STUDY OF RESERVOIR SEDIMENTATION MANAGEMENT MEASURES FOR DAMS IN THE UPPER KIZU RIVER BASIN

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In the upper Kizu river basin, five water resources development dams including Takayama Dam(1969) have been constructed. It will be necessary to secure these water resources based on reasonable reservoir maintenance works for a super long term in the future. It is, therefore, necessary to plan and carry out efficient and economically feasible reservoir sedimentation management.

In this study, we studied characteristic of inflow sediment of dam group and feasibility of various sedimentation management measures. By a case study of Takayama Dam, we evaluated the cost and the effect of sedimentation management quantitatively. As the result, we showed the advantage of dry excavation with periodical reservoir emptying and suggested the necessity for further study on the integrated sediment management such as dry excavation by turns in a group of dams.

Key Words: *Reservoir sedimentation management, Takayama dam, dry excavation*

1. Introduction

In Japan, dams had been constructed after the war, and many of these dams are nearing 50 years after the completion. In these dam reservoirs, sediments have been filled decreasing valuable water storage capacity[1]. Generally, dam reservoirs have sediment storage capacity to allow sedimentation for 100 years. For the intended purpose of flood control and water use, dams should function permanently, thus, it is undesirable for dam reservoirs to be filled with sediment that eventually makes them unusable for the intended purposes.

For the past years, the countermeasures for sediment had been implemented in those areas such as Hokuriku and Chubu regions in Japan where a severe sedimentation had been identified. In recent years, regardless of the volume of sediment from catchment area, it has been emphasized on prolonging of life span and the effective use for sustainable water resources management.

In the upper Kizu River Basin on Yodo River System, five dams including the Takayama Dam (completed in 1969 are being managed and operated. (See Fig 1)

In order to make effective use of the dams, to maintain proper function of the reservoirs and to implement efficient and economically feasible management, it is required to establish an asset management system.

This study provides the accumulated sediment of dam reservoirs in upper Kizu River Basin, the characteristics of soil type of sediment and the feasibility of various sedimentation management measures. Also some comments are made concerning asset management of the dam reservoirs.

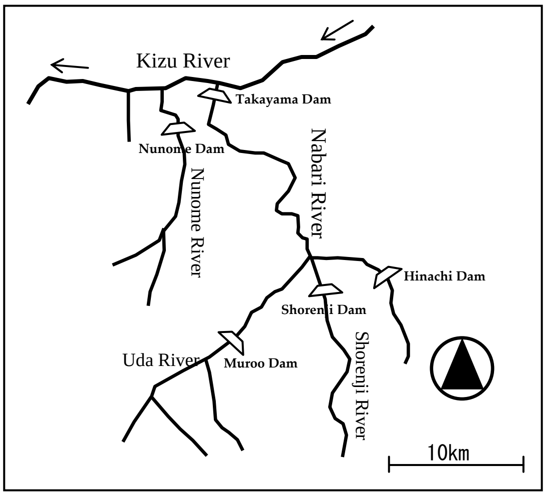


Fig-1 A group of dam in upper Kizu River Basin on the Yodo River System

2. Procedures

(1) Flow

The procedure to extend the service life of dams is shown in Fig.2. In this study, sediment control measures were verified from the viewpoint of the sustainable reservoir management for super long term.

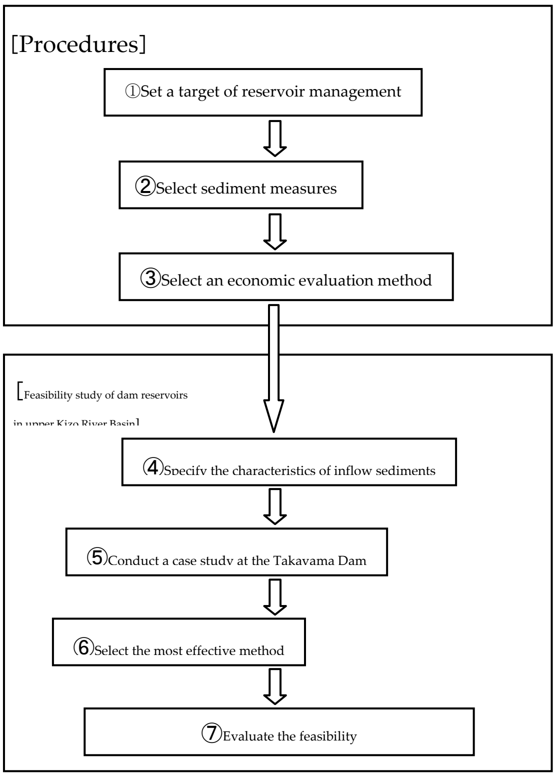


Fig. 2: The flow to extend the life span of dam reservoirs.

