DESIGNING AND OPERATING OF FLOOD RETENTION 'DRY' DAMS IN JAPAN AND USA

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ABSTRACT

Flood retention dams designed only for the purpose of flood control whose bottom outlets are specially designed at the original river bed level and can pass through inflow projects. Masudagawa dam completed in 2007 is one of good examples in Japan and there are also good examples in USA from 1920's such as 5 dams at the Miami Conservancy District in Ohio which are usually called as 'Dry' dams. This paper reviews concept as well as designing and operating points including reservoir sediment management of these flood retention dams and future challenges.

Keywords: flood retention dam, dry dam, Masudagawa dam, Miami Conservancy District, reservoir sediment management

1. INTRODUCTION

Recently, flood retention dams designed only for the purpose of flood control whose bottom outlets are specially designed at the original river bed level and can pass through inflow sediments almost naturally during flood periods are often planned for the new flood control projects.

Lempérière, F.(2006) has pointed out that 'Future dams may generally be multipurpose, but dams devoted only to flood mitigation which are completely dry except for a few weeks per century may be very acceptable environmentally; their design may be quite different from multipurpose dams and their cost much lower for the same storage'.

These dams may have advantage not only on reservoir sedimentation but also on water quality problems such as turbid water prolongment and eutrofication problems and on maintaining longitudinal river basin ecosystem such as fish migration and various material transports throughout river basin.

Masudagawa dam completed in 2007 is one of good examples in Japan and other new projects such as Tateno, Asuwagawa and Tatsumi dams are under planning. There are also good examples in USA from 1920's such as 5 dams at the Miami Conservancy District in Ohio, Mount Morris dam at the USACE Buffalo District and Prado dam at the USACE Los Angeles District, and they are usually called as 'Dry dams'.

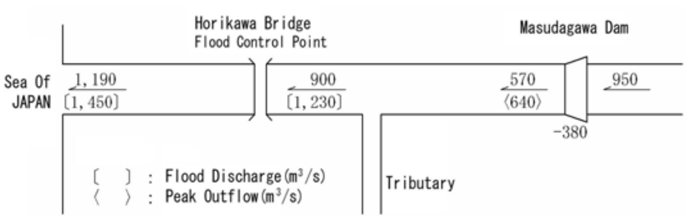
Generally, issues on these dry dams can be summarized as dam structural and hydraulic design, reservoir sediment management, quality of discharge water, maintaining of ecosystem and land management in reservoir area, clogging problems of bottom outlets by big stones or floating debris.

This paper discusses on these issues of dry dams from the point view of type classification, structural and hydraulic design, sediment management, quality of discharge water and so on in Japan and USA, and future challenges.

2. MASUDAGAWA DAM

Masudagawa dam located in Shimane prefecture is a flood control dam designed with probable flow rate of 1/100 at the Masuda River as shown in Figure 1. Detail design of Masudagawa dam is shown in Figure 2. Two gateless bottom outlets and overflow spillways are installed. For energy dissipater, conventional hydraulic jump type stilling basin with an end sill is designed where two slits are installed for self sediment flushing from the stilling basin. Inflow sediment can be naturally flushed through bottom outlets but dead capacity of 250,000m^3 is planned. Bottom outlet and some part of stilling basin are protected with stainless steel plates against for abrasion damage (Kashiwai, 2000).

Catchment Area: 87.6km^2
Dam Type: Gravity
Structural Height: 48.0m
Total Storage Capacity: 6,750,000m^3
Gross Storage Capacity: 6,500,000m^3
Dead Capacity: 250,000m^3



