Worldwide Flood Mitigation Dams: Operating and Designing Issues

T. Sumi[1], S.A. Kantoush[1] and A. Shirai[2]

[1] Disaster Prevention Research Institute, Kyoto University, Goka-sho, Uji-shi, 611-0011, Japan

[2] Water Resources Environment Technology Center, 2-14-2, Kojimachi, Chiyoda, Tokyo, 102−0083, Japan

E-mail: sumi.tetsuya.2s@kyoto-u.ac.jp, kantoush@yahoo.com, shirai@wec.or.jp

Abstract

Worldwide dams designed only for the purpose of flood mitigation have different definitions and classifications. In USA they are called “Dry dam”, in Austria “flood retention basins”, (“Hochwasserrückhaltebecken” in German), in Japan “in stream flood control dam” (Ryusuigata dam, Japanese), others “Flood Mitigation Dam” (FMD). It is one of good solutions in dam engineering for sustainable management of reservoirs, downstream river environment, and sediment transport. The paper summarizes field investigations for several flood mitigation structures in Styria river basins (Austria) and comparison between Austrian and Japanese experiences, from several points of view 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. There is direct relation between the flood magnitude and the necessary level of dissipation by the stilling basin. During high magnitude of flood the stilling basin should be more vulnerable to the impacts of flooding. An optimal stilling basin geometry with acceptable flood risk therefore requires a holistic approach, addressing the flow parameters, design flood, upstream water level in the reservoir, dissipation energy, rivers, ecology and flood inundation as well as the human and socio-economic issues of planning, development and design.

Introduction

Flood mitigation dam (FMD) is a gateless outlet dam designed only for the purpose of flood control which provides long-term and efficient protection against floods. FMD is one of good solutions in dam engineering for sustainable management of reservoirs, downstream river environment, and sediment transport. FMD is expected as environmentally friendly, since almost all incoming sediment during flood periods can pass through dam bottom outlets that designed at the original river bed level and there will be fewer impacts to downstream river environment.

Lempérière, (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’. There are still several unknown factors such as sediment trap rates, patterns and flow regimes in the upstream of the dam, number of bottom outlets, and stilling basin dimensions (height, length, width), depending on flood hydrograph and water level.

Currently FMDs have different definitions and classifications. Several definitions for the same hydraulic structure in different countries and languages are given. There is a need for detailed design and operation guidelines coupled with research on biodiversity enhancement, reliability, economics, and social acceptance. Figure 1 shows the relationship between gross storage capacity and dam height of FMD in Japan, Switzerland (Orden dam) and USA. Because of geographical conditions, there is large difference between dams. Reservoir capacities to dam height of dams in USA are very large since they constructed in mild river slope and wide valley.

In the Japanese rivers, the flood wave propagates rapidly increases and decreases in a short period, the peak discharge can be significantly reduced by using small storage capacity. Therefore, an effective way to mitigate floods in Japan is to combine reservoirs and river restorations (Sakurai et al. 2009). In Japan, small FMDs less than 1 million m^3 as shown in Figure 1 have been constructed from 1950s to protect mainly farmland against floods. Recently, relatively large dams for flood mitigation for urban areas have been planned and constructed. Masudagawa dam is one of them. In case of large reservoirs, careful attentions should be paid for hydraulic design, reservoir sediment management, ecosystem and land management, and water quality and clogging of bottom outlets. They are summarized in Figure 2.

