SEDIMENT COUNTERMEASURES AT DAMS CONSTRUCTED ON RIVERS WITH HEAVY SEDIMENT DISCHARGE

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1. Introduction

River basins in Japan characteristically produce far more sediment than rivers in other parts of the world as a result of topographical, geological, and hydrological conditions. This means that water storage dams constructed to develop water resources and to control floods are provided with sediment storage capacity, but at some dams sedimentation has exceeded the planned quantity, so their sedimentation capacity has already been lost.

Problems caused by the sedimentation of reservoirs at dams in Japan include 1) obstruction of water intake by burying intake systems, 2) sedimentation of the upstream end of reservoirs resulting in damage by inundation of the land by flood water at the upstream ends of reservoirs and along upstream river courses, 3) decline of flood control functions caused by reduction of flood control capacity, 4) decline of quantity of water supplied because of inadequate water utilization capacity, and 5) production of turbid water in reservoirs and downstream from dams.

The blockage of the supply of sediment to downstream rivers by the construction of dams causes other problems such as 1) obstruction of water intake and impact on structures such as scouring of bridge foundations caused by the fall of riverbeds, 2) impact on the river environment by the decline of the supply of sediment to the river downstream from the dam, and 3) retrogression of beaches along seacoasts caused by a fall of sediment supply.

The Ministry of Land, Infrastructure, Transport and Tourism of Japan introduced the concept of the "sediment transport system" in 1998, and has adopted comprehensive sediment control considering the continuity of sediment flow from upstream to downstream as a policy that should be a goal of river administration. Under this policy, past sediment measures for dam reservoirs which considered only reservoir management have been replaced by a new perspective: improving sediment movement throughout every river basin by comprehensively considering the entire basin from the upstream point of the river to its downstream end including the ocean near its mouth.

This means that methods of removing sediment from dam reservoirs that have been considered in the past are re-positioned in order to restore sediment transport systems throughout river basins.

A variety of measures to deal with sedimenttation of reservoirs have been considered. The major measures are (1) dredging or excavation, (2) check dams, (3) sediment bypasses, (4) Sediment flushing, and (5) discharging inflowing sediment through dam spillways.

Comprehensive sediment management is not limited to simply causing sediment to flow downstream; its application requires studies to clarify to what degree sediment should be supplied downstream throughout a river basin area or which grades of sediment should be supplied. If this perspective is also considered, it is necessary to conduct studies to develop sedimentation countermeasures by asking a new question: what kinds of sedimentation countermeasures are most appropriate.

This paper presents a report on a study undertaken by a committee of experts and researchers on measures to remove sediment at a dam group as part of comprehensive sediment management on the Tenryu River: a river with produces far more sediment than most of Japan's rivers.

2. Outline of the Tenryu River

The Tenryu River drains a river basin with total area of 5,090m^2 through its 213km long main channel which originates in the Yatsugatake Range in Nagano Prefecture in central Japan and flows through Lake Suwa into the Pacific Ocean. Land use in the river basin is about 86% mountainous, 11% farmland including paddies and dry fields, and approximately 3% residential land.

The topography of the river basin is a basin-shaped valley surrounded with high mountains on its east, west, and north sides in its upstream section, a mountainous zone in the midstream section, and a plain in the down-stream section.

The riverbed gradient is about 1/200 upstream, from 1/300 to 1/700 midstream, and between 1/500 to 1/1,000 downstream, making it one of Japan's relatively steep rivers.

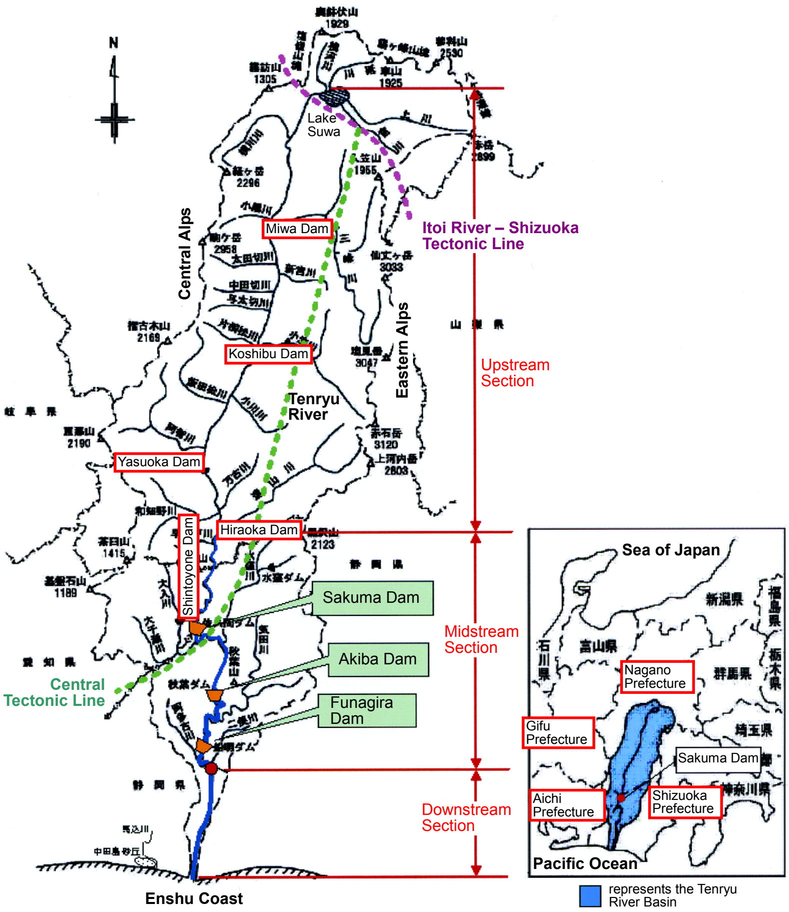


Figure 1. Tenryu River Basin

The region's geology features the Median Tectonic Line which is the largest tectonic line on the Japanese Archipelago, and the Itoi River – Shizuoka Tectonic Line. Upstream it is a Tertiary tuff region. On the west side of the Median Tectonic Line, it is granite while on the east side, it is sedimentary rock consisting of sandstone, slate, etc. Throughout the river basin, fragile geology has produced many large-scale landslide zones, and because the topography is also steep, large quantities of sediment are produced, forming alluvial fans on the downstream plain plus coastal sand dunes along the coast near the river mouth.