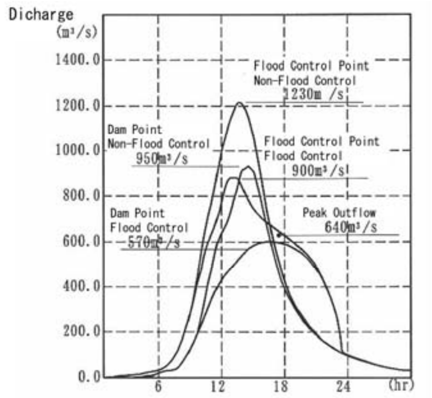


Figure 1 Flood control plan at Masuda River

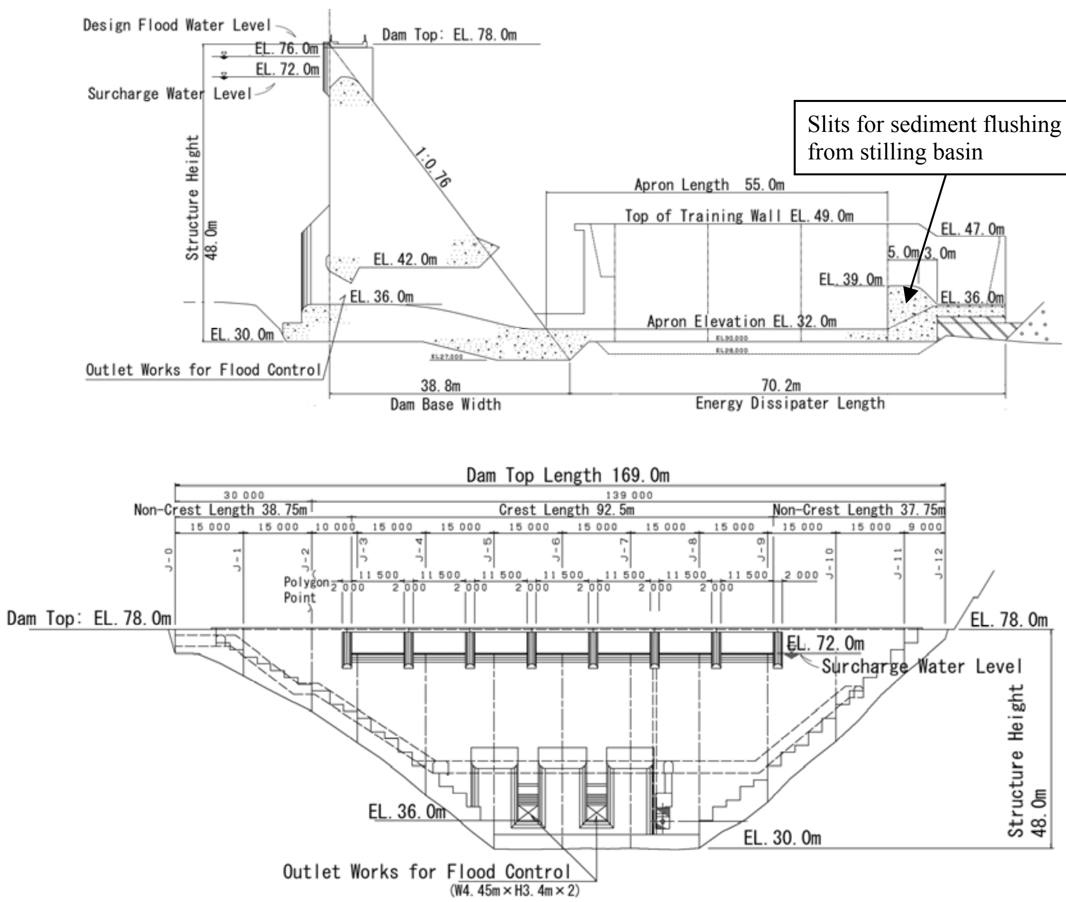


Figure 2 Detail design of Masudagawa dam

3. CLASSIFICATION AND HISTORY OF DRY DAMS

Figure 3 shows gross storage capacity and dam height of dry dams in Japan and USA including Masudagawa dam. Because of geographical conditions, there is large difference between dams in Japan and USA. Reservoir capacities to dam height of dams in USA are very large since they are constructed at the point in mild river slope and wide valley. Seven Oaks dam is only constructed in a mountain river. Orden dam in Switzerland is also similar to Japanese dams. River slope and reservoir capacity may affect way of sediment management.

