A STUDY FOR ASSET MANAGEMENT OF SLUICEWAY FACILITIES FORCUSING ON THE FACILITY IMPORTANCE

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***ABSTRACT*:** In recent years, a technique of asset management is being applied to maintenance and renewal of infrastructure facilities in consideration of a better fiscal management. Asset management of infrastructures focuses on the reduction and equalization of annual maintenance costs over the lifetime. In the field of river management, researches on the potential of maintenance cost reduction have been done for machinery and equipment, such as flood gates and sluiceway facilities. In such researches, however, social benefit and cost of the introduction of asset management, which are crucial in assuring the effectiveness, do not seem to be properly assessed. In this study, a social cost of losing the function of river management facilities is evaluated, taking sluiceway facilities for flood control as examples of such facilities. The social cost is assumed to consist of (i) maintenance and renewal cost of sluiceway facilities, and (ii) potential economic loss due to inundation resulting from the sluiceway facilities lost their functions.

In the first step, the maintenance and renewal cost of sluiceway facilities for a particular year was calculated by aggregating cost items in maintenance schedule for the year, and future costs were also calculated by accumulating the annual costs. The result of this calculation revealed that the maintenance cost varies significantly from year to year. It also showed that the equalization of the costs over the lifetime is important, which implies the necessity of prioritization of facility maintenance. In the next step, to assess the importance of each facility and to prioritize the facilities, potential economic losses due to inundation supposing that these facilities lose their function were calculated by inundation simulations and flood damage impact studies. As a result of this study, a scheme of evaluating the facilities in terms of social cost reduction is presented. The scheme enables a quantitative assessment of the importance of each facility and helps to determine the priority of maintenance of the facilities.

KEYWORDS: Asset management, facility importance, maintenance and renewal cost, flood inundation analysis, potential economic loss

1. INTRODUCTION

.In the future, demand for investment in the infrastructure facilities will increase, and its demand will increase intensively; because existing facilities (many of them were constructed intensively in the 1960's and 1970's during the Period of High Economic Growth) are becoming old and need renewal. In addition, budget for public works has been reduced as part of administrative and fiscal reform. For the reason above, it has been greatly concerned that funds for maintenance/renewal will be insufficient in the future

Against this background, cost equalization and reduction by asset management is being reviewed to maintain roads, bridges, port facilities and sewage works in an efficient manner.

On the other hand, in the field of flood control facilities, studies on reduction of the maintenance cost of mechanical equipment such as gate/operating apparatuses for sluiceway/gate facilities and other river administration facilities have been also underway, but detailed studies and discussions on this theme have just come under review[1]. The gate and sluiceway facilities are important structures for flood control that serve as part of a levee at the time of floods. Therefore, in developing asset management, it becomes important to consider value and priority assessments of these facilities, such as the degree of social implications when these facilities lose their function. However, these matters are hardly considered at the present moment.

In this study, elements necessary for the review of asset management of flood control facilities, one of the river administration facilities, were summarized, and the facility priority was analyzed in consideration of issues (flood risk, response to failure risk, etc.) peculiar to these control facilities

2. Outline of this Study

For this study, the characteristics of the flood control facilities were first summarized.

The flood control facilities characterize the construction of a wide variety of members. In particular, due to that a levee's elements are currently unknown, and it is difficult to review the asset management. The components of a gate/sluiceway, a weir and a drainage pump station are roughly determined. These facilities are made up of civil engineering, machinery and electric equipment, and various components. Though these facilities are deteriorated over time as seen in road, bridge and other facilities, they operate at a probabilistic event, such as at the time of floods, not at all time. For this reason, flooding and other unexpected events heavily affect the degree of deterioration of the facilities. Furthermore, when the facilities do not operate due to failures, accidents and other troubles, or when they cannot be used due to their renewal woks, the nonexistence of their alternative facilities greatly affects the society.