Rainfall in the river basin ranges from about 1,200mm to about 1,800mm upstream and between 1,800mm and 2,400mm from the midstream to downstream sections. Its average annual temperature is about 15 and 16ºC.

Along the Tenryu River, two multi-purpose dams have been constructed to control flooding and supply utilization water on tributaries in the upstream region. In the mountainous zone in the midstream part of the river, five dams have been constructed on the main river course to generate electricity, and on its tributaries, one dam has been constructed to generate electricity and one more to generate electricity and control flood water. Figure 1 shows an outline of the river basin.

Of dams constructed on the main course in the midstream region, the dam with the largest reservoir storage capacity is the Sakuma Dam which is the third furthest upstream. The Yasuoka Dam and the Hiraoka Dam which stand upstream from the Sakuma Dam are almost filled with sediment, and at the Sakuma Dam, about 1/3 of the reservoir capacity of about 330,000,000 tons has been eliminated by sedimentation. Sediment produced in the upstream Tenryu River Basin is deposited in the high capacity Sakuma Dam, so the Sakuma Dam is a structure that is disrupting the continuity of the sediment movement. Table 1 shows the specifications of the five dams located in the midstream section of the Tenryu River.

Table 1. Specifications of Dams on the Main Course of the Tenryu River

Dam name	Purpose	Dam type	Dam height (m)	Total reservoir capacity (1,000m³)	Dam operator	Comple-ted
Yasuoka	Electric power production	Concrete gravity	50	10,761	Chubu Electric Power Co., Inc.	1935
Hiraoka	Electric power production	Concrete gravity	62.5	42,525	Chubu Electric Power Co., Inc.	1961
Sakuma	Electric power production	Concrete gravity	155.5	326,848	J-Power	1956
Akiba	Electric power production	Concrete gravity	89	34,703	J-Power	1958
Funagira	Electric power production	Concrete gravity	24.5	10,900	J-Power	1977

Photo 1. Erosion on the Enshu Coast

On the Enshu Coast near the mouth of the Tenryu River, long-term coastal erosion has appeared, causing the regression of the shoreline at the river mouth. Coastline erosion stood at an average of approximately 300,000m³ per year from 1962 to 1980, and about 190,000m³ per year from 2001 to 2004, resulting in the exposure and runoff of garbage formerly disposed of as coastal landfill, disappearance of dunes in front of roads running parallel to the coastline area, and other phenomena resulting in a rise in the number of waves overtopping the roads. Photo 1 shows the state of erosion on the coastline.

3. Ensuring continuity of sediment movement and state of sedimentation at the Sakuma Dam

On the Tenryu River, it is essential to ensure the continuity of the sediment movement from upstream to the river mouth. So to ensure continuity of sediment movement on the Tenryu River, sediment now blocked from flowing downstream by dams on the main river course must be allowed to flow downstream. A survey of dams constructed on the main course reveals that the reservoirs at the Yasuoka Dam and Hiraoka Dam are already filled with sediment, and that almost all sediment flowing to these dams from upstream continues to flow downstream.

At the Sakuma Dam, the reservoir storage capacity is particularly large, and as shown by Figure 2, the sedimentation in the reservoir has formed a classic shoulder. A sediment shoulder advances as sedimentation progresses, and at the upstream end of the reservoir, the rise of the riverbed by sedimentation causes damaging inundation of the land at the upstream part of the reservoir during the flood discharge season.

At the Akiba Dam downstream from the Sakuma Dam, sedimenttation has advanced until its reservoir is nearly filled with sediment, but this dam has two flushing gates with sediment removal functions. The Funagira Dam further downstream has a dam height of 24.5m, and if its 9 gates are opened during flood discharge periods, all sediment from upstream can be allowed to flow down-stream. Consequently, in order to restore sediment movement from the upstream end to the mouth of the Tenryu River, measures to cause the sediment in the Sakuma Dam and