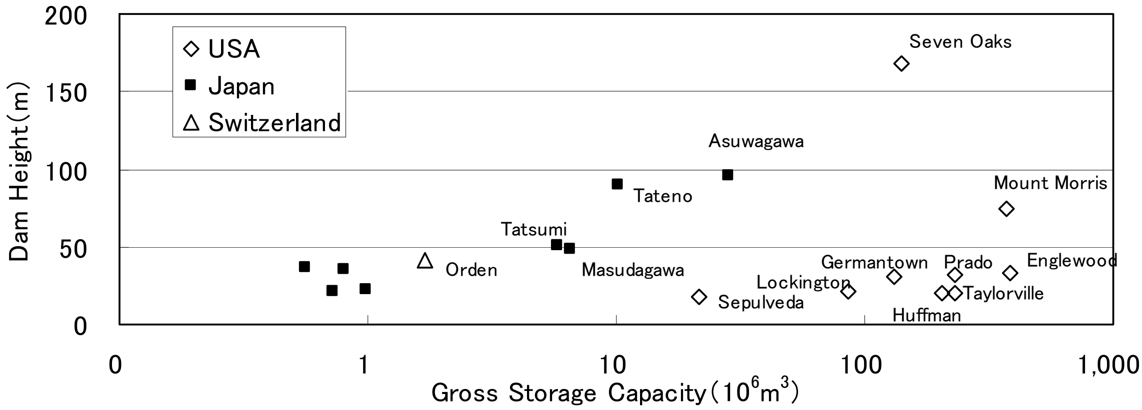


Figure 3 Gross storage capacity and dam height of flood retention 'Dry dams'

These flood retention dams can be classified as Table 1. Viewpoints of classification are 1) installing regulating gates in bottom outlets or not and 2) securing continuity of the river through these outlets or not.

The simplest form is the one that outlet are installed in the riverbed level. Masudagawa dam and five dams of MCD (Miami Conservancy District) correspond to this category. In these dams, fish migration and sediment continuity can be secured. Moreover, similar type is adopted in small-scale farmland disaster prevention dams in Japan. Olden dam in Switzerland is also classified into here.

The one that a regulating gate is installed to the bottom outlet according to the flood control operation is similar to this. If the regulating gate is completely opened usually, environmental impacts such as securing continuity of the ecosystem and the sediment transport are thought to be almost equal to the above-mentioned dam. Aswagawa dam in Japan and Mount Morris and Prado dams in USA are categorized here.

On the other hand, there is a dam where both capacities for the flood control and the sedimentation (100 years) are secured, and the outlet is installed in the middle level of dam body. Seven Oaks dam in USA is categorized here. In such a dam, environmental impacts should be very different, and it distinguishes from the above-mentioned dams.

Table 1 Classification of flood retention dams

	Dry dam	Non dry dam
Gateless bottom outlet	Masudagawa, Tateno, Tatsumi, MCD, Orden, Small-scale farmland disaster prevention dams in Japan	Natural flood control dams for small basin in Japan
Gated bottom outlet	Asuwagawa, Mount Morris, Prado	Seven Oaks

In USA, These dams are almost constructed as an embankment dam which may be standard style except Mount Morris dam as a concrete gravity and Seven Oaks dam as a rock fill dam. The MCD dams and the Prado dam may be constructed most reasonably for embankment dams since dam height are about 30m or less and crest length are about as many as 1,000m.

Bottom outlet is regularly installed in the embankment in USA, and there are two types for spillway. Taylorsville dam in MCD is the example of the installation in the upper part of the bottom outlet in a concrete dam section and Englewood dam in MCD and Prado dam are the ones that spillway is installed separately. Figure 4 shows aerial view of these dams.

