INTERNATIONAL COMMISSION ON LARGE DAMS
76th ANNUAL MEETING
SOFIA, BULGARIA, JUNE 2-6, 2008
Symposium: "Operation, Rehabilitation and Up-grading of Dams"

IMPORTANT ASPECTS FOR REDEVELOPMENT OF DAMS IN JAPAN

Tatsuo HAMAGUCHI [1] **Hiroji NAKAGAWA** [2] **Shuji TAKASU** [3]

PRESENT STATUS OF EXISTING DAMS IN JAPAN AND CHALLENGES FOR REDEVELOPMENT

More than 100 years have passed since modern concrete dams had been constructed in Japan. Now, as many as 2,700 high dams are playing important roles of water supply, electricity generation and flood control. However, many dams are facing difficulties such as deterioration of facilities due to their aging, sedimentation in reservoirs and alteration of operation rules to cope with changes in social and economic environments.

On the other hand, good dam sites, which can be said as valuable and limited natural resources, are decreasing in number. In addition, a rise of consciousness for environmental protection and a tightness of fiscal restriction have limited new construction of dams in Japan.

Under these circumstances, redevelopment of existing dams is getting more and more important in view of contribution to solving these problems, and to securing their much longer operating life. In Japan, a considerable number of redevelopment projects have already been initiated. Those problems or challenges which urged those projects are listed below.

First, the annoying problems related to recovery and maintenance of the original functions of dams are as follows:

- Dam bodies and related structures are deteriorated due to aging.
- Maintenance of dams needs a lot of manpower and high cost.
- Observed sediment in many reservoirs is more than the estimation at the planning stage, and it results in shortage of the original capacity.
- Operation of flood control gates is too much complicated, or the discharge capacity of gates does not match the needed one for proper operation.
- Floods exceeding the planned level occur so frequently that the expected flood control become insufficient to prevent inundation in downstream area.

Next, the requirements to secure higher functions of dams are:

- Enlargement of reservoir capacity is needed to strengthen the dam function for flood control, water utilization and environmental enhancement.
- Reconstruction or new installation of discharge facilities including gates is necessary to improve flood control capabilities.
- A new power generation facility needs to be constructed to expand dam functions.
- With a view to increasing efficiency of flood control and/or water utilization as a group of reservoirs, coordination measures such as optimal re-adjustment of reservoir capacity allotment and construction of water linkage facilities among reservoirs are needed.

Then, environmental problems related to reservoirs and downstream rivers are as follows:

- Habitat for plants and animals is damaged or almost extinguished.
- There occurs a water quality problem in reservoirs, such as eutrophication, discharge of cold water, and prolonged discharge of turbid water.
- Flow in the downstream of dams is exhausted as a result of water diversion for hydropower and water use, etc.
- Dam construction deteriorates the continuity along rivers in terms of sediment movement, flow regime, and trip of living creatures. When its influence is serious, measures must be taken to recover the continuity.

In connection with the problems above mentioned, the following characteristics of Japan relevant to the topographic and climatic conditions should be noticed.

- Japan consists of a chain of narrow islands with mountain ranges at their backbone, which form many small river basins with steep streams.
- Around 2/3 of the national land is covered with forests, rich in environmental assets.
- Japan belongs to the circum-Pacific earthquake belt, and is subject to strong earthquake disasters quite frequently.
- The geological constitution is very complicated, and sediment production in mountains is high.
- Major floods are brought by the “Tsuyu” rainy season in June and typhoons in autumn, whose rainfall is characterized by high intensity and short duration. Most floods end within 2 or 3 days. Snow-melt floods are often seen in the northern part of Japan.
- Alluvial plains spread in the lower reaches. Population and economic activities concentrated there need to be protected from flood disasters. This is why Japan has a long history of people’s efforts to overcome these disasters.
- The catchment area of a dam is generally small. In addition, to cope with torrential rainfalls, flood control operation must be performed accurately in a limited time. Thus, dam management requires high skill.
- In case the catchment area is very small, flood control dams are often planned as non-gate dams, not as gated ones.