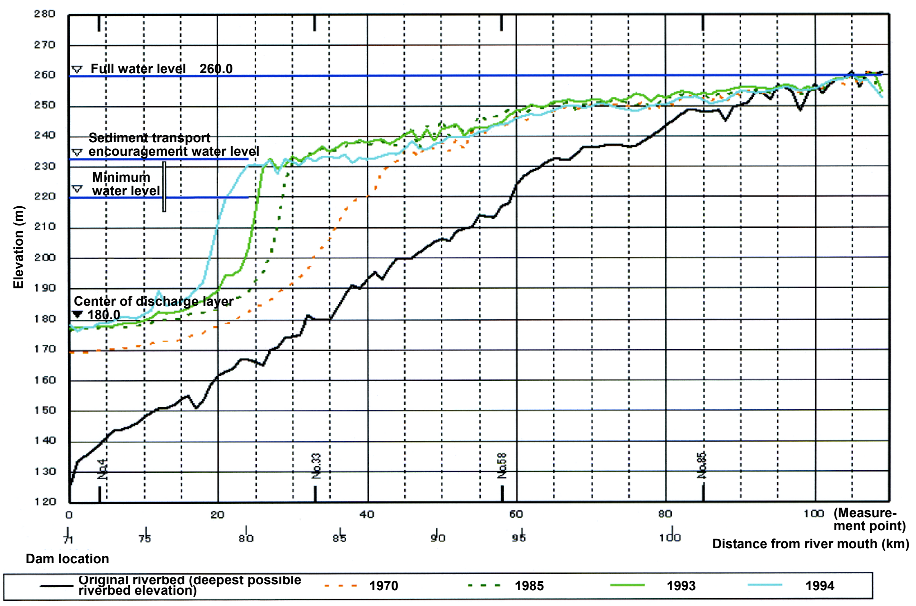


Figure 2. State of Sedimentation of Sakuma Dam

Akiba Dam to flow downstream had to be studied. (see Fig. 3)

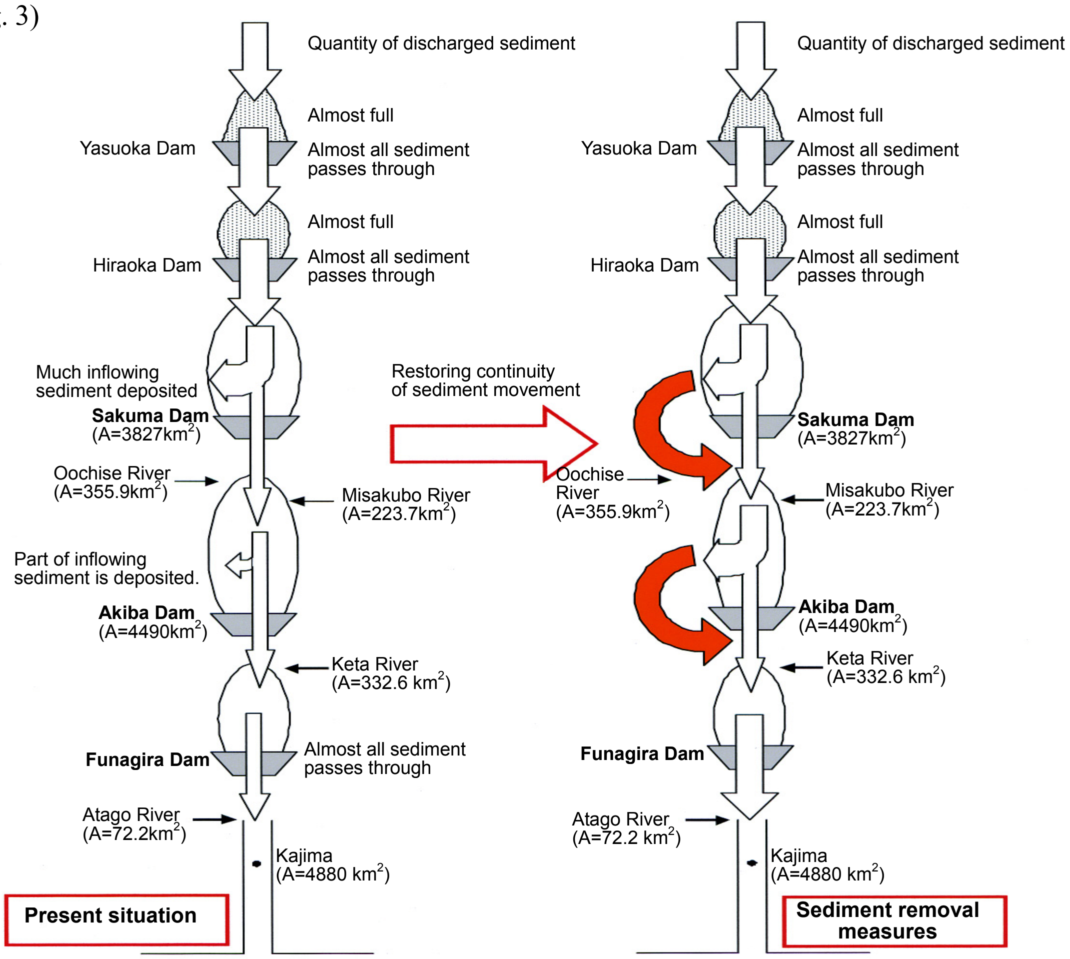


Figure 3. Image of Ensuring Continuity of Sediment Movement

4. Study by the study committee

The Chubu Regional Bureau. Hamamatsu Office of River and National Highway, Ministry of Land, Infrastructure, Transport and Tourism which manages the Tenryu River has formed a committee of scholars to study measures to ensure continuity of sediment movement on the Tenryu River. The study committee consists of 12 members including researchers, experts, and administrators involved in river hydraulics, river sediment movement analysis, coastal engineering, dam engineering, and dredging technologies.

(1) Basic concepts

The committee has enacted basic concepts to apply to study sediment removal methods needed at the Sakuma Dam and Akiba Dam. The basic concepts are:

① To halt continued sedimentation, sediment which has flowed into dam reservoirs will be caused to flow downstream.

Sakuma Dam: Of the sediment that flows into the Sakuma Dam, as much as possible will be passed through using the natural transportation capacity of flowing water during flood discharge periods to minimize the quantity deposited in the reservoir.

Akiba Dam: At the Akiba Dam constructed downstream from the Sakuma Dam, of the inflowing sediment containing sediment that has passed through the Sakuma Dam, as much as possible will be passed through using the natural transportation capacity of flowing water during flood discharge periods to minimize the quantity deposited in the reservoir.

