Measures against Sedimentation in the Makio Dam Reservoir

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1. Introduction

The Makio Dam is located at the foot of Mt. Ontake (3,067 m above sea level) in Nagano Prefecture. It is a rockfill dam constructed as a water resources facility of the Aichi Canal Project during the period from 1957 through 1961 by the Aichi Water Public Corporation. (The corporation merged in October 1968 with the Water Resources Development Public Corporation that became an independent administrative institution called the Japan Water Agency in October 2003).

In addition to the Makio Dam, the Aichi Canal Project consists of an approximately 112 km long main canal and a total of about 1,063 km long branch channels. This Water Project was implemented as a first comprehensive large-scale water resources development project in Japan to develop water resources and supply water for irrigation, drinking and industrial use purposes in Gifu and Aichi prefectures and, in addition, generate hydroelectric power by the Makio Dam. Since the opening of the system in 1961, it has greatly contributed to the development of the areas.

However, due to the eruption of Mt. Ontake in 1979 and the landslide on the slope of the mountain caused by the Nagano Seibu Earthquake in 1984 (close to the Makio Dam having a magnitude of 6.8 and the epicenter approximately 2 km deep), an extremely large amount of debris flew into the Makio Dam Reservoir thereby hindering the reservoir functions.

To solve the above-mentioned problems, when debris inflow into the reservoir caused by the earthquake settled down the Ministry of Agriculture, Fishery and Forestry (MAFF) conducted a survey during the period from 1991 through 1994 in order to restore reservoir functions and, as a result, set up a plan for measures against reservoir sedimentation problems. Based on this plan, the Japan Water Agency has been implementing the sedimentation countermeasure project since 1995 with the schedule to complete the project in Fiscal Year 2006.

The Forestry Agency and Nagano Prefectural Government constructed debris and sediment control facilities on streams coming out from the failed slope of Mt. Ontake by the previous earthquake to control the debris flow into the reservoir and planted trees on the devastated slopes. In addition, the volunteer groups in Ootaki Village where the dam is locating, and the people from beneficiaries of the Aichi Canal Project planted trees. As a result, the catchment area of the dam has been restored to the previous condition and the amount of sediment flowing into the reservoir has been reduced to almost the same level as it was before the earthquake.

This paper reports the outline of the sedimentation countermeasure project being implemented at the Makio Dam Reservoir (that once lost its storage function because of accumulated sediment) by the Japan Water Agency in order to restore its water storage function.

Photo 1 Panoramic View of the Makio Dam

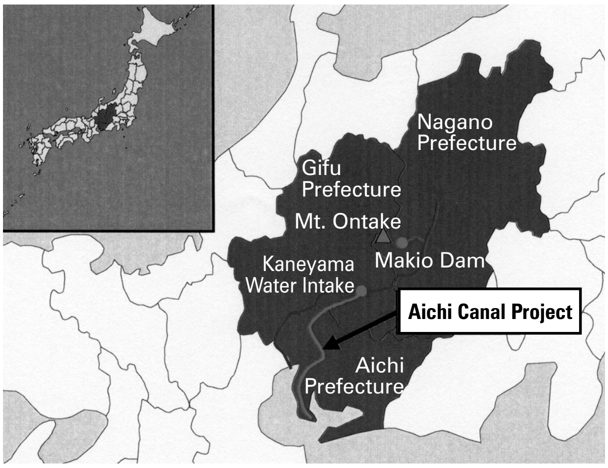

Fig. 1 Aichi Canal Project's Facility Arrangement and Outline

Table 1 Amount of Developed Water by Makio Dam for Each Use Purpose

Use Purpose	Amount of Water Developed	Remarks
Agricultural Use	21.514 m^3/s	Farm land: Approx. 15,000ha
Drinking	2.594 m^3/s	
Industrial Use	6.41 m^3/s	
Hydroelectric	35,500 kw	Kansai Electric Corporation