(2) Management target in reservoir

The objective for reservoir management is to maintain the water use capacity at the current level in the future. To achieve it, sediment control measures are examined for preventing the loss of the water use capacity.

(3) Methods for reducing sedimentation in reservoirs

Methods for reducing sedimentation are divided into main options and some comments is outlined in the **Table 2**:

(4) An economic evaluation method

As Fig 3 indicates, the economic evaluation is made including initial costs for sediment control facilities. The evaluation is calculated based on the total cost, provided that the past value is computed from the following formula which shows how much it is worth at present. Discount rate is set at 4% [2)]

$$\text{Total Cost in T years} = \sum_{t=1}^{T} \frac{Cost\ for\ the\ Tth\ year}{(1+r)^{T}} \quad (1)$$

Where, r : Discount rate at present value (=0.04)

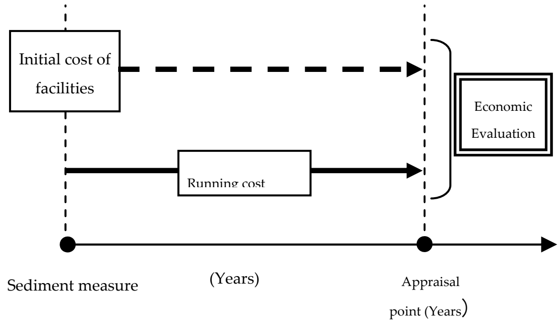


Fig. 3 A method for Economic Evaluation

(5) Characteristics of sediments

a) Sedimentation rate

In order to evaluate the progress of sedimentation, a comparison between the designed volume of sediment and the actual volume is conducted which is shown in the **Table 2.** It indicates that sediments other than the Shorenji Dam reservoir had been deposited faster than the plan, especially, in the Takayama Dam reservoir. The dam was completed 36 years ago (as of 2005) and the sediment accumulated to about 1/2 at the designed level. The sedimentation in the Takayama dam reservoir may have much impact on the other reservoirs in the upstream and countermeasures against sediment are required to secure water resources for the future.

Table 1; Methods for reducing sedimentation in reservoirs divided into main options

Main options	Description and the cost
Excavation	A method to remove soil-storing area in reservoir by heavy machine *Initial cost: None *Cost: Excavation
Dredging	A method to remove sediments settled under water by dredger * Initial cost: None *Cost: Dredging
Check dam (+excavation work)	Construction of check dam on the river and to remove sediments stored at the check dam by heavy machine *Initial cost: Construction fee for check dam *Cost: Excavation work at check dam
Flushing	Sediments flushing by temporarily lowering water level of reservoir *Initial cost: Installation fee for sediment flushing gate *Cost: Rehabilitation of facilities, the possible payment for the decreased power generation
Construction of bypass tunnel	Sediments are diverted directly downriver through the bypass tunnel *Initial cost: Construction fee for bypass tunnel *Cost: Rehabilitation of tunnel
Dry excavation to create a greater depth of water	Periodical reservoir emptying to excavate and remove sediments under water *Initial cost: None (Installation of a drawdown gate if necessary) *Cost: Excavation, the payments for decreased reduced power energy and the loss of storage volume

Table 2: Sediment transport in five dams in the upper Kizu River (As of 2005)

	years	Designed volume of sediment (m3/km2/year)	Measured mean volume of sediment (m3/km2/year)	Actual sedimentation rate in 2005
Takayam Dam	36	201	< 264	47.4%
Seirenji Dam	35	340	> 295	30.4%
Muroo Dam	31	191	< 275	44.6%
Nunome Dam	13	253	< 278	16.5%
Hinachi Dam	6	318	< 613	15.4%

b) Characteristics of soil types

Identification of soil types in reservoir is a key element in conducting the feasibility study for sediment management measures. In this study, three soil particles were examined: wash load (d<0.0775mm), sand (0.075mm<d<2.0mm), sand gravel (2.0mm<d). Moreover, the soil types in both the sediment entering reservoirs and the previously accumulated sediment (quantity and quality) were identified using the published data[3] and the measured data. The result is outlined in the **Table 3**.