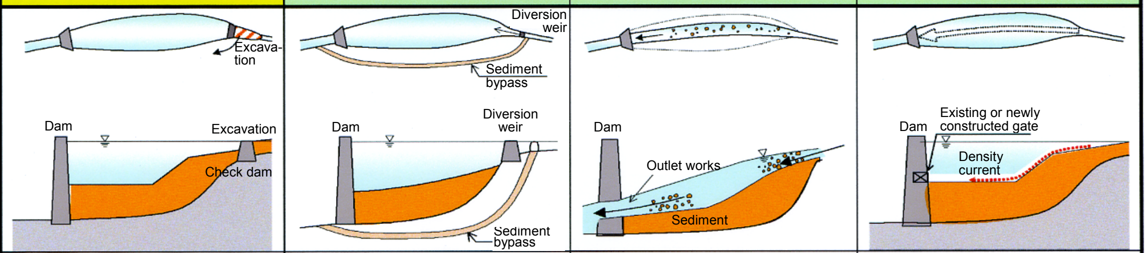
② Studies to clarify the most appropriate methods including combinations of multiple methods will be studied.

③ Total costs of methods which include maintenance costs (running costs) in addition to construction costs (initial costs) and the effectiveness of the methods in preventing shoreline regression along the seacoast (focusing on quantity and quality of the sediment supplied) will be considered.

(2) Selection of sediment removal methods

Dam reservoir sedimentation countermeasures are usually categorized into about 8 types as shown in Figure 4. These sedimentation counte-rmeasures each feature unique characteristics, so measures used were selected based on a study to confirm whether or not each is applicable to the Sakuma Dam and to the Akiba Dam.

Sedimentation counter-measures	(I) Reducing sediment inflowing to reservoir	(II) Passing through inflowing sediment		
		Bypassing the reservoir	Passing through the reservoir	
	① Check dam (excavation)	② Sediment bypass	③ Sluicing	④ Density current sediment removal
Sketch	(see sketches below)			
Outline	Constructing a check dam at the end of the reservoir restricts the inflow of sediment to the effective capacity. To ensure its permanent use, sediment deposited above the check dam is excavated and removed.	Constructing a diversion weir at the upstream end of the reservoir, thereby diverting part of the flood discharge into a bypass tunnel that bypasses the reservoir, passes inflowing sediment past the reservoir.	Lowering the water level during a flood discharge period allows inflowing sediment to continue to flow into the downstream river without being deposited in the reservoir.	Using an outlet that can discharge highly turbid density current during a flood discharge period (newly constructed as necessary) discharges the washload constituent etc. from the dam.



(III) Removal of sediment from inside a reservoir			Sediment movement inside a reservoir
⑤ Excavation or dredging	⑥ Suction method	⑦ Flushing	⑧ Sediment transport by flowing water
Sediment deposited inside a reservoir is excavated or dredged then removed from the reservoir	The water level difference between the reservoir level and the outlet opening level and the mechanical power of a pump etc. suck in deposited sediment which is then discharged downstream from the dam through a tunnel.	During the flood period, the water level is lowered, emptying the reservoir, then the transport capacity of the river course during the flood period removes the deposited sediment.	The reservoir water level is lowered to use the transport capacity of the flowing water during flood discharge to move the sediment which has been deposited upstream to the downstream river (within the sedimentation capacity).

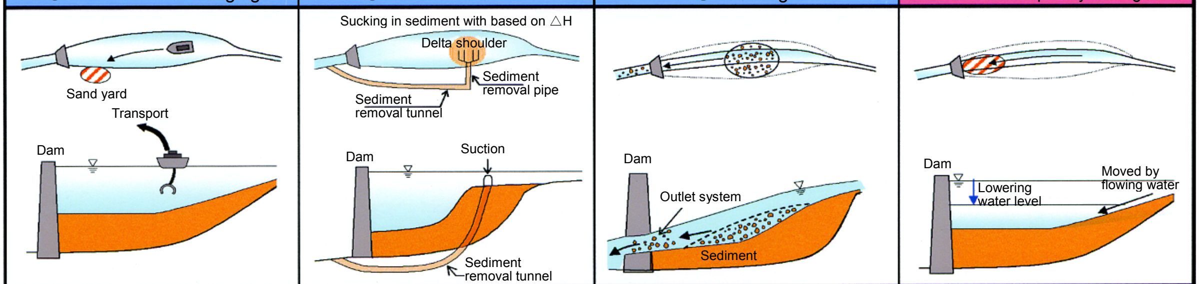


Figure 4. Types of Sedimentation Countermeasures

The applicability of these sedimentation countermeasures to the Sakuma Dam and Akiba Dam were studied. Initially it was assumed that applicability of a check dam to both the Sakuma Dam and Akiba Dam was low, because it would have a great impact on the aggradation and back water of the reservoir, and there is a danger of submersion of the land upstream from the reservoir. To build a sediment bypass at the Sakuma Dam, a detailed study was necessary concerning items related to water quantity because the total length of the tunnel is 17km and its gradient is 1/130, but it was judged to be applicable. However, at the Akiba Dam, with total length of 16km and gradient of only 1/570, sediment could be deposited inside the tunnel, so its applicability was judged to be low. The applicability of sluicing at the Sakuma Dam is low, because the reservoir of this dam is used as the lower reservoir of a pumped storage electric power generation system, but at the Akiba Dam, the reservoir rotation rate is relatively high, so sluicing was considered to be applicable. Density current flushing can be applied at the Sakuma Dam, although it is a stratified reservoir and the sediment which can be removed is limited by grain diameter. And at the Akiba Dam, its applicability is low because it is a stratified reservoir. Dredging and excavation have been used and are still applicable at the Sakuma Dam and Akiba Dam. The suction method and its technologies are under development, but can be applied to both dams. Flushing is, like sluicing, difficult to apply at the Sakuma Dam because of restrictions on reservoir operation, but it can be applied at the Akiba Dam. Transporting sediment by flowing water has been done at the Sakuma Dam and can be applied; it can even be imple- mented at the Akiba Dam. Table 2 summarizes the applicability of various removal methods to the object sediment and to the two dams.