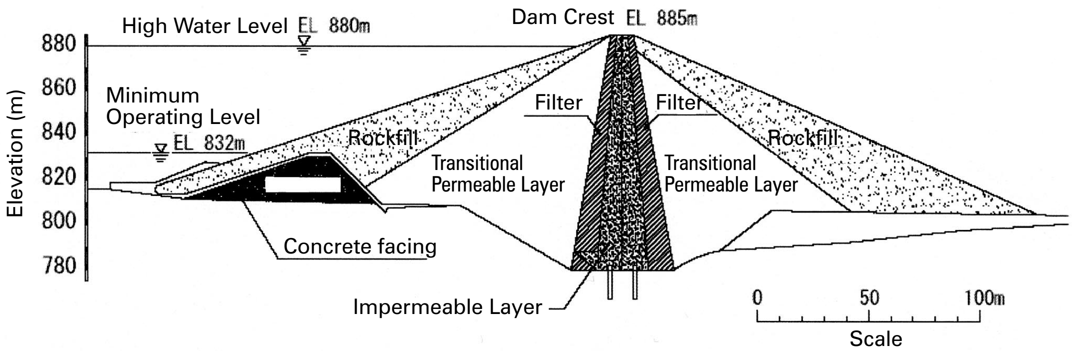

Fig. 2 Standard Cross Section of the Makio Dam

Table 2 Features of Makio Dam

List of the Features of Makio Dam			
Name of River:	Ootaki River of Kiso River system.	Effective Capacity:	68,000,000 m^3
Location:	Ootaki and Mitake villages, Kiso county, Nagano Prefecture.	Design Sediment Cap:	7,000.000 m^3
		Dam Type:	Central impervious core type rockfill
Catchment Area:	Approx. 304 km^2	Crest Elevation:	El. 885.0 m
Reservoir Area:	Approx. 2.47 km^2	Crest Height:	105 m
Normal Water Level:	El. 880.0 m	Crest Length:	264 m
Minimum Operating Level:	El. 832.0 m	Embankment Volume	3,615,000 m^3
Reservoir Capacity:	75,000,000 m^3	Spillway Capacity:	Max. 3,100 m^3/s

2. Outline of the Makio Dam

The Makio Dam is constructed on the Ootaki River, a tributary of the Kiso River, at a location approximately 120 km upstream of the Kaneyama Water Intake of the Aichi Water Project built on the left bank of the Kiso River in Yaozu-cho, Gifu Prefecture. It is a central impervious core type rockfill dam constructed by introducing American technologies. The dam's specific technological features are the use of the core material for the first time in Japan that contained an average of 60% of grain size larger than 4.4 mm in diameter and a very thin core width (ratio of the maximum core width to the embankment height is 1/4) comparing with other dams in Japan. In addition, another feature was the use of large sized construction equipment for embankment construction that was quite unusual at that time in Japan and the embankment construction speed that completed the dam in a one and a half year period.

The amount of water developed by the Makio Dam by each category is shown in Table 1. The embankment's standard cross section and the dam's features are shown in Fig. 2 and Table 2 respectively.

3. Amount of Sediment Inflow caused by the Nagano Seibu Earthquake

1) Nagano Seibu Earthquake

The Nagano Seibu Earthquake occurred in September 1984 that had a magnitude of 6.8 and its epicenter was in the southern slope of Mt. Ontake. The earthquake caused the failure of the slope of Mt. Ontake and a large amount of soil flew into the Denjyo River and the Suzugasawa Stream, the tributaries of the Ootaki River, and caused the debris flow into the Ootaki River. The earthquake caused 29 deaths and inflicted a tremendous amount of damage to public facilities, forests and housing. The largest slope failure occurred on the slope of Mt. Ontake at its eighth stage. It was called the Ontake Failure over a wide area of the length of 600 m and a maximum width of 480m. The amount of failed soil reached approximately 36,000,000 m^3 of the volume. Over 21,000,000 m^3 of soil flew into the 4.3 km section of the Ootaki River.

2) Amount of Sediment Flew into the Makio Dam Reservoir

A large amount of debris produced by the land failure on the slope of Mt. Ontake flew into the Ootaki River. The debris was entrapped by the narrow gorge

