138,304	0	214,287,760	214,287,760	0.0
136	Open channel	5,656,348	179,233,911	0	184,890,259	184,890,259	0.0
137	Open channel	1,008,262	179,233,911	0	180,242,173	180,242,173	0.0
134	Open channel	806,609	179,233,911	0	180,040,521	180,040,521	0.0
135	Pipeline	806,609	179,233,911	0	180,040,521	180,040,521	0.0
139	Pipeline	7,707,320	169,429,529	0	177,136,849	177,136,849	0.0
140	Open channel	4,486,764	169,429,529	0	173,916,293	173,916,293	0.0
141	Pipeline	1,947,563	169,429,529	0	171,377,092	171,377,092	0.0
138	Water bridge	1,078,840	169,429,529	0	170,508,369	170,508,369	0.0
142	Open channel	6,975,154	143,763,096	0	150,738,250	150,738,250	0.0
100	Open channel	1,103,118	100,195,886	0	101,299,004	101,299,004	0.0
101	Open channel	1,023,182	100,195,886	0	101,219,068	101,219,068	0.0
99	Pipeline	863,310	100,195,886	0	101,059,196	101,059,196	0.0
145	Open channel	2,585,119	76,062,623	0	78,647,742	78,647,742	0.0
143	Open channel	2,426,683	76,062,623	0	78,489,306	78,489,306	0.0
144	Open channel	1,066,908	76,062,623	0	77,129,532	77,129,532	0.0
146	Open channel	464,270	76,062,623	0	76,526,893	76,526,893	0.0
153	Open channel	6,965,526	35,305,421	950,496	42,270,947	7,916,022	81.3
152	Open channel	2,039,313	35,305,421	1,900,992	37,344,734	3,940,305	89.4
151	Open channel	849,714	35,305,421	1,900,992	36,155,135	2,750,706	92.4
156	Open channel	7,895,993	27,160,501	178,218	35,056,494	8,074,211	77.0
154	Open channel	6,308,018	27,160,501	356,436	33,468,519	6,664,454	80.1
157	Open channel	4,679,073	27,160,501	178,218	31,839,573	4,857,291	84.7
155	Open channel	606,118	27,160,501	356,436	27,766,619	962,554	96.5
150	Open channel	4,401,531	15,680,767	0	20,082,298	20,082,298	0.0
149	Pipeline	3,865,376	15,680,767	1,131,327	19,546,143	4,996,703	74.4
147	Pipeline	3,686,961	15,680,767	1,131,327	19,367,728	4,818,288	75.1
148	Open channel	1,025,832	15,680,767	905,062	16,706,600	1,930,894	88.4
158	Open channel	15,993,554	0	0	15,993,554	15,993,554	0.0
159	Open channel	4,084,104	0	0	4,084,104	4,084,104	0.0
160	Open channel	655,474	0	0	655,474	655,474	0.0

Table 7 Total earthquake risk and total risk with BCP of facilities at right bank (yen)

Eathquake risk	Risk with BCP	Risk withBCP / Earthquake risk
71,592,199,000	48,601,499,000	0.68

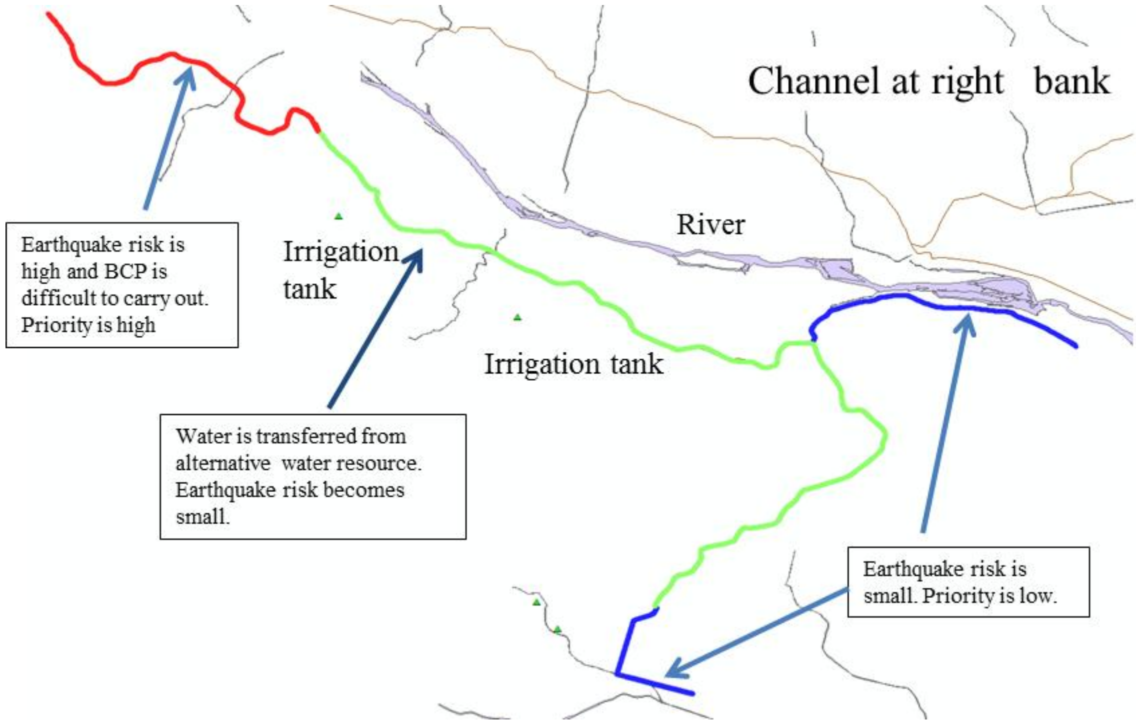

Fig.10 Rough schematic view of the risk condition of the facilities at right bank

1) The asset management result is dependent on the degradation curve. In this study, the early degradation curve is set up at the period a standard deviation earlier than the average degradation period. If the facilities degrade according to the early degradation scenario, the total cost increases by 45 % more than the average scenario in this study. The degradation curve has to be carefully identified.
2) To rank the facilities for repair project, the risk analysis for earthquake is applied in this study. While the ordinary risk management intends to minimize the loss by the accident, the business continuity after disaster is also important to secure the profit after disaster. By considering BCP, the eventual loss can be reduced. The eventual loss is reduced by about 70% of the loss without BCP in this study.
3) By considering BCP, the plan for repair project changes. If the facility can be secured by BCP, the loss by the failure of the facility reduces because the cost of BCP is smaller than the loss by the failure.

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