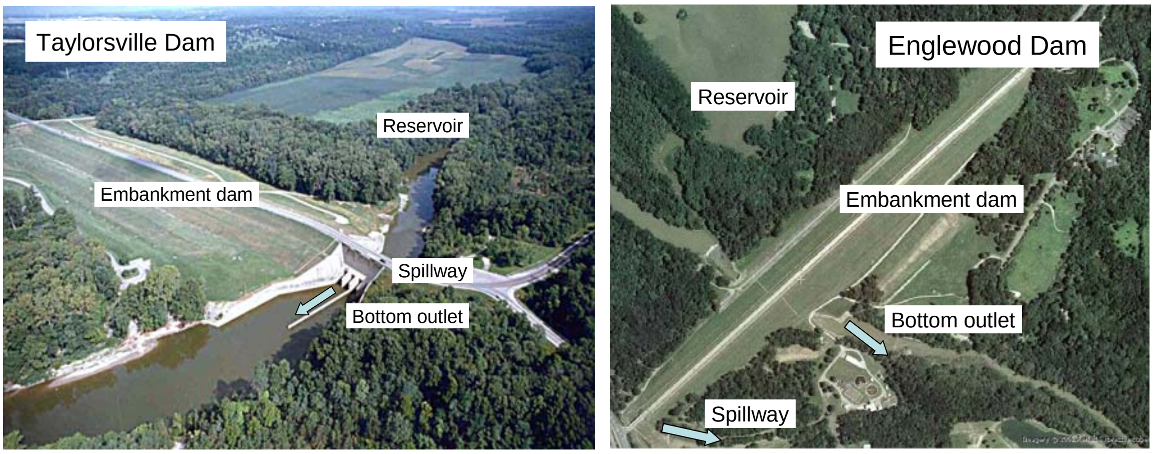


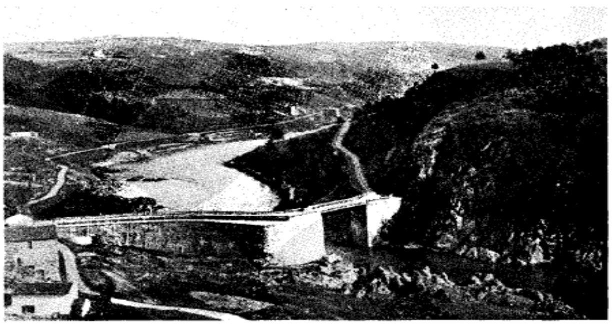
Figure 4 Taylorsville and Englewood dams in MCD

The oldest dry dam in USA is five dams that MCD (Miami Conservancy District) constructed. MCD is an organization established in 1914 to execute flood control project of the Great Miami River flowing through Dayton city in the state of Ohio. Arthur E. Morgan (1878-1975), a chief engineer of MCD, conducted the project and proposed dry dams for flood control.

He selected dry dams for the Great Miami River from the following point of views.

- There was little necessary for multipurpose such as domestic water supply or hydro power.
- Since the project was also supported by citizens' fund-raisings, it was necessary to reduce costs by site purchasing a minimum.
- The continuous use for the farmland was possible. (the farmer opposed the project)

He also referred to the precedent of dry dams, Pinay and La Roche, which were constructed in Loire River in France about 200 years ago. Pinay dam completion in 1711 was a big slit dam set up in the river channel such as Figure 5. Local farmers accepted the dam because of reducing downstream flood risks and bringing a fertile soil in the submerging area at the winter and spring floods. The Pinay dam has been decommissioned because of the construction of Villerest dam completed in 1984.



The Pinay Dam on the Loire River in southern France.

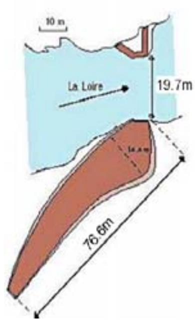


Figure 5
Pinay dam in Loire River in France completed in 1711

4. HYDRAULIC DESIGN OF DRY DAMS

It is necessary to examine the following items by a hydraulic design of dry dams in consideration of the past experiences.

4.1 Bottom outlet

Appropriate abrasion proof design is needed such as with metal linings in case relatively coarse sediment will be discharged. Especially, if the regulating gate is set up at the bottom outlet for flood control, it may be necessary to install the sediment scouring sluice separately from the bottom outlet to secure the certainty of the gate operation.

It is necessary to set up trashracks at appropriate openings to prevent clogging and debris damage to regulating gates. Engineering manual of USACE (EM 1110-2-2400) is recommending to set up simple trash structure, usually of reinforced concrete, with clear horizontal and vertical openings not more than two-thirds the gate width at the upstream end of the bottom outlets. Figure 6 shows trash structures of Prado dam. Trash boom constructed of logs or floating pontoons is also recommended to capture floating trash and debris.