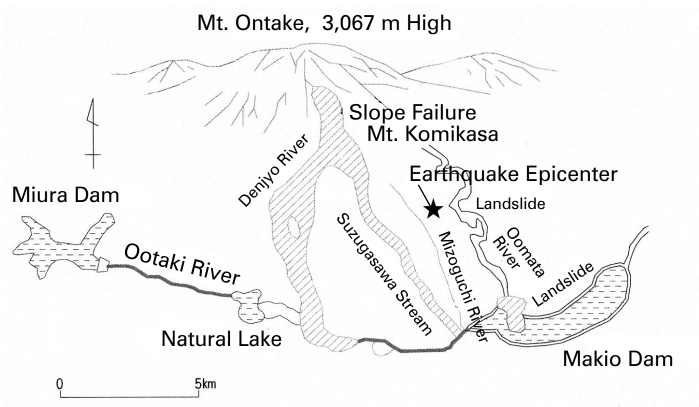

Fig. 3 Distribution of Debris Flow

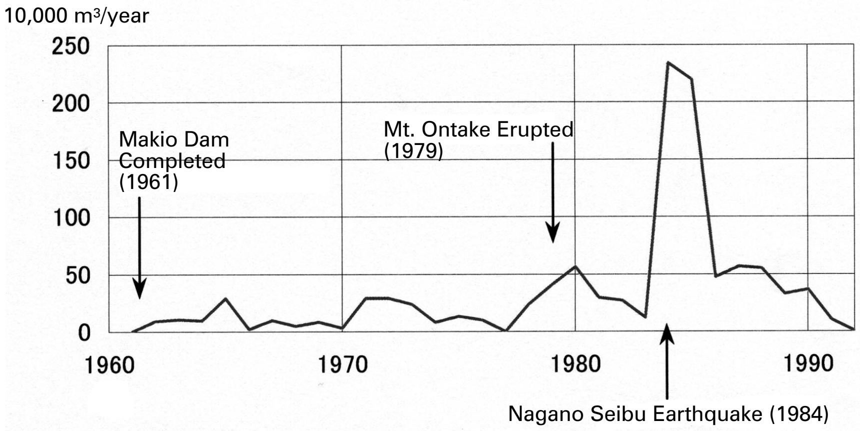

Fig. 4 Change in the Annual Inflow Amount of Sediment in the Makio DamReservoir

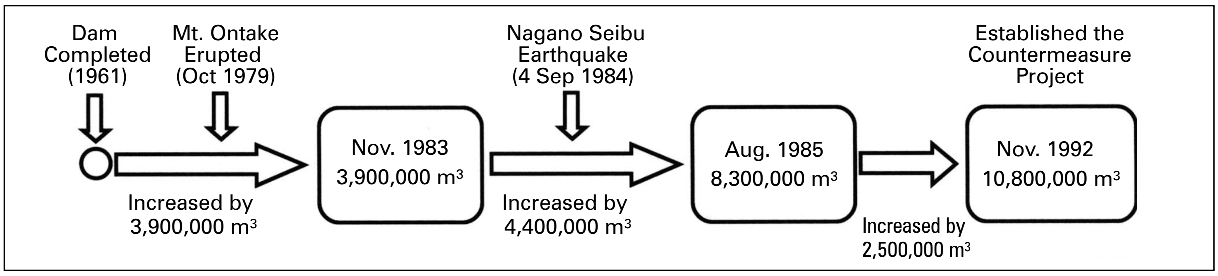

Fig. 5 Change in the Amount of Sediment Accumulated in the Makio Dam Reservoir

Photo 2 Condition of Deposited Sediment in the Makio Dam Reservoir (Upstream part of the reservoir bottom upgraded to the maximum of 15m by sediment deposit)

Photo 3 Slope Failure on Mt. Ontake

Photo 4 Sediment Deposited in Reservoir

of the Ootaki River and most of it settled in the river upstream of the narrow gorge. Thus, although some amount of debris flew into the Makio Dam Reservoir, the reservoir function was not hindered immediately after the earthquake. However, later on the debris accumulated at the narrow gorge flew into the reservoir during each storm. The amount of debris that flew into the reservoir reached 2,000,000 m^3 by the year after the earthquake and debris inflow still continued there after. The amount of sediment that flew into the reservoir reached 10,800,000 m^3 in 1992 that exceeded the design sediment storage capacity of the reservoir by 7,000,000 m^3 and hindered the storage function of the reservoir.

The distribution of debris flow caused by the Nagano Seibu Earthquake and the change in the annual inflow of sediment in the Makio Dam Reservoir are shown in Figs. 3 and 4 respectively. The change in the amount of sediment accumulated in the reservoir is shown in Fig. 5.

4. Sedimentation Countermeasure Project Plan

The Water Resources Development Public Corporation (presently an independent administrative institute, Japan Water Agency) held a series of meetings concerned to the concrete plan for the restoration of the functions of the Makio Dam with various agencies related to the Makio Dam including the Ministry of Agriculture, Fishery and Forestry (MAFF) immediately after the Nagano Seibu Earthquake. As a result, when the amount of sediment inflow was stabilized in Fiscal Year 1991, MAFF conducted the planning and study of sedimentation countermeasures, prepared the design of the measures and, as result, established the sedimentation countermeasure project in Fiscal Year 1994.