In addition to these challenges, global warming adds another risk of extreme floods and droughts as reported by IPCC. To cope with these situations, a comprehensive framework, covering planning methodology, operation of dams, sedimentation management, environmental conservation measures and the development of new technologies for dam facilities, is necessary as listed in Table-1.

Japan has examples of long-life dams with more than 1,000 years' operation history. The Sayama-Ike earth dam, built in the early half of 7th century, has been in operation for 14 centuries with efforts of repair and improvement works. Learning from these remarkable achievements, we should make every effort to have the existing dams serve for several centuries, even a millennium, abandoning the idea of legal durable years which is some 80 years or so.

Table-1 A Comprehensive Framework for Redevelopment of Dams

Items and sub-items		Remarks (examples etc.)
Planning methodology		
	Effective utilization of existing dams	raise of dam height, reorganization of functions among several dams
	Measures for floods exceeding the original target flood	improvement of discharge facilities and gates, expansion of reservoir capacity
	Dams for crisis management purpose	provision of substitutive reservoir capacity in preparation for crisis
	Evaluation of economic efficiency	reexamination of legal durable years, minimization of Life Cycle Cost (LCC)
Operation of dams		
	Suppression of cost for operation and maintenance	more laborsaving maintenance, integration of management unit, training of personnel
	More reliable and laborsaving flood control operation	introduction of ungated spillway for flood control
	Efficient information system	reinforcement of information system which supports dam operation
	More flexible and resilient flood control	device to produce flood control effect in case of exceeding floods
	Diversification of intake-discharge capabilities	installation of medium-scale discharge facility
	Utilization of natural energy around dams	small/medium-scale hydropower generation, Dam Air-energy System (DAS)
	Asset management	minimization of Life Cycle Cost of dam management
Sediment management		
	Sedimentation management for realizing longer operation life	maintenance of the effective capacity by means of "equilibrium sedimentation"
	Establishment of selection method for sediment management	priority setting and combination of various management tools
	Development of sediment management technology	technology for taking-out, transportation, discharge/flow-down of sediment
	Environmental conservation measures in sediment management	mitigation of environmental impact in discharge/flow-down process
Environmental conservation measures		
	Continuity along the river course	improvement of continuity in terms of sediment, flow and aquatic creatures
	Water quality in reservoirs	measures against eutrophication, discharge of turbid/cold water
	Environmental conservation around reservoirs	securement of habitat for fauna and flora
Development of new technology for dam facilities		
	Durability of dam body and related structures	technology for detection of damaged concrete and its repair
	Diagnosis of aging deficiencies and improvement measures	establishment of a total system (inspection-diagnosis-repair/improvement)
	Compliance with newly established technical guidelines	establishment and application of the technical standard for redevelopment
	Technology for raising dam body	analyzing methodology, technology for unifying the old and new dam body
	Technology for large-scale hole-forming through dam body	design and safety analysis, construction method under dam operation

IMPORTANT ASPECTS FOR REDEVELOPMENT OF DAMS (PROPOSAL)

In this section, 7 important aspects are focused among the afore-mentioned frame work, and related proposals are described.

Reorganization and Coordination of dams as a group

In case of redevelopment of a single dam to cope with changes in natural conditions and social needs, enlargement of reservoir capacity by raising the dam height or by excavation of sediment in the reservoir is a typical method. Also, new installation or improvement of intake/discharge facilities is often planned for the purpose of more efficient dam operation.

Moreover, enhancement of flood control and water supply capabilities can be achieved by reorganization and coordination of dams as a group. One method is to re-allot reservoir capacities optimally in consideration of reservoir volume, inflow volume, water utilization conditions and challenges for flood damage mitigation. Another method is to construct linking channels among reservoirs with a view to more efficient water management. These kinds of projects have been started in the Tone River system which supports water supply for the Tokyo Metropolitan Area.

In river systems or areas where plural dams have already been constructed, it is advisable to prepare an integrated and optimal plan for flood control, water utilization and environmental enhancement by making maximum use of existing facilities as a group, then to promote the projects of reorganization/coordination type.