The following are sediment removal methods applicable to the Sakuma Dam and Akiba Dam.

Sakuma Dam: sediment bypasses, suction method, density current flushing, excavation or dredging

Akiba Dam: suction method, sluicing, flushing, excavation or dredging

(3) Combinations of sediment removal methods at the Sakuma Dam and Akiba Dam

The study not only considered the sediment removal methods defined above as independent methods, but also studied combinations of these methods. The following are the concepts followed in this case.

① An approach combining a sediment bypass with the suction method is studied as a proposed combined method for the Sakuma Dam. (A sediment bypass and the suction method both require a tunnel to discharge the sediment downstream, and sediment removed by the suction method can be discharged downstream through the sediment bypass. And by combining the sediment bypass which has been applied at other dams, but can remove only a limited quantity, with the suction method that removes a large quantity but has been used only rarely, it is possible to boost their reliability as construction methods.)

② A proposal for a sediment bypass which can pass sediment consecutively through the Sakuma Dam and Akiba Dam is also studied.

③ Priority is put on a method that removes sediment using the power of flowing water. (Dredging and excavation which use mechanical power are secondary methods.)

As a result, the six proposed combinations from proposal A to proposal F were selected as sediment removal methods for the Sakuma Dam and Akiba Dam as shown in Table 3. Figure 5 presents outline drawings of each proposal.

Table 2. Applicability of Sedimentation Countermeasures

Sedimentation counter-measures	(I) Reducing sediment inflowing to reservoir	(II) Passing through inflowing sediment			(III) Removal of sediment from inside a reservoir			Sediment movement inside a reservoir
		Bypassing the reservoir	Passing through the reservoir					
	① Check dam (excavation)	② Sediment bypass	③ Sluicing	④ Density current sediment removal	⑤ Excavation or dredging	⑥ Suction method	⑦ Flushing	⑧ Sediment transport by flowing water
Applicability to Sakuma Dam	×	○	×	○	○	○	×	○
Applicability to Akiba Dam	×	×	○	×	○	○	○	○

○ : Applicable × : Inapplicable

Table 3. Proposed Combinations of Removal Method

Construction method		Proposal A	Proposal B	Proposal C	Proposal D	Proposal E	Proposal F
Sakuma Dam	Sediment bypass	●	●			● Continuous at 2 dams	
	Suction method	●	●	●	●	●	● Continuous at 2 dams
	Density current sediment removal	●	●	●	●	●	●
Akiba Dam	Sluicing and flushing	●		●			
	Suction method		●		●		