According to the experience of MCD, it is necessary to install at least two conduits so as to allow inspection during low flow periods in which all the flow is diverted to the other conduit(s) since in case that the conduits have been completely blocked, intentional inspection of the conditions of the conduits is needed.

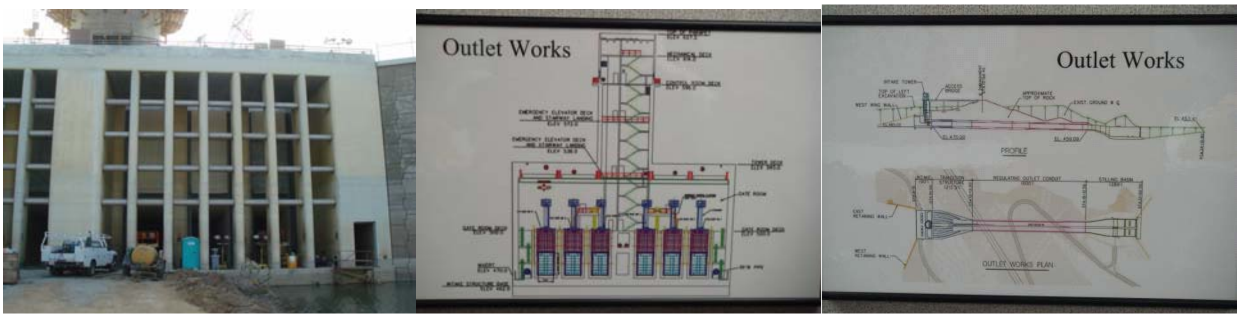


Figure 6 Prado dam bottom outlet and trash structures
(Openings of Trash structures: B1.83m×D1.95m, Gate width: B=3.02m)

4.2 Stilling basin

According to the experience of MCD, the stilling basins are recommended to be built "in-ground" to provide the necessary staggered drops needed to dissipate the outflow water velocity. The openings of the bottom outlets are built at the elevation in which the original low-level flow of the rivers would be able to pass through the outlets. "In-ground" stilling basin is friendly for fish migration since there is no obstacle on the river surface. In such design, some sedimentation problems may occur in the stilling basin between flood events. But once a high flood occurs, the deposited sediment can be easily flushed out. Figure 7 shows "In-ground" stilling basin of Taylorsville dam of MCD.

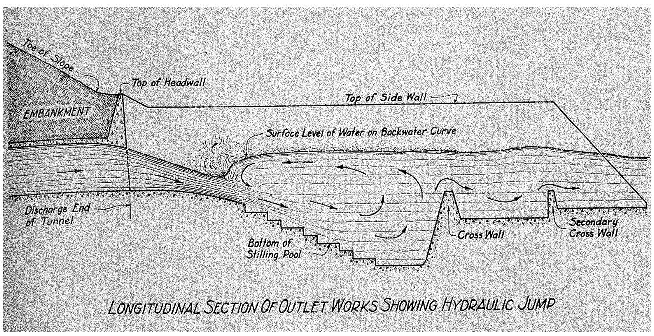


Figure 7 Stilling basin of Taylorsville dam

5. RESERVOIR SEDIMENT MANAGEMENT OF DRY DAMS

5.1 Reservoir sedimentation

Dry dams may have advantage on reservoir sedimentation since almost all inflow sediments can pass through bottom outlets during each flood events. Difference of reservoir sedimentation between conventional impounding dams and dry dams can be summarized as shown in Table 2.

Table 2 Difference of reservoir sedimentation between impounding dams and dry dams

Dam type	Impounding dam	Dry dam
Planned sedimentation volume	Prepare 100 years sedimentation volume for almost all inflow sediments	Sedimentation volume can be reduced by periodical sediment flushing during natural draw down period after flood impounding
Effects on continuity of sediment transport	Sediment trap rate is generally 80-90% though it depends on the turnover rate of water and sediment grain size.	Sediment trap rate is generally 10-20% though it depends on the turnover rate of water and sediment grain size.