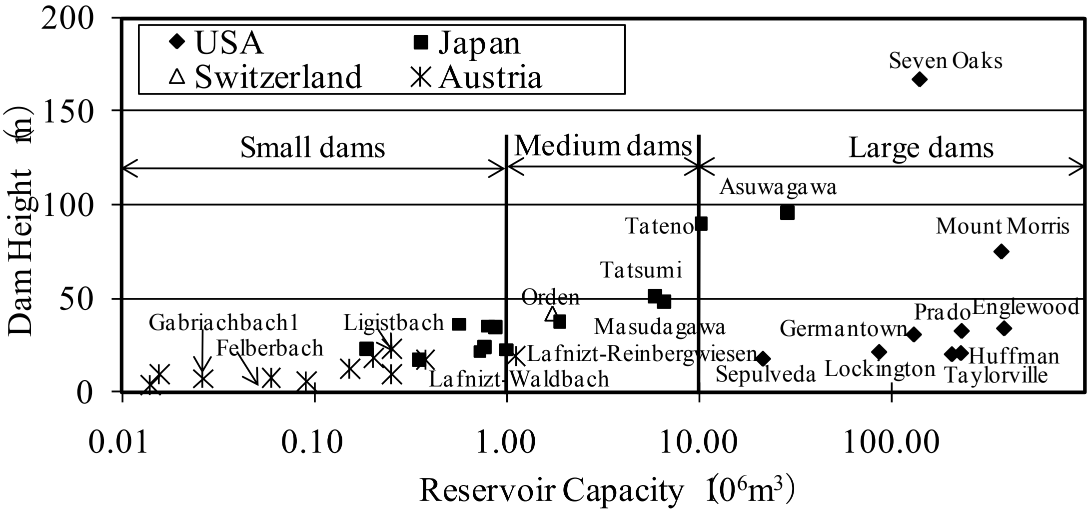

Figure 1: Classification of worldwide FMD based on reservoir capacity and dam height

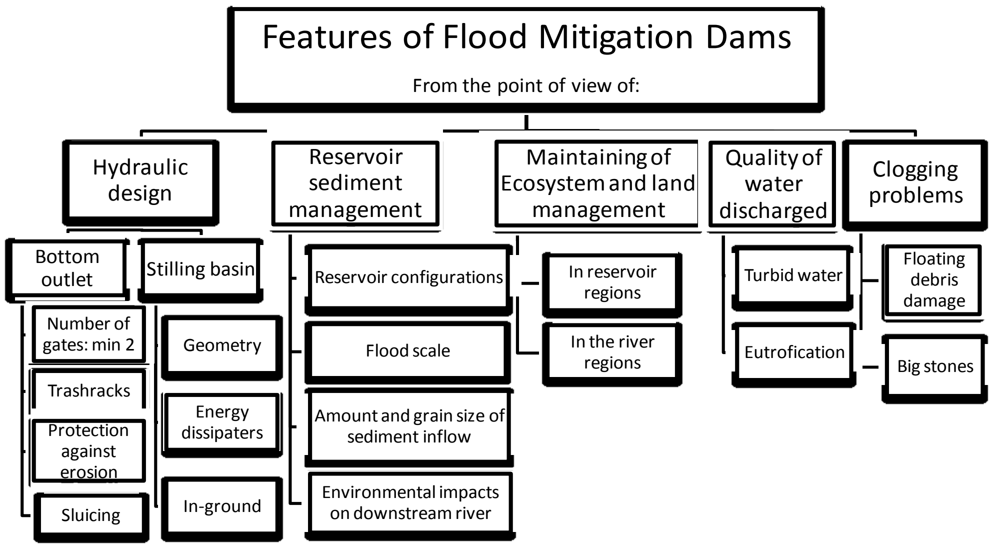

Figure 2: Features of designing and operating of flood mitigation dams.

Field Investigation in Styria, Austria

Key parameters

In the republic of Austria, Styrian government has actively constructed FMD from 1960s. More than 100 dams are located at small tributaries nearby city of Graz and mountain regions. In 1992, an interesting guideline for planning, designing and operation of FMD which explains engineering, economical and ecological aspects is published. In order to determine and characterize all relevant and particularly the key classification variables for FMDs in Japan and Austria, Table 1 summarizes these key points: rainfall; dam height, dam length; dam arrangement- concentrated or distributed; construction material, fish passage; screen system; basin and channel connectivity; design flood frequency; outlet arrangement; gate operation; catchment size; stilling basin design; and landscape planning and aesthetic.

Table 1: Classification and comparison of Flood Mitigation Dams in Austria and Japan

Item	Austria	Japan
Names of field investigation flood mitigation basin and dams	12 dams (Bärndorfbach, Dobelbach, Felberbach, Gabriachbach1 & 2, Labuchbach, Lafniz-Reinbergwiesen, Lafniz-Waldbach, Ligistbach, Sauhalt-bach, Stullneggbach, Gamlizbach)	8 dams (Sotomasuzwe, Rentaki, Kawachi, Matsuo, Sagatani, Ootouge, Sasakura, Takaono)
Dam Height (min-max)	5.8-23.2 m	17-37.7 m
Dam Length (min-max)	84-241 m	63.6-169 m
Gross Capacity (min-max)	14,000-1,100,000 m^3	186,000-6,500,000 m^3
Catchment area	0.8-162 km^2	5.5- 16.8 km^2
Dam arrangement in river basin	Distributed set of dams	Concentrated dam
Mean Annual Rainfall	865 mm/yr	1700 mm/yr
Utilization of reservoir area	Playground, habitat	Playground
Fish passages	Well design (Stepped ladder with natural sun light)	Under development
Screen system design	Bar pitches are designed by guideline	Under development
Design Flood frequency	Return period is 30-50 years	Return period is 80-100 years
Outlet Arrangement	Only one with bypass outlet for emergency	Usually two bottom outlet
Gate Operation	With gate (Automatic and Fixed opening)	Usually gateless
Stilling basin design	In-ground stilling basin and hydraulic jump	Hydraulic jump with end sill
Construction material	Earth fill with concrete outlet sections	Mainly concrete for gravity dams
Landscape planning	Well match with nature	Under development
River and basin bed gradient	Mild slope	Steep slope
Sediment load	Medium sediment yield	High sediment yield
Reservoir sedimentation	Less deposition	Less deposition