1) Distribution and Characteristics of Sediment in the Reservoir

The distribution of the amount of 10,800,000 m^3 sediment deposited in the reservoir by elevation was as listed in Table 3. 3,820,000 m^3 of the sediment, i.e. 35% of the total deposit amount, occupied the dead storage of the reservoir below the elevation of EL. 832.0 m. 6,980,000 m^3 of the sediment, that is, 65% of the total amount, occupied the effective capacity of the reservoir at an elevation between EL. 832.0 m and El. 880.0 m.

Table 3 Distribution of Sediment Deposit in the Makio Dam Reservoir by Elevation (Unit in 1,000 m^3)

Elevation	<832 m	832 ~860 m	860 ~870 m	870 ~880 m	Total
Amount of Sediment	3,820	5,710	830	440	10,800

The geological profile of sediment deposit in the reservoir was as shown in Fig. 6. At an elevation higher than the zone between El. 850 m to El. 860 m (upstream reach of the river), sediment material was mainly gravel and sand. At a lower elevation (downstream reach of the river), sediment material was mainly clayey soil.

2) Amount of Sediment Concerned to the Sedimentation Countermeasure Project

It was necessary to estimate the amount of sediment to be handle by the sedimentation countermeasure project to take into consideration the already deposited sediment in the reservoir that was hindering the reservoir's storage function and also the amount of sediment that would flow into the reservoir in the future in order to maintain the service water capacity of the reservoir in the future.

The amount of sediment deposited in the reservoir

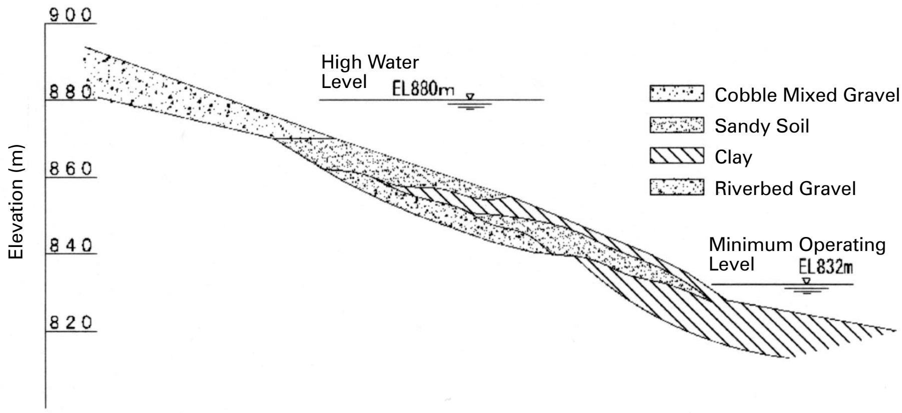

Fig. 6 Geological Profile of Sediment Deposit in the Makino Dam Reservoir

as of 1992 exceeded the reservoir's design sediment storage capacity by 3,800,000 m^3 (10,800,000 – 7,000,000). By assuming that the amount of sediment that accumulates in the reservoir in the future would be equivalent to the amount that accumulates during the remaining service life of the Makio Dam, i.e. 69 years (based on the entire service life of 100 years from 1961 to 2061), this amount was estimated as 4,830,000 m^3 based on the annual sediment accumulation rate of 70,000 m^3 (70,000 m^3/year x 69years).

Due to the above reasons, the amount of sediment to be handled by the sedimentation countermeasure project was decided upon as 8,630,000 m^3 that was the total of already deposited sediment amount and the amount that accumulates in the future.

3) Selection of the Method of the Countermeasure

The following five methods were investigated:

Plan 1: To increase the sediment storage capacity of the reservoir to store the concerned amount of sediment for the project (8,630,000 m^3) by raising the dam height.

Plan 2: To secure the sufficient sediment storage capacity to store the concerned amount of sediment for the project (8,630,000 m^3) by constructing a new dam.

Plan 3: To install a scour pipe to discharge deposited sediment out of the reservoir into the downstream reach.

Plan 4: To remove the entire amount of the concerned sediment for the project (8,630,000 m^3) from the reservoir.