c) Determination of sedimentary fraction (Statistical analysis on sediment volume)

Statistical analysis is performed based on the data measured by each dam reservoir so that sedimentary fractione would be determined.[4)5)]. On the basis of statistical analysis, the return period was evaluated to the maximum annual amount. The concept of sedimentary fraction and statistical analysis are shown in Fig. 4 and Table 4, respectively. It was calculated that the maximum annual amount (the measured maximum amount of sediment due to the sporadic inflow sediments) was about 10-15% of the designed capacity, and the return period was about 1/10-1/50 years. In this context, it is desirable to allow the sediment storage in time for sporadic inflow sediment at the rate of 10-15% of sediment storage capacity. Thus, the sedimentary fraction is designated at 80%. (It is assumed that sediment will be controlled within 80% of the designed level)

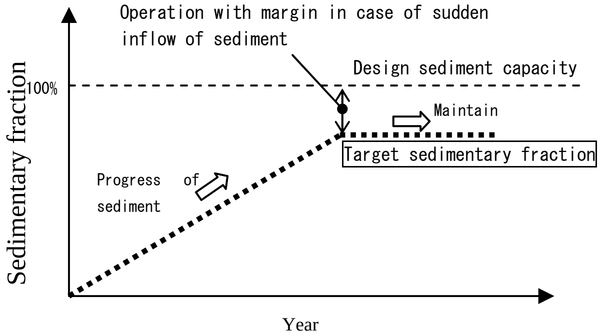


Fig-4 A concept of sedimentary fraction

Table 4: The results of sedimentation evaluation

	Designed volume of sediment	Annual maximum volume of sediment (year)		
		Volume of sediment	Sedimentation rate	Return period
Takayama Dam	7.6 mil.m^3	621,000 m^3	8.2%	1/52year
Shorenji Dam	3.4 mil.m^3	336,000 m^3	9.9%	1/35year
Muroo Dam	2.6 mil.m^3	314,000 m^3	12.1%	1/45year
Nunome Dam	1.9 mil.m^3	230,000 m^3	12.1%	1/51year
Hinachi Dam	2.4 mil.m^3	140,000 m^3	5.8%	1/12year

3 A case study in Takayama Dam

Qualitative evaluation on the main options was conducted at the Takayama Dam which is located downstream among a group of dams and has largest storage capacity.

(1) Cost-effectiveness in main options

a) Sediment removal cost

In this study, "dry excavation" was added to the conventional methods. (See **Table 1**) The dry excavation is to remove deposited sediments empting reservoirs periodically by suspending dam operation for one year. An advantage of this method should be compared with other options considering the relationship between the loss of reservoir function and an affordable excavation method.

For conducting the dry excavation, the cost covers the loss of water use capacity together with the compensation

Table-3 Characteristics of inflow sediment to each dam classified by grain size

	Average inflow sediment	Portion Classified by grain size			Capture rate of wash load	Average Sedimentation volume per year	Sedimentation volume by grain size		
		Wash load (≦0.075mm)	Sand (0.075mm< <2.0mm)	Sandy gravel (2.0mm≦)			Wash load (≦0.075mm)	Sand (0.075mm< <2.0mm)	Sandy gravel (2.0mm≦)
Takayama	104,550 m^3	46,770 m^3 44.7 %	53,380 m^3 51.1 %	4,400 m^3 4.2 %	44.3%	78,500 m^3	20,720 m^3 26.4 %	53,380 m^3 68.0 %	4,400 m^3 5.6 %
Shorenji	41,740 m^3	29,080 m^3 69.7 %	11,390 m^3 27.3 %	1,270 m^3 3.0 %	57.9%	29,500 m^3	16,840 m^3 57.1 %	11,390 m^3 38.6 %	1,270 m^3 4.3 %
Muroo	45,510 m^3	31,070 m^3 68.3 %	14,250 m^3 31.3 %	190 m^3 0.4 %	73.9%	37,400 m^3	22,960 m^3 61.4 %	14,250 m^3 38.1 %	190 m^3 0.5 %
Nunome	23,550 m^3	15,400 m^3 65.4 %	7,980 m^3 33.9 %	170 m^3 0.7 %	82.8%	20,900 m^3	12,750 m^3 61.0 %	7,980 m^3 38.2 %	170 m^3 0.8 %
Hinachi	56,810 m^3	36,760 m^3 64.7 %	19,860 m^3 35.0 %	190 m^3 0.3 %	71.4%	46,300 m^3	26,250 m^3 56.7 %	19,860 m^3 42.9 %	190 m^3 0.4 %