In consideration of these effects, the important things in the review of asset management of the flood control facilities are a) to summarize the concept of forecasts about deterioration of the facilities and their equipment, b) to extract and summarize elements that are critical to operation of the facilities and c) to prioritize the facilities in order of importance (social effect). For a) and b), studies on reduction of the maintenance cost for the facilities and the study of selection of their important equipment are being promoted in terms of mechanical equipment[2]. For c), however, it is said that there are few review cases such as from macroscopic evaluation of value and priority of the facilities.

Therefore, in this study, focusing on a group of facilities (sluiceway facilities) within a certain area, id est., the left bank of the Kizu River, each facility's future maintenance and repair costs over time were predicted. In the next step, with the aim of identifying the social significance of individual facilities, a risk of inundation damage occurred when each facility does not operate during flooding was calculated to determine the level of facility importance. Conditions on which the sluiceway facilities do not operate as the loss of functions during flooding were examined per recovery period. In addition, the risk was divided into external water flooding (external water risk) that results from inflow of external water due to the impossibility of closing the sluiceway facilities during flooding, and internal water flooding (internal water risk) that

Table.1 List of specifications of facilities reviewed

	Construction or renovation year	Fan type	switchgear type	Equipment quantity	Fan		Opening area(m^2)	Size category	Painting area(m^2)	Length of water-tight rubber(m)
					Width	Height				
Sluiceway1	1997	Roller	rack	4	5.9	3.28	77.4	Medium	625.70	73.44
Sluiceway2	1996	Roller	rack	2	9.1	4.4	40.0	Medium	210.67	54.00
Sluiceway3	1999	Roller	rack	4	5.2	3.28	68.2	Medium	528.82	67.84
Sluiceway4	1987	Roller	rack	2	3.8	3.18	24.2	Medium	223.75	27.92
Sluiceway5	1991	Roller	wire	2	6.85	3.5	48.0	Medium	605.90	41.40
Sluiceway6	1987	Roller	rack	2	3.27	3.01	19.7	Small	251.26	25.12

Table.2 Inspection cost per gate (annual)

Source: 2)

Gate class	Monthly inspection man-hours (year)	Annual inspection man-hours	Total of man-hours	Cost (thousand yens)		
				Inspection Cost (annual)	Maintenance cost (year)	Total (annual)
Small gate (rack type)	4×7=28	9	37	280	40	318
Medium gate (rack type)	4×7=29	9	38	280	40	325
Medium gate (wire rope winch type)	6.5×7=46	18	64	480	60	540
Large gate (wire rope winch type)	9×7=63	40	103	770	120	893

Note: Inspection cost = Man-hours × 20,000 yen/8 hours × 300% (cost calculated from the man-hours plus indirect cost)
Maintenance cost: Materials cost (about 12% of inspection cost) for simple maintenance implemented simultaneously during inspection (replacement of electrical parts, refueling, etc.)

Table.3 Major repair details and cycles, and costs

Source: 2)

Repair item	Repair content	Gate category	Cycle per equipment category	Cost unit price	Unit
Painting	Repainting	Small	13 years	20	Thousand yen/m^2
		Medium	12 years		Thousand yen/m^2
		Large	11 years		Thousand yen/m2
Fan / Door stop	Replacement of water-tight rubber	All size	20 years	100	Thousand yen/m
	Overhaul of roller	Small	15 years	500	Thousand yen
		Medium	12 years	800	Thousand yen
		Large	10 years	2,000	Thousand yen
Overhaul of switchgear	Overhaul of rack-type switchgear	Medium	15 years	300	Thousand yen
		Large	12 years	500	Thousand yen
	Overhaul of wire rope winch type switchgear	Medium	12 years	1,000	Thousand yen
		Large	10 years	2,000	Thousand yen
Renewal of switchgear	Renewal of rack-type switchgear	Small slide	19 years	5,000	Thousand yen
		Small roller	21 years	5,000	Thousand yen
		Medium	23 years	10,000	Thousand yen
	Replacement of wire rope	Medium	17 years	3,000	Thousand yen
		Large	14 years	5,000	Thousand yen
	Replacement of wire rope winch switchgear's motor	Medium	25 years	1,000	Thousand yen
		Large	23 years	6,000	Thousand yen
	Replacement of hydraulic push-up brake	Medium	30 years	1,000	Thousand yen
		Large	27 years	4,000	Thousand yen
	Replacement of reduction gear	Medium	32 years	6,000	Thousand yen
		Large	29 years	7,000	Thousand yen
	Replacement of changer	Medium	32 years	2,000	Thousand yen
		Large	29 years	3,000	Thousand yen
Control equipment	Replacement of local operation pane	Small	20 years	3,000	Thousand yen
		Medium	21 years	5,000	Thousand yen
		Large	19 years	6,000	Thousand yen