Plan 5: To remove the amount of sediment necessary to secure the effective storage (5,480,000 m^3) and construct a sediment storage dam.

The above five methods were examined by comparing with each other and, as a result, Plan 5 was selected as a favorable method from the viewpoint of its reality to implement, environmental concern, and economy for the following reasons:

① Sediment material deposited at a higher elevation in the reservoir consists mainly of gravel and sand. It is possible to excavate and remove it when it dries.

② The Makio Dam Reservoir is mainly operated for hydroelectric power generation during a period from December 1 through March 31 and the reservoir operation is scheduled to make the reservoir empty on March 31. Thus, the high elevation area in the reservoir becomes dry during this period.

③ By excavating the sediment deposited in the reservoir by dry work and temporarily placing the excavated sediment into the sediment storage dam as much as possible during this period of the year, most of the concerned amount of sediment for the project can be removed under dry work conditions.

By constructing a new sediment storage dam, the effective storage of the reservoir may be secured even after the original service life of the dam.

4) Outline of the Sedimentation Countermeasure Project

Based on the above-mentioned policies, the countermeasure project was established to remove sediment already deposited in the reservoir and the sediment that inflows in the future by constructing a sediment storage dam in the upstream part of the reservoir in order to restore and maintain the storage function of the reservoir and thereby prevent a natural disaster. The established project is outlined as follows:

Major Work

(1) Sediment Removal: 5,480,000 m^3 (the reservoir's effective storage can be secured when the sediment material removal work is completed)

Amount of sediment that exceeds the design sediment storage capacity:

10,800,000 m^3 – 7,000,000 m^3 = 3,800,000 m^3

Expected amount of sediment that flows into the reservoir prior to project completion date:

70,000 m^3/year x 14 years = 980,000 m^3

Capacity of the sediment storage dam: 700,000 m^3

Total: 5,480,000 m^3

Note: As the sediment storage dam is to be constructed within the reservoir in order to remove the amount of sediment in the reservoir equivalent to the sediment storage capacity of the storage dam and to secure the effective capacity of the reservoir, the capacity of the storage dam was decided upon to be sufficient to store the sediment that will flow into the reservoir for a 10 year period.

(2) Construction of One Sediment Storage Dam
The purpose of the Sediment Storage Dam is to entrap sediment inflow into the reservoir after the removal of deposited sediment and maintain the service water capacity of the reservoir.

(3) Consolidation Work: One place
This work is to prevent the inflow of sediment material accumulated on the upstream part of the reservoir when the sediment deposited in the reservoir is removed and when the reservoir bottom is lowered.

(4) Project Implementation Schedule
12 years starting from Fiscal Year 1995 and ending in Fiscal Year 2006 (12 years)

5. Detail of the Sedimentation Countermeasure Project

1) Use of Reservoir Water and Sediment Removal

The relationship between the operation of the Makio Dam Reservoir and the amount of sediment removal is shown in Fig. 7. The operation water level shown in the figure means the reservoir level that is targeted for reservoir water use. The sedimentation countermeasure project was set up to excavate and remove sediment deposited at an elevation higher than the operation water level so that sediment removal work will not disturb the operation of the reservoir. In detail, it was set up to remove 5,480,000 m^3 of mainly gravel and sand material deposited at an elevation higher than El. 855 m under the dry work condition