In Japan, reservoir sedimentation of dry dams should be prepared as the following procedure. Total sedimentation volume is a) + b).

a) 100 years' total volume of deposited sediment that is calculated by the one dimensional numerical model for deposition and flushing of reservoir sediments.
b) Temporal volume of deposited sediment by the design flood on top of the final river bed of 100 year's calculation obtained by a).

In case of Masudagawa dam, a) and b) are estimated as 230,000m^3 and 20,000m^3 respectively, and total sedimentation volume of 250,000m^3 is 11.8% of total inflow sediment volume of 1,950,000m^3.

Sedimentation in dry dams may be different depending on reservoir configuration as well as the scale of the flood, the amount and the grain size of the inflow sediment and so on. Figure 8 shows actual sedimentation of Orden dam in Switzerland. Relatively coarse sand and gravel have been deposited in reservoir area and channel erosion can be observed. From the hydraulic model study, continuous channel excavation was recommended to prevent excess sedimentation but it seemed to be no such management works.

Figure 8 Reservoir sedimentation of Orden dam in Switzerland
(Left: From dam to upstream view, Middle: Aerial view, Right: From upstream to dam on the model study)

Figure 9 shows actual sedimentation of Mount Morris dam. Relatively fine silt and sand have been deposited in reservoir area and channel erosion can be also observed.

Figure 9 Reservoir sedimentation of Mount Morris dam in USACE Buffalo District
(Left: Channel erosion, Right: Sediment deposited just upstream of dam is periodically dredged)

5.2 Environmental impacts to downstream river

Generally, dry dams have also advantage on environmental impacts to downstream river since there may be almost no change in water quality and sediment transport in river with and without dams, rather than conventional normally impounding dams. But if we consider these points more detail, there still remain so much unknown factors. For examples, some amount of sediment will be deposited in reservoir area during severe flood times and be gradually eroded afterwards which may cause turbidity problem to the downstream river.

Kashiwai (2006) has conducted a study on sediment transport through dry dams. Figure 10 shows one of these results. Fine sediments such as silt and clay can be discharged in almost the same concentration as the inflow one according to the same timing. However, relatively coarse sediments such as sand and gravel may be discharged in a low concentration a little delaying from the inflow one. This delay may cause sedimentation in reservoir and sediment deposition in the downstream river channel.

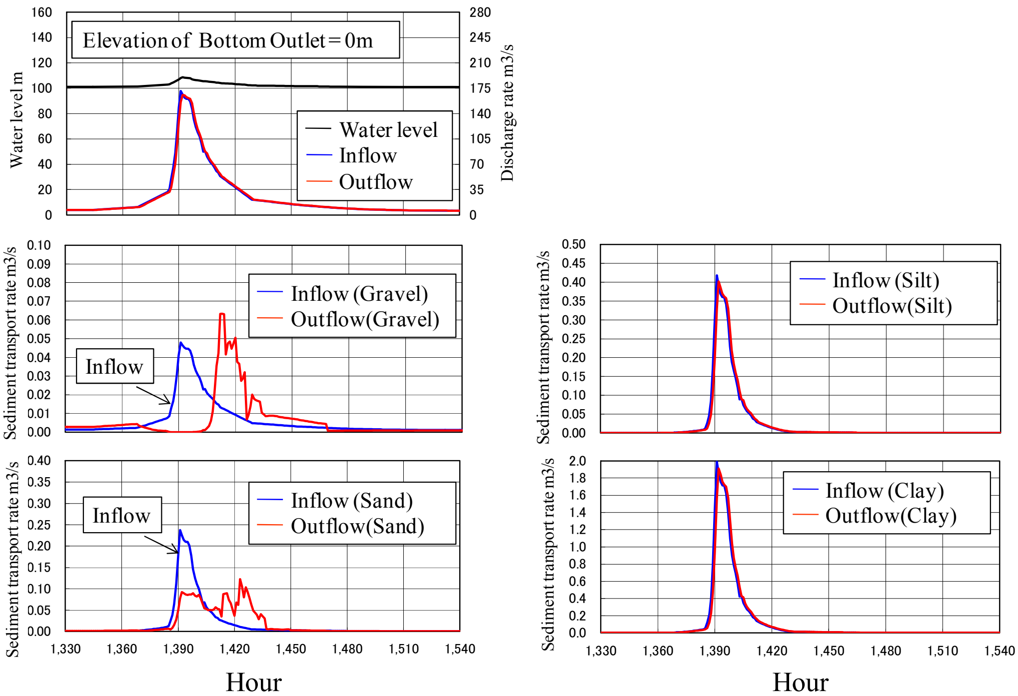


Figure 10 Changes on sediment fluxes depend on sediment grain sizes (Kashiwai, 2006)