●: Method adopted

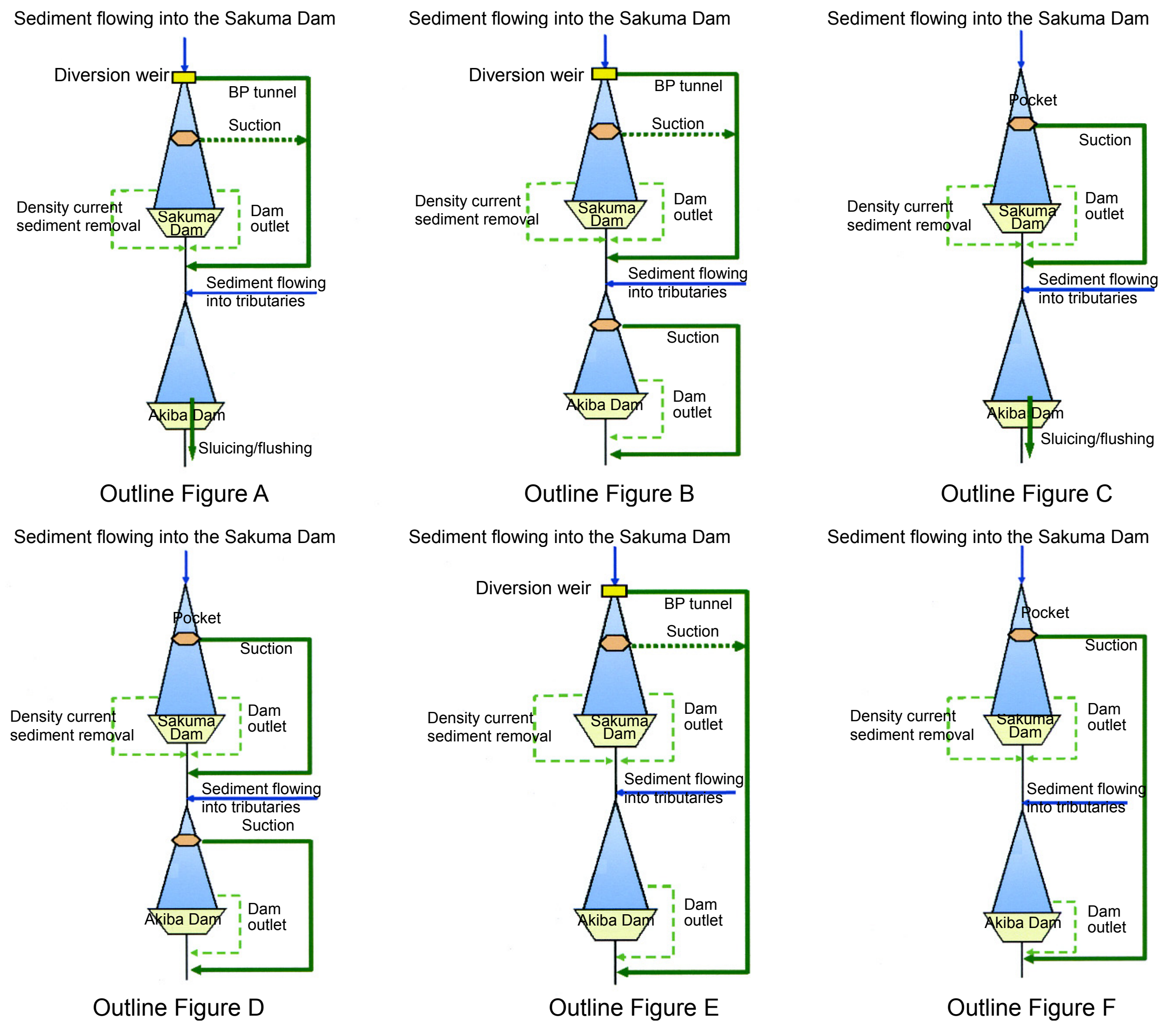


Figure 5. Outline Figures of Proposed Combinations of Sediment Removal Methods

(4) Method of evaluating proposed combined methods

Proposed combined methods were evaluated by setting four evaluation perspectives and establishing evaluation methods and evaluation indices for evaluation items under each perspective. And scores were given for each evaluation item according to a priority sequence, then the overall evaluation done based on the total score.

The following are the four perspectives of the evaluation.

Perspective ①: Project effectiveness and economic potential

Perspective ②: Reliability of the method

Perspective ③: Sustainability of social capital

Perspective ④: Ability to deal with impacts on the social environment and river environment

The following are evaluation methods and evaluation indices for each perspective. The evaluations were done by a study premised on facility service life of 100 years, considering its use for a long period in the future. The period, 100 years, is the same as the period which is hypothesized based on the sedimentation capacity ensured by plans for many dams in Japan.

(Perspective ①: Project effectiveness and economic potential)

1. Economic potential: cost required over 100 years (total of initial and running costs)
2. Efficiency: project investment efficiency (cost per $1m^3$ increase of sediment that flows downstream to the Akiba Dam)
3. Increase of sediment flowing downstream: effectiveness in restoring the sediment transport system (quantity of increase of sediment flowing downstream from the Akiba

Dam (per year))

4. Work period: work period required for execution (number of years until effects of the project are manifested)

(Perspective ②: Reliability of the method)

1. Certainty: certainty of the method (evaluated separately for the Sakuma Dam and Akiba Dam, and the lower evaluation is selected.)
2. Frequency the work method can be proven: number of times the PDCA cycle can be performed at stage where the sediment removal method is executed

(Perspective ③: Sustainability of social capital)

1. Ease of maintenance: ease of execution during facility reconstruction and backup system during execution of work methods at the Sakuma Dam
2. Running costs: sustainability of labor force needed to operate the facility
3. Responsiveness to crisis management: ability of construction methods at the Sakuma Dam to respond to cases where sedimentation exceeding the planned scale has occurred and to cases where a serious problem with the functioning of the sediment countermeasure facility has occurred

(Perspective ④: ability to deal with impacts on the social environment and river environment)

1. Ease of control: ease of handling sediment removed from Akiba Dam and placed downstream as a way to deal with uncertainty concerning the impact of the construction methods at the Sakuma Dam on the downstream river environment
2. Flexibility under changes to plans: flexibility under the uncertainty of quantity of sediment flowing into the main river course and into tributaries
3. Impacts on present operation: impact on electric power production and the Mikatagahara Irrigation System of the work methods at the Akiba Dam
4. Range of removable sediment grain diameters: prioritizing a method which can remove sediment with a wide range of grain diameters
5. Adaptability to sediment management as a river basin: ability to deal with quantity of sediment flowing into tributaries

Perspective ①: regarding the increase of sediment under evaluation indices which are within the perspective of project effectiveness and economic potential: a model including reservoir, dam, and river course is created and used to perform riverbed fluctuation analysis to calculate and evaluate the quantity of sediment caused to flow downstream by each sediment removal method.

Perspective ②: regarding the evaluation item, “certainty”, which is within the perspective of reliability of the work method; sediment bypass, sluicing, and flushing have been used often in Japan and were given high evaluations, while the suction method was given a low evaluation as a method requiring proving, because it has not been used very much. The evaluation item, “frequency the work method can be proven”, means performing a trial operation of the sediment removal method in order to implement the sediment removal method, and the number of times the results could be fed back to the facility provision was evaluated.

Perspective ③: Regarding the evaluation item, “ease of maintenance”, which is within the perspective of sustainability of social capital; regarding the suction method, with priority on sediment removal methods at the Sakuma Dam, because the suction pipes can be improved or replaced relatively easily, proposed combinations of the sediment removal methods at the Sakuma Dam with the suction method, which is the control point for sediment flowing downstream, were given high evaluations, but other combinations were given low evaluations.

Perspective ④: Regarding the evaluation item, “impact on present operation”, that is within the “Possibility of responding to impacts on social environment and river environment”; it was judged that in a case where, at the Akiba Dam, water is taken in to generate electric power and to be used for agriculture etc., and the reservoir water level is lowered to perform sluicing and flushing, the impact is “great”; and because the suction method can remove sediment without changing the reservoir water level, but the water level must be lowered to draw it into the suction pocket, its impact was judged to be “small” and in the case of a sediment bypass, the impact was judged to be “none”.