Measures for floods which exceed the original scale of the flood control plan

In Japanese river management, when flood control capacity of a dam is estimated to run short because of excess inflow of a flood which exceeds the original scale of the flood control plan, the dam operation is shifted from the usual flood control operation to the special operation for exceeding floods which aims to gradually equalize the outflow with the inflow.

As for a reservoir capacity plan concerned, it is a common practice in Japan to add 20% of margin capacity to the calculated flood control capacity for the target flood. The said special operation is usually started when the reservoir water level reaches a certain level below the surcharge water level.

Judging from the increase of risk of extreme floods due to global warming and prolonged operation life of dams, more attention to measures against these exceeding floods should be paid. Even in case of exceeding floods, flood control effect should be secured as much as possible, with due consideration of certainty and easiness of dam operation.

Here described are some proposals.

First, it is advisable to expand the reservoir capacity by raising dam height. In this case, improvement of emergency discharge facilities will be necessary accordingly.

Next, improvement of gate facilities is important. Most of Japanese dams are equipped with lift-up type gates (fixed wheel gates or radial gates) at the spillway. These gates need to be operated from the initial stage of the special operation for exceeding floods, imposing heavy burden on dam operators. We propose to reconstruct these facilities to flap gates which are usually laid horizontally at the starting level of the special operation (Fig-1). This enables safe and smooth start of the special operation for exceeding floods through natural overflow. This also realizes flood control against exceeding floods by raising the overflow level with increased safety and certainty.

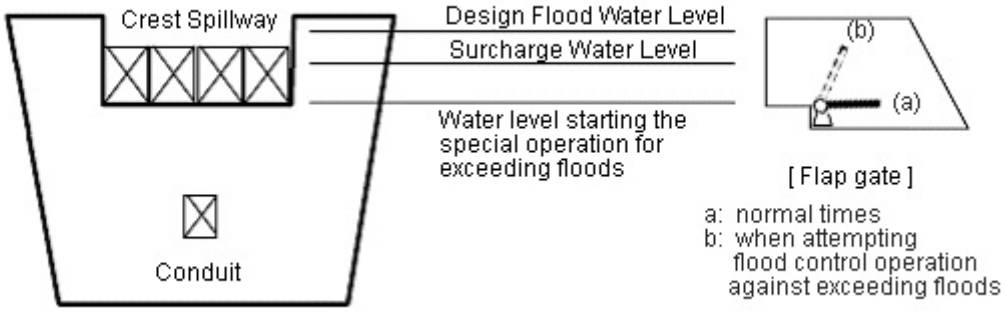

Fig.1 Schematic View of a Spillway with Flap Gates

Third, there is a possibility of occurrence of an exceeding flood, not in the catchment area of the dam but in the downstream basin. In case of a non-gate flood control dam with conduit or free overflow spillway, installation of regulating gates will be effective for flood control against exceeding floods in the downstream, except for cases of small reservoir capacity or small catchment area.

Equilibrium sedimentation management

How to handle sediment problems in reservoirs is a vital challenge for longer operation life of dams. So far, in a reservoir planning, a capacity for estimated 100-year sedimentation has been allotted. Unlike this scheme, “equilibrium sedimentation management” to keep balanced sedimentation by discharging the same amount of sediment load as the incoming one should be a basic principal (Fig.2).

Equilibrium sedimentation management should be considered not only from the quantity of sediment load, but also from the shape and grading of sediment. In consideration of these factors, as well as other factors including shape of the reservoir, flow regime, and fluctuation of water level, a plan which enables to pass or discharge sediment load down from the dam economically and effectively is to be established.