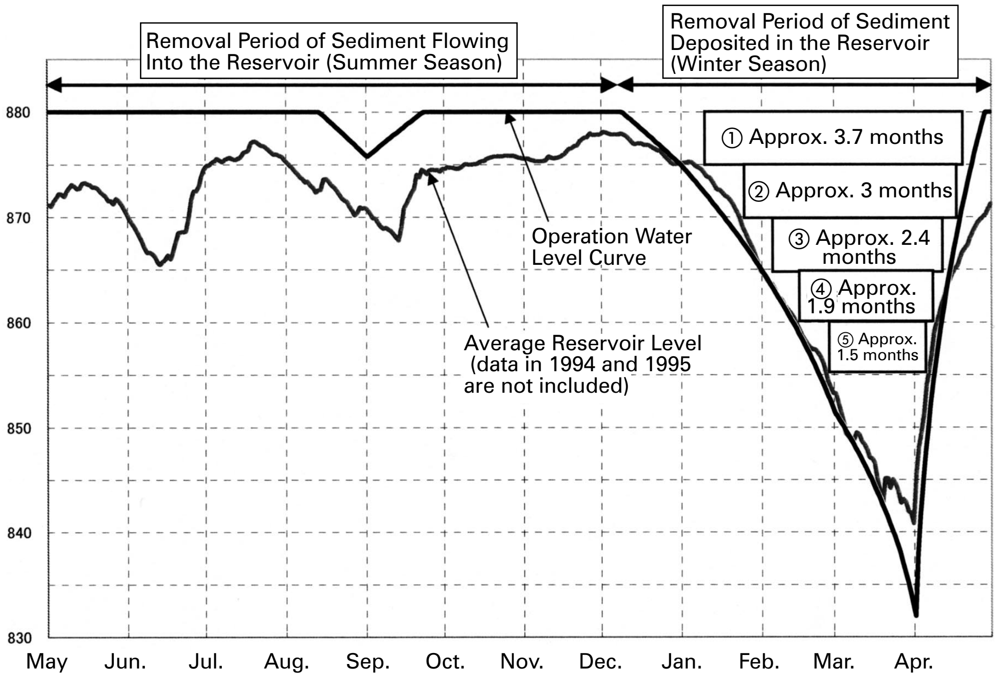

Fig. 7 Relationship between Operation Water Level and Sediment Removal

Table 4 Sediment Removal Schedule by Elevation

Elevation	Amount to be Removed (1,000 m³)	Number of Work Block	Work Period	Work Year Phase	Total Work Period
El.880 to El.875	511	5	3.7 months (112days)	1st to 2nd	7.4 months
El.875 to El.870	822	8	3.0 months (91days)	2nd to 5th	12.0 months
El.870 to El.865	992	10	2.4 months (73 days)	2nd to 8th	16.8 months
El.865 to El.860	1,168	12	1.9 months (57 days)	2nd to 8th	13.3 months
El.860 to El.855	1,155	12	1.5 months (44 days)	2nd to 8th	10.5 months
Total	4,650	47	– –	–	

when the trafficability of heavy excavation equipment is secured during the above-mentioned several months of dry condition.

It was planned to implement the project during a winter period from the early part of January when the reservoir level is lowered through the middle of April when the reservoir level starts to rise. In addition, it was also planned to conduct sediment material excavation and removal work whenever the reservoir level is lowered even during the summer season.

① During Winter Period: Reservoir level decreases and a planed number of workable days can be set up. Sediment excavation work can be conducted by using large excavation equipment.

② During Summer Period: Sediment flows into the reservoir every year during the summer period. It is planned to remove sediment deposited at an elevation higher than El. 870m using ordinary earthwork equipment whenever it is possible.

2) Amount of Sediment to be removed at Each Different Elevation

Out of the total amount of 5,480,000 m³ sediment to be removed by the project, the amount that should be removed at the upstream side of the reservoir during the winter season was decided upon as 4,650,000 m³ judging from the number of workable days during this season as shown in Table 4. This amount of sediment is to be removed by setting up an amount at each different elevation.

As for the remaining 830,000 m³ of sediment, of which 630,000 m³ that would flow into and deposit in the reservoir during the project implementation period was planned to be removed during the summer season. As for another 200,000 m³, it was planned to remove from the area at an elevation higher than EL. 855 m in the left side of the reservoir immediately upstream of the dam.

3) Securing of Disposal Sites

It was planned to move excavated sediment material in the reservoir to disposal areas. The Makio Dam site is surrounded by a mountain range. As it was difficult to find suitable disposal sites near the dam site to stockpile a total amount of 5,480,000 m³ of sediment material, several disposal sites were secured. When selecting these disposal sites, the residents in the Ootaki and Mitake villages expressed a favorable understanding and offered a great deal of cooperation.