Note: The cost unit price is set as a reference value from data on past results. The price is positioned as a reference (measure) for simulation, and not a numerical value representing a precise cost unit price.

results from inflow of internal water due to the impossibility of opening the facilities after flooding, for calculation of the damage.

3. Simulation for Maintenance Cost

(1) Facilities under consideration

The study area covered the left bank of the Kizu River which is one of the tributary of the Yodo River. This study focused on sluiceway facilities which are scattered within the area and for which data are easily collected, although there are various flood control facilities in the drainage area.

Furthermore, construction year or the latest renovation year, fan type, switchgear type, equipment quantity, fan size specifications and painting area specifications were summarized for the individual target facilities. Table.1 shows a list of specifications of these facilities.

(2) Outline of cost simulation

In order to calculate each facility's life cycle cost (LCC) by cost simulation, the costs of the following items were estimated in reference to the past reviews[2] and in consideration of the size of the sluiceway facilities, each inspection/renewal item and renewal cycles.

LCC = Inspection cost (monthly and annual Inspections)
+ Repair cost (painting, fan/door stop, switchgear inspection, switchgear renewal, and controller)

For reference, these costs were simulated according to the past reviews. The outline of the cost simulation is given in the following. First, the following size category specified in the "Technical Standard for Dam & Weir Facilities" (1999), the Japan Association of Dam & Weir Equipment Engineering was applied to the cost estimation in order to set a unit price according to the facility size.

- Large fan: Area of more than 50 m^2
- Medium fan: Area of more than 10 m^2 and less than 50 m^2
- Small fan: Area of less than 10 m^2

Table.2 applied to the inspection costs. On the assumption that the inspection costs (annual cost + monthly cost) given in the table are charged every year, these costs were calculated.

The content and cycle of repairs to be reviewed, and repair costs were first established under Table.3. The repair costs were simulated from each sluiceway's construction year or the latest renovation year on the assumption of cyclic occurrence of the costs shown in the table.

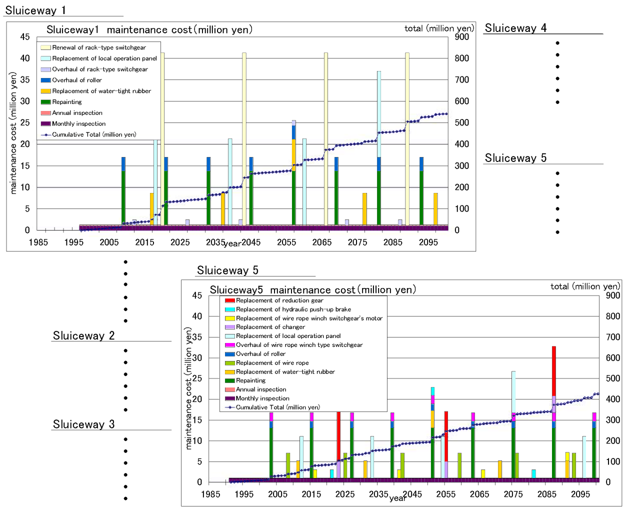

Fig.1 One example of LCC results for individual facilities

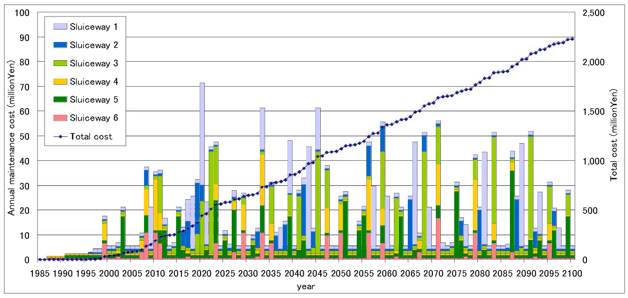

Fig.2 Secular changes in LCC (Total of LCCs for all sluiceway facilities)