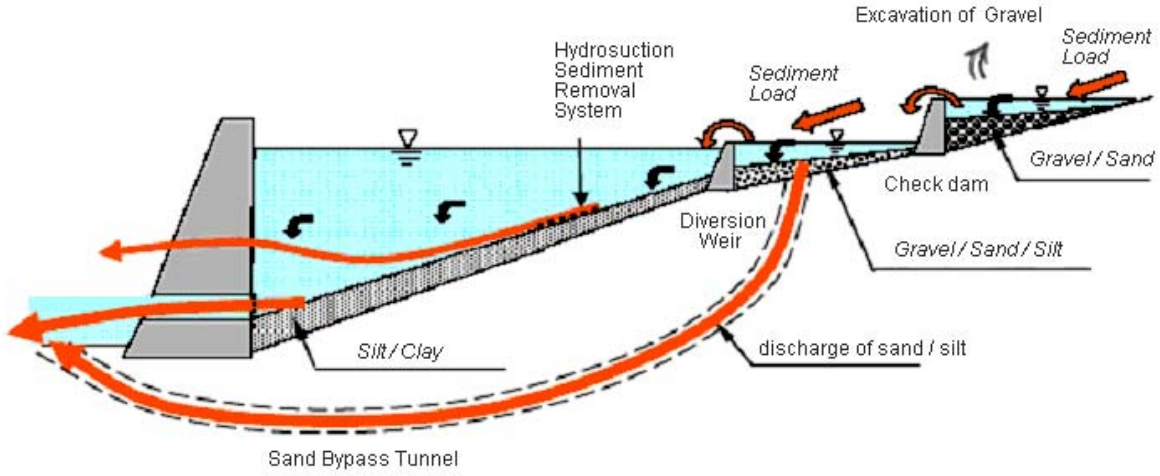

Fig.2 A Model of Equilibrium Sedimentation Management in a Reservoir

More precisely, in the upstream part of a reservoir, sediment is mainly formed by gravel and sand. These coarse materials should be basically trapped by check dams not so as to flow into the main reservoir body. The trapped load is to be excavated and transported using dumper trucks, or slurry conveying system, etc. Then, the load may be utilized as concrete aggregate, or may be stacked downstream of the dam expecting to be flushed during floods.

In the middle part of the reservoir, sediment mainly comes from sand, along with some gravel and silt. Suspended or bed material load can be conveyed downstream through a sand-bypass channel at a time of flood. Newly developed technology, such as HSRS (Hydro-suction Sediment Removal System) can be applied for transportation of materials.

Finally in the downstream part, sediment consists of silt and clay. Potential transportation/discharge methods include flushing, density flow and HSRS. For more effective discharge during floods, it is desirable to move and accumulate these fine materials to a certain location in a reservoir suitable for discharge during ordinary times. Utilization of natural energy such as small-scale hydropower generation will help economic operation for this piling work.

Measures based on the equilibrium sedimentation management are available not only for the dams threatened by increasing sediment, but also for the rest of dams in view of longer operation life.

Securement of continuity along the river course

Construction and operation of a dam hinders the continuity between upstream of the dam and its downstream. This sometimes results in deterioration of river environment, including change of flow regime, river bed degradation, and obstacle for upstream/downstream migration. It is important to improve these situations through securing continuity along the river course, in terms of flow, sedimentation, and aquatic creatures.

From the viewpoint of flow regime, water utilization and operation of a dam sometimes have direct impact on the downstream flow of the dam: almost drained stream, extreme evenness of river flow, heavily modified fluctuation pattern, etc. Improvement of operation, reexamination of water use regulation, introduction of flushing flow operation of dams must be considered in these cases.

When serious degradation of river bed or coastal erosion is brought by construction of a dam, suitable measures should be considered based on the idea of equilibrium sedimentation management.

In case when the blocked migration of creatures at the dam has a major impact on the river environment, installation of a fish path to the dam should be considered from the viewpoint of smooth migration of aquatic creatures. Development of a more effective fish path facility is also a challenge for us.

A new scheme in deployment of dams – separation of flood control function and water utilization function -

In Japan, many multi-purpose dams with both flood control capacity and water utilization capacity in one reservoir have been planned and constructed mainly because of high economic efficiency. However, in view of easiness of sedimentation management and minimization of environment impact, a new scheme in deployment of dams is proposed.