The evaluation items, evaluation indices, the priority of each item and the scoring table are shown in Table 4. Table 5 shows the results of evaluation based on such concepts. The results of the evaluation earned high marks for two proposals: A and E.

Table 4. Evaluation Items, Evaluation Methods, Priority and Scores for Each Item

Evaluation perspective	Evaluation items		Priority	Evaluation indices	Scores
① Project effectiveness and economic potential	1. Economic potential (100 year cost)		A	◎	9
				○	6
				△	3
	2. Efficiency (sediment removal cost)		B	◎	6
				○	4
				△	2
	3. Increase of sediment flowing downstream (flowing down to the Akiba Dam)		A	◎	9
				○	6
				△	3
	4. Work period (period of the execution)		B	◎	6
				○	4
				△	2
② Reliability of the method	1. Certainty (lower adopted)		B	◎	6
				◎	6
				○	4
				△	2
	2. Frequency method can be proven		C	◎	3
				○	2
				△	1
③ Sustainability of social capital	1. Ease of maintenance		C	◎	3
				◎	3
				△	1
	2. Running cost		B	◎	6
				○	4
				△	2
	3. Responsiveness to crisis management		C	◎	3
				○	2
				△	1
					-
④ Ability to deal with impacts on the social environment and river environment	1. Ease of control	Sand	C	◎	3
				○	2
				△	1
		Wash load		△	1
	2. Flexibility under changes to plans	Main river: Sakuma	C	◎	3
				○	2
				△	1
		Tributary: Akibaa		◎	3
				○	2
				△	1
	3. Impact on present operation (for Akiba Dam)		C	◎	3
				○	2
				△	1
	4. Range of removable sediment grain diameter		C	◎	3
				○	2
				△	1
	5. Applicability to management of sediment as a river basin (for Akiba Dam)		C	◎	3
				○	2
				△	1

*1 The evaluation indices evaluate the evaluated items by allotting points shown as: ◎ highest evaluation, △ lowest evaluation, and ○ median evaluation. However, the following priority was assigned to the evaluation items, and the higher the priority, the higher the points allotted. The relationship between the prioritization, evaluation indices, and points allotted is shown in the following point allocation table.

*2. If any serious functional problems occur under the dam linkage proposal, it may become impossible to remove sediment, so it is "One rank lower".
In other words, under proposal E, ◎ will be changed to ○, and under proposal F, ○ will be changed to △.

Evaluation item priority
A: Can permanently ensure flood control capacity which is an aim of the restructuring project (removal of large quantity of sediment by flowing water).
B: Can economically and quickly manifest effectiveness of executing the project.
C: Can ensure certainty of operation and management, reducing their burden. Can respond to future changing needs of society.

Scoring Table

	A	B	C
◎	9	6	3
○	6	4	2
△	3	2	1

Table 5. Evaluation Results

Construction method		Proposal A	Proposal B	Proposal C	Proposal D	Proposal E	Proposal F
Sakuma Dam	Sediment bypass	●	●			● Continuous at 2 dams	
	Suction method	●	●	●	●	●	● Continuous at 2 dams
	Density current sediment removal	●	●	●	●	●	●
Akiba Dam	Sluicing and flushing	●		●			
	Suction method		●		●		
	Perspective ① Total score	30	19	24	16	30	27
	Perspective ② Total score	7	5	5	5	7	4
	Perspective ③ Total score	12	8	9	7	11	10
	Perspective ④ Total score	15	18	11	14	15	11
	Total score	64	50	49	42	63	52

For details of the evaluation results, see reference document P. 58.

(5) Selection of sediment removal methods

A more detailed comparative study was made of proposal A and proposal E which received high evaluation scores as a result of the selection.
As a result, it was judged that proposal A was superior for the following reasons.

- Initial cost is lower than that of proposal E.
- The sediment bypass tunnel is shorter than that in proposal E.
- It responds very flexibly to the quantity of sediment flowing into the tributaries.
- The effects of a project can be counted on to be manifest quickly by a staged execution.

Contents of Proposal A:

Sakuma Dam: sediment bypass, suction method, density current sediment removal
Akiba Dam: sluicing and flushing

5. Effectiveness of sediment removal methods

The sediment removal countermeasure proposal studied in 4 was proven by performing one-dimensional riverbed fluctuation analysis of its effectiveness. One-dimension riverbed fluctuation analysis, which was performed using a model linking the reservoirs of the two dams, Sakuma Dam and Akiba Dam, analyzed the inflowing sediment by dividing it into 14 categories including silt, clay, sand, gravel, etc. The calculation period was set at 100 years, and the flow rate for this 100 year period was prepared by linking three 26-year flow regime data cycles observed from 1979 to 2004 plus data for a 22 year period within the 26 year cycle. The initial riverbed inside the dam reservoir was a riverbed surveyed in 2005, and the water level in the reservoir was set considering the control water level during the flood discharge period and the non-flood discharge period at the Sakuma Dam. The quantity of inflowing sediment was obtained by setting the LQ formula based on the grading of the sediment deposited in the reservoir and on observation results during flood discharge period at the two dams. The analysis results are shown in Figure 6. Figure 6 shows the results of the riverbed fluctuation calculation for a 100 year period as an annual average and by grain diameter.