The turbid water discharge may also become a problem if the deposited sediments in the reservoir include large amount of fine materials. Difference of these environmental impacts to downstream river between impounding dam and dry dam relating reservoir sedimentation is summarized in Table 3.

Table 3 Difference of environmental impacts to downstream river between impounding dam and dry dam relating reservoir sedimentation

Dam type	Impounding dam	Dry dam
Water turbidity	Usually clear, but long-term turbidity may occur after large floods if inflow sediment contains very fine particles hard to settle.	Usually clear, but short-term turbidity may occur during flood latter term because once deposited sediment is re-suspended along with the reservoir drawdown. Turbidity may also occur because of sediment erosion during small and middle floods or gully erosion on the sedimentation created by the heavy rainfall.
River morphology	River morphology may largely change by river bed degradation and armouring. Sand bar and river channel may be fixed and severe vegetation growth may occur in the river channel.	Deposition of fine materials may occur on river bed surface after floods.

5.3 Future challenges on reservoir sedimentation management of dry dams

Dry dams are much more advantageous than usual impounding dams in the point that sediment is not trapped as much as possible. However, as shown in the case of Orden and Mount Morris dams, some sedimentation will occur depend on the reservoir condition.

To predict the ultimate sedimentation volume in dry dams, one dimensional sediment deposition and erosion model should be studied. RESCON model based on the following Atkinson's formula to assess reservoir sustainability by sediment flushing may also be useful. Figure 11 shows schematic diagram and Eqs.1, 2 and 3 show the formula where SBR (Sediment Balance Ratio)>1.0 and LTCR (Long Term Capacity Ratio)>0.5 are requested for reservoir sustainability.

$$SBR = \left(\frac{Q_s T_f \cdot 86400}{N} \right) \Big/ M_{in} \cdot TE \qquad (1)$$

$$LTCR = \frac{B}{A+B} \qquad (2)$$

$$Q_s = \Psi \frac{Q_f^{1.6} S^{1.2}}{W_f^{0.6}} \qquad (3)$$

$$W_f = \alpha Q_f^{0.5} \qquad (4)$$

where, Q_s=Flushing sediment volume(t/s), T_f=Flushing duration (day), N=Flushing interval (year), M_{in}=Annual sediment inflow volume (t/year), TE=Sediment trap ratio by the Brune curve, Q_f=Flushing discharge (m^3/s), S=River bed slope, W_f=Erosion channel width (m), Ψ and α = constants.

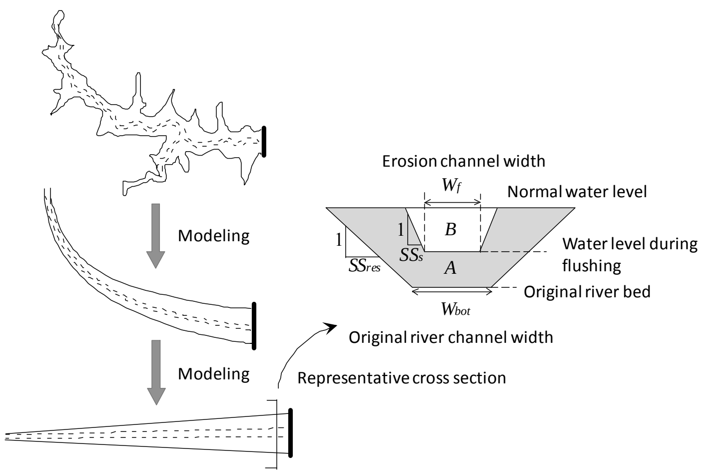


Figure 11 Schematic Diagram of the Atkinson's Formula for Sediment Flushing

In RESCON model based on the Atkinson's formula, Ψ mainly depends on data obtained in China as Ψ = constant such as Loess sediment; 1500, D_{50}<0.1mm; 650, $D_{50}\geq$ 0.1mm; 300, small flushing discharge; 180. Regarding W_f, α=12.8 is also proposed in Chinese reservoirs. As Atkinson has already pointed out, Q_s is calculated much larger than actually expected in other reservoirs outside of China and he recommended one third of these values. From Japanese experiences, Ψ and α should be modified in case for relatively steep rivers with coarse river bed materials.