for declined energy generation and excavation work. The cost reflects the loss of reservoir function described below. Under the assumption that the dry excavation was conducted during non-flood period, the cost would cover only water use capacity. In this respect, the compensation for water loss was calculated from the allocation cost for water use. This calculation is used to evaluate the relationship between the allocation cost and water use capacity in the Hinachi Dam reservoir which is the newest dams among the group of the dams.

- It is assumed that the life span of dam reservoir is 100 years. The cost per volume (1m3)= the cost for water use/water use capacity/ 100 years.
- Based on the above the assumption, the cost was calculated in case for one year suspension of reservoir.

If dry excavation was conducted on a long-term basis, we set the cycle of empting reservoir at 1/10 years, considering frequency of sporadic inflow sediment and the aforesaid return period (1/10-1/50 years). The estimate is shown in the **Table 5** in case that dry excavation work were done in the Hinachi Dam reservoir. On the basis of the above assumption, the cost was estimated in case of the Takayama Dam reservoir as outlined in the **Table 6**.

Table-5 The estimated cost when water level is lowered at the Hinachi Dam reservoir

Capacity For water use	Allocation fee for domestic water	Annual cost required for water use for 100 years (Compensation)	Per unit
15,300,000m^3	34,843 mil. yen	348,435,000yen	23yen/m^3/year

Table-6 The estimated cost when water level is lowered at the Takayama Dam Reservoir (to be implemented 1/10 years)

Reduced power generation	Cost for the loss of water use capacity
43,700,000yen/year (Unit：8,760,000yen/hr)	31,740,000yen /year (Cost 317,400,000yen/time)

b) Cost and effect

The cost and effect for sediment control measure was evaluated based on the feasibility study on reservoir management for super long term. The estimated "annual removal rate" (the removal rate versus inflow sediment) and the cost and effect of each option is outlined in the Table 7

(2) Combination of each option

In the previous section, the removal rate was outlined. In this section, the combination of each option is considered. According to the study, it was recognized that it was unable to remove sediments completely by each option except "dredging" and "dry excavation." It means the sediment could remain to some extend by the methods (excavation, check dam, flushing and bypass,) and the remaining sediment eventually fills the designed sediment capacity. To keep proper function of the reservoirs, application of either "dredging" or "dry excavation" to each option was considered when it is confirmed that the sediment reaches the designed sedimentary fraction. The result is shown in the **Table 8**. It shows an advantage of dry excavation with options except flushing. Flushing was more effective with "dredging." The validity was verified because only small amount of sediment should be dredged after flushing, however, in this method, the total cost was estimated

Table-7 The cost and effect of sediment measures

	Cost		Removed rate (%)			Annual removed volume		
	Initial cost of facilities)	Running cost	Wash load	Sand	Gravel	Wash load (※including naturally removed volume) Inflow sediment 46,770 m^3/year	Sand Inflow sediment 53,380 m^3/year	Gravel Inflow sediment 4,400 m^3/year
Excavation	―	2,500 yen/m^3	10%	50%	100%	28,123 m^3/ year	26,690 m^3/ year	4,400 m^3/ year
Dredging	―	20,000 yen /m^3	100%	100%	100%	46,770 m^3/ year	53,380 m^3/ year	4,400 m^3/ year
Check Dam (＋Excavation)	5,400 mil. yen /each (Check Dam)	2,500 yen /m^3	10%	70%	100%	28,123 m^3/ year	37,366 m^3/ year	4,400 m^3/ year
Flushing	10,100 mil. yen / each (Gate for sediment flushing)	22 mil. yen /year	100%	100%	50%	46,770 m^3/ year	53,380 m^3/ year	2,200 m^3/ year
Bypass tunnel	13,163 mil. yen / each (Bypass for sediment flushing)	121 mil. yen /year	50%	60%	100%	36,410 m^3/ year	32,028 m^3/ year	4,400 m^3/ year
Dry excavation	―	2,500 yen/m^3 (Excavation) 75 mil. yen /year (Compensation)	100%	100%	100%	46,770 m^3/ year	53,380 m^3/ year	4,400 m^3/ year

high due to the initial cost for flushing.