While the quantity of sediment flowing in from upstream of the Sakuma Dam is 2,430,000m^3 (including 800,000m^3 of sand), at this time, the quantity of sediment flowing downstream from the Sakuma Dam is 600,000m^3

(including 0m^3 of sand) and the quantity of sediment discharged from the river mouth is 970,000m^3 (including 220,000m^3 of sand), but after execution of the countermeasure works, the quantity of sediment discharged from the river mouth will be 1,730,000m^3 (including 80,000m^3 of sand).

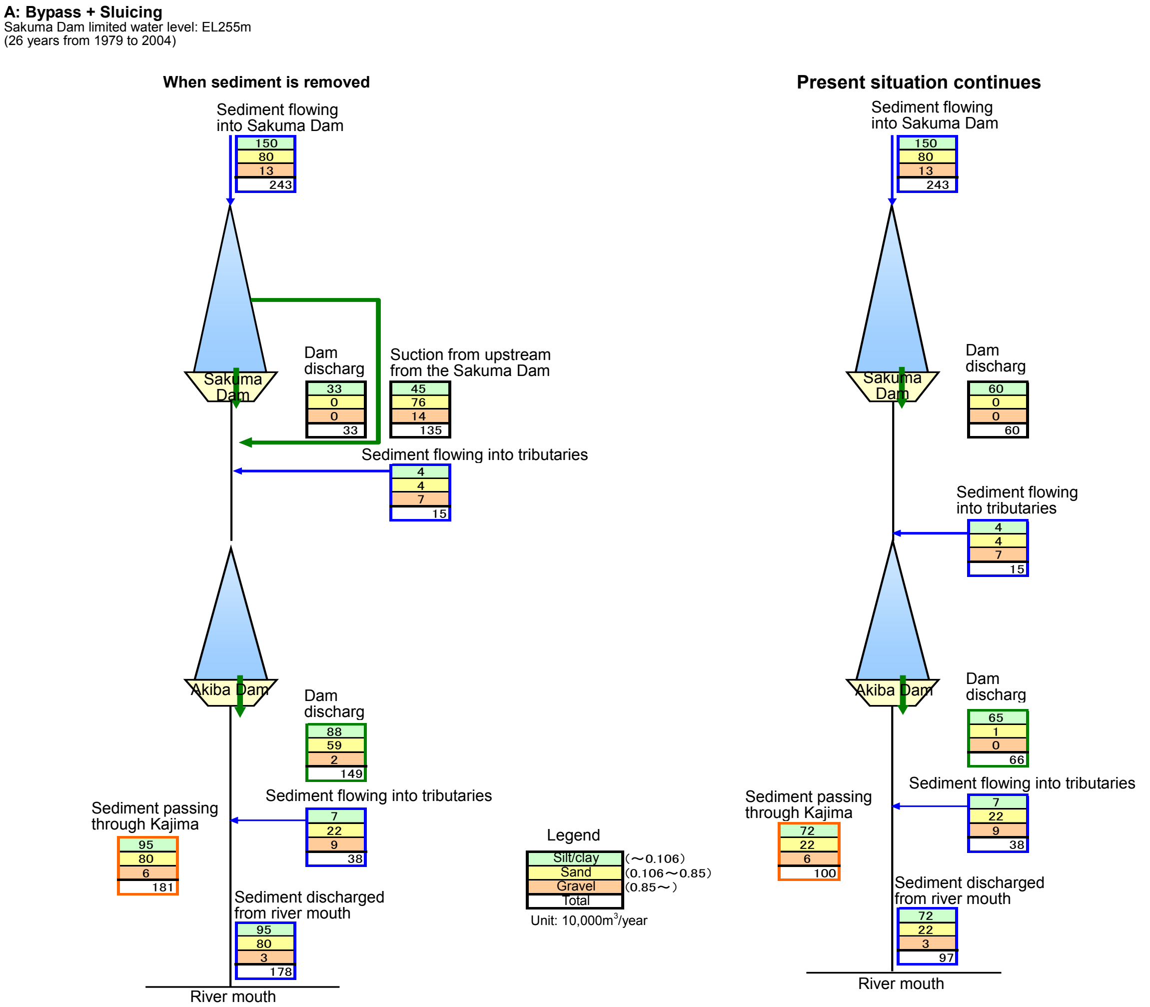


Figure 6. Results of Riverbed Fluctuation Analysis

It is assumed that approximately 400,000m^3 of sand will be necessary to maintain the seacoast near the mouth of the Tenryu River. At this time, only 32% of the sediment flowing in from upstream from the Sakuma Dam and from tributaries downstream from the Sakuma Dam, and only 21% of its sand flows downstream, but when the sediment removal countermeasures have been completed, 69% of the sediment flowing into the Sakuma Dam or up to 75% of its sand will be able to flow downstream, indicating that it will be possible, to a considerable degree, to restore the sediment movement linking the upstream end and the mouth of the Tenryu River.

6. Results of the study by the committee

The results of the study by the committee has shown that appropriate sediment removal countermeasures which will permit smooth sediment movement from the upstream to the downstream end of the Tenryu River are, at the Sakuma Dam, a sediment bypass, suction method, and density current discharge, while at the Akiba Dam, combined sluicing and flushing. This proposed set of countermeasures can cause a large quantity of sediment now held back by the Sakuma Dam to continue to flow downstream. But the results are the results of a study premised on as much as possible of the sediment flowing down from the upstream Tenryu River being caused to flow downstream, and if the countermeasures are restricted by initial cost and running cost, the results might be different. This proposed set of sediment removal measures was narrowed as a dominant proposal which is the foundation for future studies to actually implement the project, and the decision to undertake the project was not decided by this proposal, so it will be necessary to carry out a more detailed study from the cost perspective and from the facility maintenance perspective.

Sources:

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