(3) Result of cost simulation

The results of calculation of LCCs for individual facilities are given in Fig. 1. As shown in the figure, a large cost in the relevant year of the repair is generated due to that repair costs for each repair item and for each cycle occur. By summing up the maintenance cost of each facilities, the secular distortion of the whole maintenance cost is shown in Fig.2. This figure shows that the maintenance cost varies widely in each year and becomes high in a year with the overlapped renewal of several facilities. Consequently, it is important not only to reduce repair and renewal costs but also to equalize costs temporarily occurring. Therefore, as described in the subsequent chapters, assessment of the facility importance was reviewed to assign renewal/repair priorities to the facilities and determine whether a low-priority facility can be renewed /repaired later.

4. Assessment of Facility Importance

(1) Outline of the review

In assessing the importance of each facility, the damage assumed when each facility does not operate is calculated to evaluate the effectiveness of flood control by each facility. The result shall be used as information for assessing the importance of the facilities. The outline of the review is shown in the following.

a) Setting of target block

First, in consideration of the range of review facilities affected, each target block is set. Important facilities within the block, and assets and topographical conditions in the block are determined.

b) Establishment of inundation analysis model

In the next step, an inundation analysis model is established with rectangular meshes (100m size mesh) for each block set above. For an external water risk, in order to determine external water inflow conditions for the analysis, an inundation discharge hydrograph is developed from this main river’s time-series of water levels, the conditions of the sluiceway’s opening and its branch river’s bank height. For an internal water risk, an inflow into an internal water river (branch river flowing into the relevant sluiceway) is calculated by rational runoff formula to prepare an inundation discharge hydrograph.

c) Damage image by operating status

When the sluiceway normally operates, it is considered that there is no inflow of the external water or internal water will be drained away from the sluiceway. On the other hand, the following two types of damage when the sluiceway cannot be operated due to any trouble, such as power trouble and insertion of driftwood, were set. First, when the sluiceway cannot be closed during flooding, external water with the flow discharge set above (b)) intrudes from the sluiceway (external water inundation). When the sluiceway is in closure and cannot be closed due to any trouble after the progression of the flood, it was assumed that water with the flow discharge calculated above (b)) would be inundated at the sluiceway (internal water inundation).

On the assumption of the conditions from the hydrograph based on these conditions, inundation analysis and damage calculation are made to determine damage in each block. Those facilities which its property of the block is greatly damaged due to the loss of facility's functions, is deemed to have a high importance, and evaluated.

(2) Review conditions

Two risk scenarios when the sluiceway does not normally operate; when it cannot be closed during flooding (external water risk) and when it cannot be opened after the progress of the flood (internal water risk), are supposed. A time from when the sluiceway cannot be operated due to any trouble, to when it is restored is set as follows based on the result of hearing from Kansai Branch, the Japan Construction Mechanization Association.

When the sluiceway cannot be closed during flooding, it is possible to restore it in about 3 hours. Consequently, assuming that the facility can be recovered in 3 hours, the inflow of water in initial 3 hours of the external water inflow hydrograph calculated above was set (Case 1).

Restoring the sluiceway's open manipulation often requires heavy equipment and about one day. Consequently, 24-hour internal water hydrograph was set. It was exaggeratedly assumed that the branch river's outflow could not be discharged and would cause the inundation at the sluiceway when a 10 mm/hour rainfall continues for 24 hours (Case 2).

(3) Outline of analysis model

An inundation analysis model was established based on a two-dimensional calculation model for unsteady flow with a 100 m-mesh grid. In establishing an analysis model, a 100-mesh average was calculated from a commercially available "digital map 50 m-mesh (altitude)" to determine a average ground height. A coefficient of roughness, a coefficient of discharge and a building cover rate were determined for each land use classification based on a commercially available "detailed digital information (10 m-mesh land use) and the "digital national land information (land use mesh)" on the Web of the Ministry of Land, Infrastructure and Transport.