Table 8 Evaluation result of combined methods

	Removed sediment (m³/year)	Remaining sediment (m³/year)	[Proposed methods]] Annual cost (10^3 yen)	
			Dredging	Dry excavation
Check dam (+ Excavation)	69, 889	34, 661	693, 220	162, 093
Excavation	59, 213	45, 337	906, 740	188, 783
Bypass tunnel	72, 838	31, 712	634, 240	154, 720
Flushing	102, 350	2, 200	44, 000	80, 940

(3) Evaluation in Takayama Dam reservoir

Based on the proposed methods above, the evaluation was conducted in the Takayama Dam Reservoir. The total cost was calculated as shown in the Fig. 5,6 and 7. The estimate was after 300 years of reservoir because the cost in 200 years of reservoir indicated near 0 point which was unable to evaluate the cost and effect. The estimate shows that the combination of “excavation and dry excavation” was the most cost-effective. For the removal rate, bypass tunnel and flushing methods would be effective, but it should cover the initial cost for the facilities, therefore, it was assumed to be disadvantage in terms of the cost.

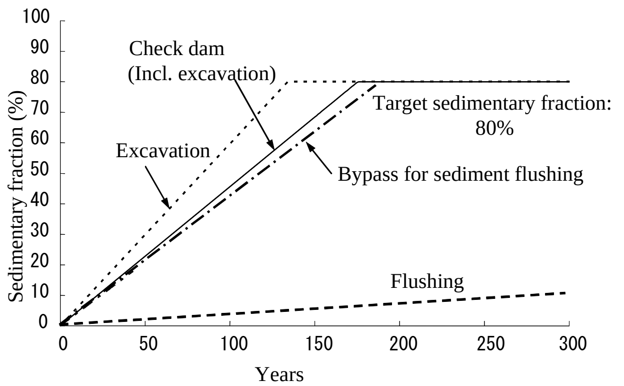


Fig-5 Variation prediction of sedimentary fraction in Takayama Dam

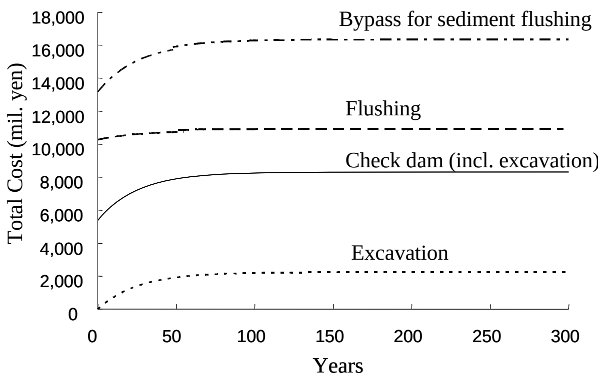


Fig-6 Total cost in each countermeasure in Takayama Dam

Table-9 Total cost for Takayama Dam reservoir after 300 years

Options	Combination	Total cost after 300 years
Check dam (+Excavation	+Dry excavation	8, 307 mil. yen
Excavation	+Dry excavation	2, 259 mil. yen
Bypass tunnel	+Dry excavation	16, 190 mil. yen
Flushing	+Dredging	10, 625 mil. yen

4. Feasibility study on sediment management measures in dams in upper Kizu River

(1) Feasibility study

Based on the evaluation on the Takayama Dam, the feasibility studies on the other four dams (Hinachi, Seirenji, Muroo and Nunome Dams) were conducted. The guidelines for estimating the cost of each option is summarized:

Table-10 Guidelines for estimating each option

Check dam (+Excavation)	・Cost for land acquisition (Effect backwater from check dam) is calculated on the basis of the Takayama dam body volume versus the check dam body volume
Bypass tunnel	・Tunnel cost is calculated as the same way of the Takayama Dam ・Volume of diversion weir is calculated based on the Takayama Dam body versus sediment storage capacity ・The cost for intake gate is calculated as the same way of the Takayama Dam ・The cost for land acquisition is calculated as the same way of the Takayama Dam ・Diameter of the tunnel is the same as the Takayama Dam
Flushing	・Flushing gate is installed at bedrock. Tunnel length is estimated at 1,000mmm ・The cost (training dyke, intake gate, etc) is calculated as the same way of the Takayama Dam ・Diameter of tunnel, the payment for reduced power generation are calculated as the same way of the Takayama Dam (At the Nunome and Muroo DAmsThe calculation does not include the payment for reduced power generation)

(2) Evaluation on four dam reservoir

The feasibility studies on the four dam reservoirs (Hinachi, Sirenji, Muroo and Nunome) were conducted. The result is shown in the **Table 11.** It shows an advantage of the combination of “dredging and dry excavation” methods as shown in the case of the Takayama Dam reservoir. In this respect, the applicability of bypass tunnel and flushing was assumed low because the volume of inflow sediment in the group of dams is relatively low.

In the meantime, it was assumed that the volume of inflow sediment (See the **Table 2**) was increased by 4 times than current level. For example, the current volume in the Takayama Dam reservoir is 264m3, the volume was calculated at 1,056m3/km2/year (264m3/km2/year× 4) In this case, it proved that flushing and bypass tunnel method were applicable to the Takayama Dam reservoir and other dam reservoirs. That is why flushing and bypass tunnel have been widely used in the Amaryu River System and it is considered this would be effective for a super long-term.

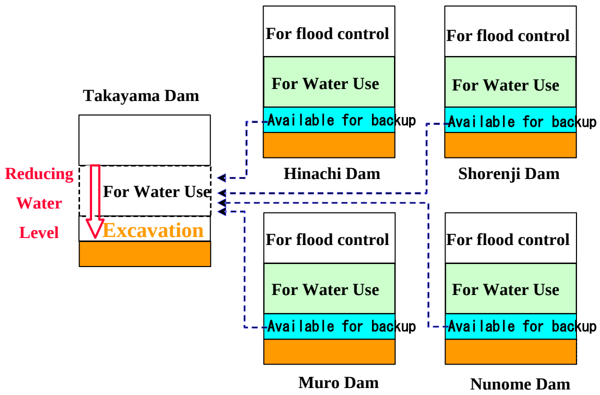
5. Future asset management in dams in upper Kizu River

Based on the feasibility study, asset management in the Kizu River Basin would be;

a) Facilities such as bypass tunnel is not necessarily required in the scope of the sediment measure to be taken at solely the Takayam Dam reservoir where inflow sediment is relatively small due to the effect of the sediment measures at the three dams in the upstream,

b) The above-said (a) indicates the possibility that could to conduct permanent sediment control measure for the Takayama Dam reservoir if inflow sedimentation would increase due to excavation and sediment flushing from upstream dams (3 dams) and the possibility that could carry out economically feasible sediment measures in cooperation with a group of the dams in upstream.

c) It is presumed that the payment for the loss of water use capacity is not an easy task; therefore, "sustainable dam reservoirs management in these dams is necessary with an appropriate method such as an integrated operation (to cover a lack of water supplemented by other dam reservoirs) and permanent sediment control measure for the Takayama Dam reservoir. The conceptual image of the integrated operation in the group of dams is shown in the Fig. 7.



When emptying Takayama dam reservoir, water can not be allocated to water users. In this case, the loss of water use capacity will be covered by other four dams by using unused sediment storage capaci

Fig-7 Image of cooperating among 5 dam operation
(in case of the Takayama Dam to lower water level)

6 Conclusions

Focusing on "sustainable reservoir management for super long term," this study provided the characteristics of inflow sediment and the feasibility of the various countermeasures against sediment. Based on the result, future asset management are mentioned. In the group of dams in the upper Kizu River Basin, efficient and economically feasible reservoir management is necessary by achieving the optimum method such as an integrated operation among the group of dams and permanent sediment control measure for the Takayama Dam reservoir.