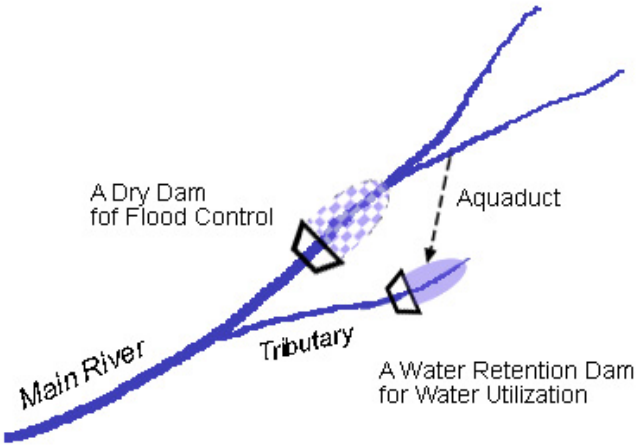

Fig.3 A Schematic Plan Separating Flood Control and Water Utilization Functions

Generally speaking, a trunk river has more flood discharge and sediment transportation than a tributary. To have a maximum flood control effect, it is therefore desirable to deploy a regulating capacity in a trunk river. On the other hand, from the viewpoint of securing continuity, deployment of a reservoir in a tributary has minor impact than that in a trunk river. Thus, a comprehensive plan, consisting of a dry dam for the purpose of flood control in a trunk river and a water-retention dam for the purpose of water utilization in a tributary, is expected to achieve both high efficiency in river flow regulation and securing continuity (Fig-3).

Capacity for river environment

Recently, some dam managers try to increase low flow, or to execute flush discharge with the intention of re-creating original flow regime, through more flexible operation of reservoirs.
At this stage, these efforts are only on a temporary basis. Therefore, it is advisable to have a special capacity for river environment, which enables this kind of operation on a permanent basis and on a massive scale. In case of existing dams, this capacity is created by raise of dam height, or by reorganization of dam functions.

Emergency response dam

When a redevelopment project, such as raising dam height, repair of dam body, or placing a new conduit through a dam body, is implemented, it may inevitably require the reservoir level to be lowered. Also, a strong earthquake or an unforeseen accident may force the reservoir to be drained. These incidents will cut down the dam function, and may finally lead to social and economic turmoil.
To avoid this, it is necessary to have an emergency response dam, whose capacity is used as a substitute in case of emergency or redevelopment of other dams. In California, U.S.A., this type of dam is already constructed. This emergency response dam also serves to have more stabilized water supply in case of extreme drought.

Conclusion

This report first summarizes various challenges concerning existing dams in Japan, and the comprehensive framework of dam redevelopment. Then, 7 important aspects for redevelopment and related proposals are described. Specially, the idea of equilibrium sedimentation management is important for longer operation life of dams.

Acknowledgement

This report is based on the discussions of the Investigation Commission on Redevelopment of Dams, which was organized in the Japan Dam Engineering Center, to study necessary measures for longer operation life and effective use of dams. We express our sincere gratitude to the members of this commission, as well as to the Ministry of Land, Infrastructure and Transport, and related prefectural governments who kindly provided valuable information.

References

1) T. SAKAMOTO, A.YAMAZUMI: Redevelopment projects for multipurpose dams in Japan, Trans. of 18th ICOLD, 1994
2) T.KADOMATSU, S.TAKASU, T.FUJISAWA: Recent circumstances of dam rehabilitation in Japan, Trans. of 21st ICOLD, 2003
3) Session Report IWRM-033: Challenges to the Sedimentation Management for Reservoir Sustainability, The 3rd world water forum, 2003
4) T.Sumi, M.Iguchi: Technical Feasibility Study of Sediment Flushing in Reservoir Using the RESCON Model, J.of Japan Society of Dam Engineers, Vol.15 No.2, 2005
5) Japan Dam Engineering Center: Future Directions of Dam Redevelopment, Report of Dam Engineering Research Institute, No.200601, 2007

[1] Japan Dam Engineering Center, hamaguchi@jdec.or.jp
[2] Ritsumeikan University, hiroji@mte.biglobe.ne.jp
[3] Japan Dam Engineering Center, takasu@jdec.or.jp