In addition, property data used for damage calculation were established based on the "statistical maps on grid square basis compiled from the results of the population census" and the "statistical maps on grid square basis compiled from the results of the establishment and enterprise census of Japan" developed by the Statistics Bureau, the Ministry of Internal Affairs and Communications, and the "100 m-mesh gross floor area data" issued by the Japan Construction Information Center.

Fig. 3 shows an inundation discharge hydrograph that was used for the constructed inundation analysis model chart and assessment of external water risk (Case 1). In individual blocks for Sluiceway 1-6 shown in the figure, inundation analysis was made under the condition on which water with the flow discharge given in the hydrograph overflows at each sluiceway.

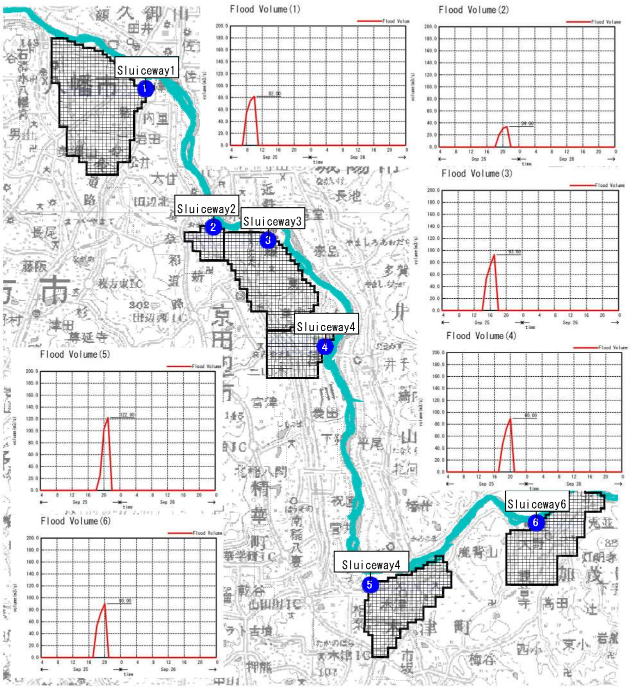

Fig.3 Analysis model chart and hydrograph

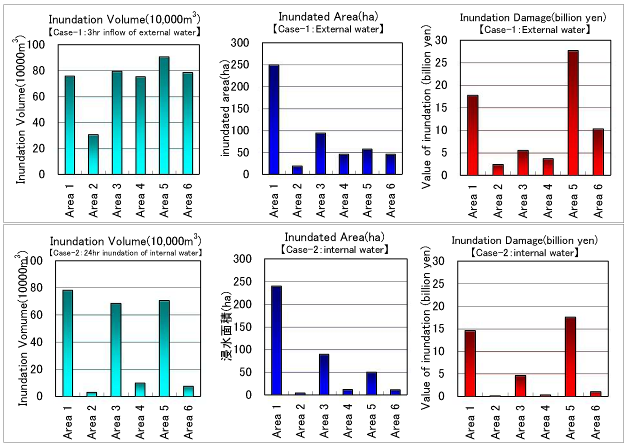

Fig.4 Results of damage calculation (Upper figure: External water risk, Lower figure: Internal water risk)

(4) Result of assumed inundation analysis

a) Assessment of external and internal water risks

The results of damage calculation for external (Case 1) and internal (Case 2) water risks set above are shown in Fig. 4. The figure shows an inundation volume, an inundation area and inundation damage in each block for both of the cases of external and internal water risks. From this figure, it is found that Area 1 provides a maximum inundation area and Area 5 provides a maximum damage. This is considered to be due to that inundated water expands in Area 1 and an inundation area is small but an inundation depth is deep in Block in terms of topographic details, and that assets are concentrate on immediate sluiceway facilities in Area 5. From the comparison between external and internal water risks, it is found that an inundation volume/area of the external water is almost same as that of internal water in Area 1 and 5, but a great flood inundation occurs at points with concentrated assets when the damage is estimated. Consequently, the damage from the external water is considered to be relatively larger than from the internal water.