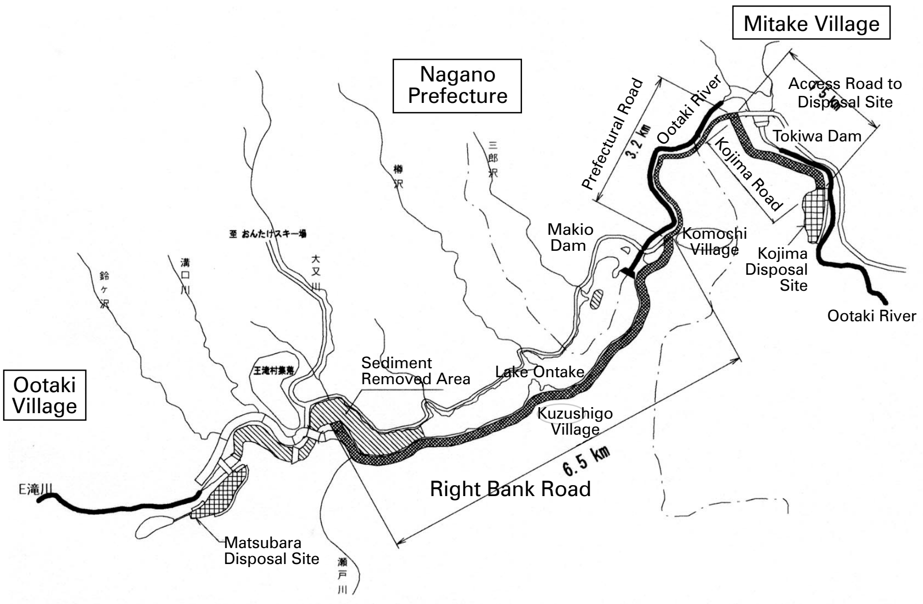

Fig. 8 Transportation Route to the Kojima Disposal Site

Table 5 Sediment Removal Plan in Each Fiscal Year

(Unit in 1,000 m^3)

Fiscal Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	Total
Removal Amount of Deposited Sediment	30	640	650	830	884	775	628	413	–	4,850
Removal Amount of Flowing In Sediment	70	70	70	70	70	70	70	70	70	630
Total	100	710	720	900	954	845	698	483	70	5,480

Two major disposal sites among the selected ones are outlined below:

(1) Matsubara Disposal Site

The Matsubara Disposal Site is located on the right side of the upstream part of the reservoir and has an area of approximately 21.5 hectares. It is possible to store an approximately 3,000,000 m^3 of removed sediment material. As it is possible to remove sediment material directly from the reservoir to the disposal site without using road transportation, the sediment removal operation does not interrupt road traffic. It is possible to efficiently remove sediment material by using large-sized excavation equipment and dump trucks. This is an economical disposal site. (Fig. 8)

(2) Kojima Disposal Site

The Kojima Disposal Site is located on the right bank of the Ootaki River downstream of the dam and has an approximately 126 hectares of area. It can store an approximately 1,500,000 m^3 of removed sediment material. The site is approximately 12 km towards the downstream direction from the sediment excavation site at the upstream part of the reservoir. As excavated sediment material has to be transported using an existing village and prefectural roads, it was planned to transport excavated sediment material by 10-ton dump trucks. Thus, it was necessary to take measures for traffic congestion, vibration, and noise problems.

4) Transporting of Sediment Material to Disposal Site

(1) Transporting of Sediment Material to Matsubara Disposal Site

A temporary construction road was to be built within the reservoir and it was planned to use 42-ton large sized dump trucks to transport sediment material to the disposal site.

(2) Transportation of Sediment Material to Kojima Disposal Site

It was planned to transport sediment material to the disposal site using 10-ton dump trucks over an ordinary public road. However, as the amount of sediment to be removed in a day during the winter season is 4,600 m^3, if 10-ton trucks were to be used for the transportation, 920 dump trucks would be necessary. Further, it was impossible for 10-ton trucks to pass each other on the 5m wide village road located on the right bank of the river. In addition, as the prefectural road section planned for sediment material transportation is the only access road to the center of Ootaki Village and the Ontake Ski Resort, if traffic congestion occurs on the road, the effects of vibration and noise to area residents were feared.

5) Measures for Transportation to Kojima Disposal Site

(1) Securing of Both Direction Traffic on the Village Road on the Right Bank

The existing village road on the right bank of the Ootaki River was only 5 m wide and it was impossible for 10-ton dump trucks to pass by each other. The entire 6.5km section for dump truck use was widened to an 7m width.

(2) Measures for Traffic Congestion, Vibration and Noise Problems

Traffic congestion forecast by traffic simulation and traffic vibration and nose prediction by a vehicle test driving were conducted and the allowable daily traffic volume of the village road was decided upon as 800 vehicles a day (between 8:30 to 16:30).

As for the amount of sediment material that cannot be transported to the Kojima disposal site due to the limitation of the allowable daily traffic volume, it was decided to provide a temporary storage site, store the sediment material temporarily in the site and transport it to the Kojima disposal site when road traffic becomes lighter during the summer season.