Sumi et al.(2005) examined Ψ by the following equation with existing sediment transport equations and field data.

$$\Psi(d, S, Q_f) = K \cdot d^a \cdot S^b \cdot Q_f^{\ c} \tag{5}$$

where d=sediment grain size, K, a, b and c = constants. By comparing Eq.5 with bed load transport by Ashida-Michiue formula, and suspended load transport by Lane-Kalinske formula for concentration profile with the equilibrium concentration derived from Ashida-Michiue formula, Eqs. 6 and 7 were obtained for bed load Ψ_B and suspended load Ψ_S where d=0.1～2.0mm, S=1/50～1/500, Q_f=30～400m^3/s, W_f is obtained by Eq.4 as α=6 which is generally used in Japan, Manning's roughness n=0.030, density of sediment σ=2.65 (t/m^3).

$$\Psi_B = 12.7 d^{-0.043} S^{-0.11} Q_f^{-0.33} \tag{6}$$

$$\Psi_S = 0.042 d^{-2.6} S^{-0.35} Q_f^{\ 0.073} \tag{7}$$

Finally, Ψ is described as follows.

$$\text{Loess sediment;} \quad \Psi = 1500$$

$$d < 0.1\text{mm;} \quad \Psi = 650/3$$

$$0.1\text{mm} \leq d\,; \quad \Psi = \Psi_B + \Psi_S = 12.7 d^{-0.043} S^{-0.11} Q_f^{\ -0.33} + 0.042 d^{-2.6} S^{-0.35} Q_f^{\ 0.073} \tag{8}$$

In dry dams, it is very much important to predict Q_s by assuming T_f, N, Q_f *and* W_f since every flood events can be counted for flushing events but flushing discharge is always smaller than inflow discharge. How to set up TE is also a question. It is, therefore, important to pick up significant flood events and assume these values based on each hydrograph for the calculation. In dry dams, SBR>1.0 and LTCR>0.5 will be easily secured. However, if reservoir area is very wide (that is W_{bot} is larger than W_f), LTCR may be dropped.

In order also to predict turbid water discharge, deposition and re-suspension model of fine materials is needed. Through these studies, optimum design and operation of bottom outlets to minimize sediment deposition, especially fine materials, should be examined.

6. Conclusions

This paper discuss on type classification, structural and hydraulic design, sediment management, quality of discharge water and so on of flood retention dry dams in Japan and USA. From the sustainable management of reservoirs and river environment, these sedimentation free reservoirs may be one of good solutions in dam engineering.

Major conclusions are as follows.

1) The flood retention dams can be classified from the viewpoints of 1) installing regulating gates in bottom outlets or not and 2) securing continuity of the river through these outlets or not. Masudagawa dam in Japan and five dams of MCD (Miami Conservancy District) in USA are categorized into the simplest 'Dry dam' that gateless outlet is installed in the riverbed level where fish migration and sediment continuity can be secured.
2) In hydraulic design of dry dams, trashracks at appropriate openings to prevent clogging and debris damage to regulating gates of bottom outlet and "In-ground" stilling basin that is friendly for fish migration might be considered.
3) Dry dams may have advantage on reservoir sedimentation and environmental impacts to downstream river since almost all inflow sediments can pass through bottom outlets during each flood events. However, studies on reservoir sedimentation and fine sediment discharge are needed to secure appropriate sedimentation capacity and to obtain optimum design and operation of bottom outlets.
4) To predict reservoir sedimentation of dry dams with the Atkinson's formula, it is necessary to consider periodical sediment flushing from bottom outlets and to modify for relatively steep rivers with coarse river bed materials.

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