However, it is hard to say that the conditions for inundation of internal water (conditions of rainfall, inflow region, etc.) reviewed in this section are sufficiently reasonable. For this reason, it is necessary to investigate topographic conditions, the state of the water's inflow into the target branch river, a network of waterways in a flood plain, the establishment of sewage works and other elements and reflex them in the analysis model and review conditions.

The risk of internal water was reviewed under a condition that a 10 mm/hour rainfall continues for 24 hours. This rainfall is considered to be excessive as a quantity of rain immediately after the progress of the flood. A close investigation into the conditions must be made, such as collection and compilation of data on the quantity of rain after the progress of the flood and selection of a proper rainfall with the highest probability.

b) Assessment for each restoration time

In addition to the conditions for a recovery period set above (Case 1 and 2), the result of review of a changed recovery period is shown in Fig. 5.

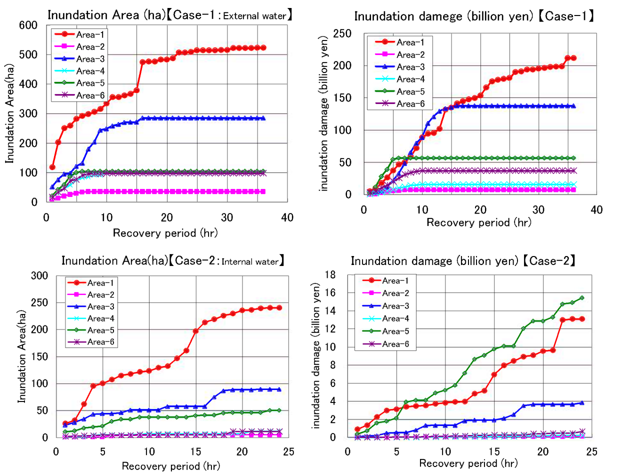

Fig.5 Result of damage calculation for each restoration time (Upper figure: External water risk, Lower figure: Internal water risk

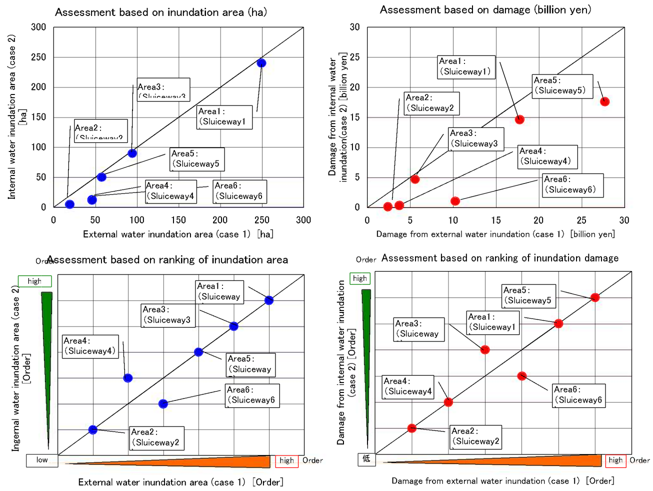

Fig.6 Assessment of external and internal risks (Assessment of inundation area, damage and order)

Base on this result, in the above Case 1 and 2, a recovery period was set at 3 hours and at 24 hours for opening and closing of the sluiceway, respectively. The figure shows that a delay of a recovery period naturally provides a larger inundation area. It is also indicated that the damage varies with a distribution of property in each block, and that the property concentrated on the immediate sluiceway are heavily damaged even if the recovery period is shorter. When the damage is evaluated in consideration of a recovery period and short-time restoration, a distribution of the property in the Block is found to have a great influence on the damage.

(5) Assessment of priority of each facility

a) Comparison between external and internal water risks

Based on the result of the above review, Fig. 6 shows the result of a comparison between external (Case 1) and internal (Case 2) water risks. As shown in the figure, a Block with a large risk of external water has the same risk of internal water, and the external risk is relatively larger than the internal risk.

b) Summary of assessment of facility priority

The summary of the above review results and facility assessment for each Block produce Table 4. As shown in the table, a facility in a Block with a large damage has a high importance, and a numerical evaluation indicator for each item enables assessment of importance of each facility.