In order to prevent traffic congestion to be caused by the slower speed of dump trucks due to the effects of snowfall and freezing, it was planned to take sufficient snow removal and freeze-prevention measures.

6) Sediment Material Removal Yearly Plan

The sediment material removal plan that was prepared based on the above-mentioned concept in each fiscal year is as listed in the following table: (Table 5)

6. Implementation Condition of the Sedimentation Countermeasure Project

Based on the above-mentioned policies, the excavation and removal of sediment material deposited in the reservoir began in Fiscal Year 1999. The sediment material removal work was 83% complete as of the end of March 2005. The removal work of the remaining sediment material is presently being conducted and the construction of a sediment storage dam is simultaneously carried out. The project is smoothly progressing on schedule to be completed by March 2007. It is expected that the storage function of the Makio Dam Reservoir be sufficiently restored.

7. Restoration of the Catchment Area by the Progress of Erosion Control Work

The point that should not be overlooked in the sedimentation countermeasure project is the restoration measure of the devastated catchment area of the Makio Dam. Since immediately after the Nagano Seibu Earthquake, the Nagano Prefectural Government and Forestry Agency have been carrying out the construction of debris control dams and channel work and tree planting on severely scoured slopes and debris deposited bare land along stream banks created by debris flow. The residents in the water source areas of the reservoir, such as Ootaki Village, and the water-use beneficiaries of the Makio Dam conduct tree planting activities every year. Personnel exchange between the people in the water source areas and the people in the downstream region is eagerly taken place through the tree planting activities. In particular, since 2001 a large-scale tree planing activity called "Green Button Connecting to the Future Centuries" has been conducted with the participation of Ootaki Village as its center, Mitake Village, Chunichi Newspaper Company, Chubu Forest Management Bureau, Japan Water Agency, and the beneficiaries. This activity held on the slope of Mt. Ontake aims at handing over the abundance of water and greenery to the future generations by the cooperation of the people in the water source areas and the people in the downstream regions through the restoration activities of forests in the water-source areas of the Makio Dam that was devastated by the previous earthquake.

Photo 5 Condition of the Catchment Area immediately after the Earthquake

For the sake of debris control work and tree planting activities being carried out in the catchment area of the Makio Dam since immediately after the earthquake, the severely damaged catchment area of the Makio Dam has recovered to such a level that the amount of sediment flowing into the reservoir is almost equivalent to that prior to the earthquake.

As for the new sediment storage dam that is being constructed by part of the sedimentation countermeasure project, sediment material to be entrapped by the dam should be periodically removed after dam completion. This project being implemented is an extremely important measure to exhibit the effects of sedimentation countermeasure to control the inflow of sediment into the reservoir.

The sedimentation countermeasure project for the Makio Dam aims at the restoration of the reservoir functions. As this project suggests the importance of

Photo 6 Present Condition of the Catchment Area

Photo 7 Tree Planting Activities in the Makio Dam's Catchment Area

measures to be taken for the dam's catchment area, this paper introduced these measures.

8. Conclusion

The Japanese economy has entered into a stabilized period. It is forecasted that the population of Japan will reach to the peak in 2010 then begin to decline thereafter.

Demand for water is assumed to maintain almost the same level. Water resources development in Japan has achieved a certain result. From now on, it is the time to appropriately maintain and efficiently use existing facilities. For this reason, it is inevitable to proceed with sedimentation countermeasures.

This paper introduces the restoration method of reservoir functions without interrupting water-use operation that is being conducted at the Makio Dam whose reservoir functions were severely damaged by sediment inflow and themes and their measures related to sediment material transportation. In addition, the paper also introduces the debris control work, tree planting activities and the dam's catchment area restoration project being conducted by related agencies. In order for the dam to fully exhibit the reservoir functions, it is considered that, in addition to tree planting activities, continuous maintenance and preservation of the catchment area by conducting periodical thinning and weeding work under the cooperation with area residents and water-use beneficiaries and the promotion of effective use of wood produced by thinning would be very important.

It is the authors' great pleasure if this paper will provide some reference to those who are encountering similar reservoir sediment problems.

At last the authors would like to express their sincere appreciation to those in the water-source areas, water-use beneficiaries, and related organizations and agencies that provided extensive cooperation for the implementation of the project.

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