5. Conclusion

(1) Application of facility priority assessment to LCC leveling

Based on the above result, when priorities are assigned to individual facilities by two indicators, or the scales of external and internal risks (damage), Sluiceway 5, 1, 6, 3, 4 and 2 can be ranked in order of importance. This ranking enables the review of LCC leveling.

For example, consider cost equalization so that an annual maintenance cost does not exceed 50 millions yen. If the renewal of a facility with a low priority is postponed when the renewal cost exceeds a given upper limit, the cost can be equalized as shown in Fig. 7. When the renewal/repair of a facility is postponed, however, it is necessary to

Table.4 List of facility priority assessment

Block No.		1		2		3		4		5		6	
Name of sluiceway facility		Sluiceway1	order	Sluiceway2	order	Sluiceway3	order	Sluiceway4	order	Sluiceway5	order	Sluiceway6	order
Inflow area (km^2)		8.8	1	0.2	6	6.5	3	1.1	4	7.7	2	0.7	5
Block area (km^2)		7.3	1	0.9	6	4.9	2	2.5	5	3.8	4	4.3	3
Condition of sluice way	(1)Sluiceway height TP.+m	10.2	–	15.3	–	16.5	–	20.4	–	26.4	–	33.5	–
	(2)Bank height for branch river TP.+m	13.0	–	21.2	–	19.7	–	24.2	–	32.1	–	36.6	–
	(3)Level of external water H.W.L.TP.+m	19.2	–	23.5	–	25.0	–	28.7	–	34.9	–	43.1	–
	Inflow easiness :(3)−(1)	9.0	2	8.1	6	8.5	4	8.3	5	8.5	3	9.6	1
	Inundation easiness :(3)−(2)	6.2	2	2.3	6	5.3	3	4.5	4	2.8	5	6.5	1
	LCC(100-year sum total) 100millions yen	6.5	1	3.2	4	6.3	2	3.0	5	4.9	3	2.3	6
Asset value (100 millions yen)		1,307	2	258	6	2,116	1	724	4	996	3	632	5
*** Comparison of inundation damage ***													
Case 1	【External water risk : 3-hour delay in closing the sluiceway】												
	Inundation area (ha)	250	1	19	6	94	2	46	5	58	3	46	4
	Damage (100 millions yen)	177	2	24	6	56	4	37	5	277	1	103	3
	Damage per LCC	27.2	3	7.4	6	8.9	5	12.4	4	56.7	1	44.2	2
Case 2	【Internal water risk : 24-hour delay in opening the sluiceway】												
	Inundation area (ha)	240	1	5	6	90	2	13	4	50	3	12	5
	Damage (100 millions yen)	146	2	1	6	47	3	3	5	176	1	10	4
	Damage per LCC	22.4	2	0.3	6	7.4	3	1.1	5	36.0	1	4.5	4
*** Total assessment ***													
	Sum of orders	4	2	12	6	7	3	10	5	2	1	7	4
	Sum of damage	324	2	25	6	102	4	40	5	452	1	113	3

evaluate the safety of the facility and confirm that there is no danger even if the work is put off for one year before decision-making.

Though the safety of the machine and equipment in the facility must be evaluated, the method shown in this study enabled to assign priorities to individual facilities. This can provide information for making a decision to equalize any maintenance cost.

(2) Conclusion and future issues

The framework of this review is roughly divided into 1) estimation of secular distortion in a future maintenance cost by simulation for maintenance cost and 2) quantitative assessment of facility importance by damage calculation according to a recovery period for a damaged facility.

The application of this framework enables visualization of secular distortion in a maintenance cost for a group of facilities in a target river basin, and also prioritization of each facility's importance. This enables the administrator of these river facilities to determine whether a facility can be repaired / renewed within an annual budget, and to select facilities to be prioritized or to assign priorities to the facilities in a quantitative manner when a budget for repair/renewal is tight. Once these frameworks established, even when conditions (facilities, recovery period, and property in the flood plain) are changed, the setting of a condition appropriate for the change enables a proper review.

The application of these frameworks is

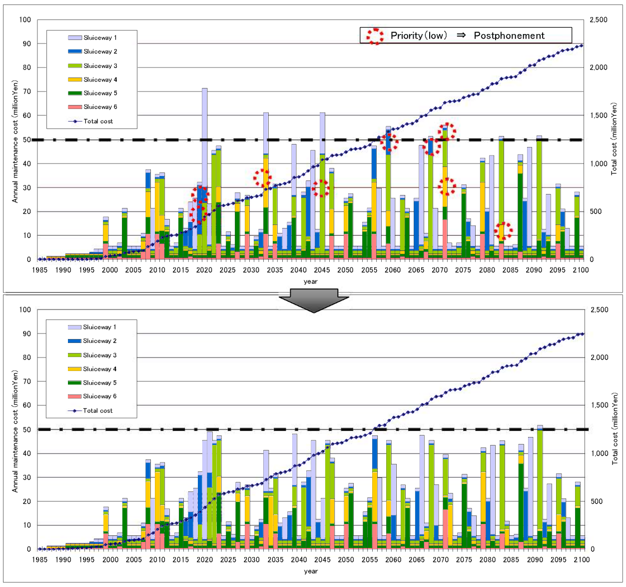

Fig.7 Case of application of facility priority assessment to LCC leveling

expected to help a manager of a group of facilities to administer government policymaking.

The results of this review include:

- Cost simulation for calculation of secular maintenance cost for each facility
- Quantitative assessment of facility importance for review of asset management of flood control facilities
- Provision of information for making a decision for cost equalization, one of purposes for asset management

The challenges in this review include:

- Analysis precision for damage calculation and close investigation into the concept of assessment of property in a flood plain
- Calculation of maintenance cost in consideration of telecommunications facilities and civil engineering structures other than mechanical equipment and of conponents consisting of each flood control facility
- Determination of necessity of preventive/post maintenance by assessment of importance of facilities and equipments consisting of each

flood control facility

- Prediction of deterioration of facilities and equipments consisting of each flood control facility
- Expansion to flood control facilities other than sluiceways
- Expansion of a review target region to each local office and each regional development bureau controlling several offices
- Review of asset management for flood control facilities

Though these challenges cover a broad spectrum, this study is considered to have enabled quantitative assessment and provision of a framework for the review.

Acknowledgments

We express our gratitude to the Yodo River Office, the Kinki Regional Development Bureau, the Ministry of Land, Infrastructure and Transport that provided materials and data. Furthermore, our thanks must go to the Kansai Branch, the Japan Construction Mechanization Association that provided information on operation and control of sluiceway facilities.

REFERENCES

1) National Institute for Land and Infrastructure Management / Ministry of Land, Infrastructure and Transport, Japan : Development of Asset Management Technology for Housing, Infrastructure and Building Stocks, *PROJECT RESEARCH REPRT of National Institute for Land and Infrastructure Management* No.4, Jan.2006

2) Japan Institute of Construction Engineering: Materials for "Review Meeting on Efficient Maintenance of Gate Facilities", Mar.2007

3) Japan Association of Dam & Weir Equipment Engineering "Technical Standard for Dam and Weir Equipment", 1999

4) Yoshio IWASA, Kazuya INOUE and Masafumi MIZUSHIMA: Method of Hydraulic and Numerical Analysis of Inundated Water, *"Bulletin of the Disaster Prevention Research Institute, Kyoto University"* No. 23B-2, Apr.1980

5) Minoru KURISHIRO, Chuji SUETSUGU, Tadashi UMINO, Yoshito TANAKA, Hiroaki KOBAYASHI: Inundation Simulation Manual (draft) - Simulation Guide and Verification of New Model-, *Public Works Research Institute's materials*, No. 3400, 1996

6) River Bureau, Ministry of Construction: Manual for Economic Evaluation of Flood Control (draft), May.2000