The examined Styrian basins capacities range from 14,000 m^3 to 1,100,000 m^3, the dam heights are between 5.8 m and 23.2 m, and they were all earth fill dam combined with concrete outlets. While the Japanese Flood mitigation dam heights are between 17m to 37.7 m from concrete, the reservoir volume is ranging between 186,000-6,500,000 m^3. During our visit, we have discussed several unique points in Styrian case studies which will be very much valuable to improve performances of FMDs.

Unique points of Styrian flood mitigation dams

1- Bottom outlet design

Based on the guideline, bottom outlets are all gated. They are classified into (a) fixed small gate opening, (b) closed gate with small gate opening section, and (c) circular small diameter with automatic gate as shown in Figure 3. All gates are designed large enough for maintenance.

Figure 3: Bottom outlet design: (a) Lafiniz-Waldbach, (b) Ligistbach and (c) Labuchbach.

2- Safeguard for clogging of bottom outlet

Preventing from clogging by floating woods or big stones, all bottom outlets are covered by screens. These bar pitches are ranging from 15 to 50 cm based on design discharge of bottom outlets as Figure 4. These screens are installed at not only inlet level but also on top of the bottom outlets to maintain enough discharge for safeguard. Periodical cleaning or screen design modification is requested because unexpected water storage is occurred by sediment and tree leaves trapping (Figure 5).

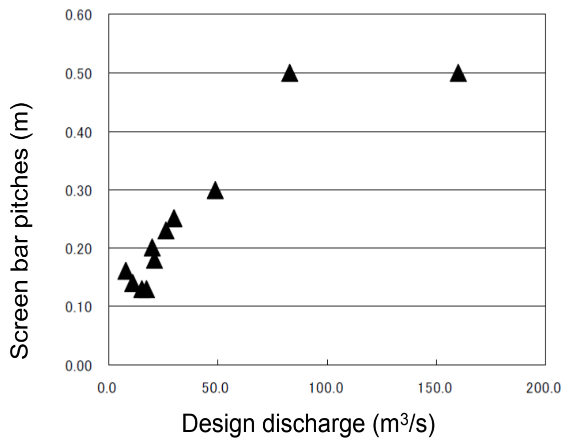

Figure 4: Screen bar pitches based on design discharge of bottom outlets

Figure 5: Screen bar design, and sediment and tree leaves trapping in front of a bottom outlet

3- Fish passage
Bottom outlets are also designed for fish passage. Big stones or stepped pools are used to create natural stream in the channel by reducing velocity (Figure 6). Natural sunlight is also introducing to the channel by mesh opening at both upstream and downstream sides.

Figure 6: Bottom outlet design for fish passage by using natural stones and stepped pools

4- Reservoir area design
Total landscape design in reservoir area is well discussed with local communities and experts. Biotopes are designed in reservoir area for river restoration (Figure 7). In a reservoir, swimming pool is created for recreational use.

Figure 7: Reservoir area and biotopes on the right side

Conclusion and Future Challenges

Recent flood events in Austria and Japan have shown the need for improved flood mitigation (retention) dams along the rivers. Therefore, several further research works is needed to update planning, designing and operating of flood retention dams. Flood mitigation dams (FMD) are considered eco-friendly because of their peak reduction reputation without rupturing the normal flow regime of the river. The FMD individualized and characterized for three future challenges parts have to be studied, reservoir area and the inlet, outlets and gate operation, and stilling basin with downstream reach of the dam.

1- In the upstream reservoir and the dam inlet: During the flood discharge retardation, the characteristics of sediment (sand and gravel) outflow rate are changeable and unknown compared with the normal stage. The degree of change varies according to flood control plans, inflow sediment properties, and scale of the flood, so dams must be studied individually. Moreover, the development of a prediction and an optimum management measure of sedimentation in flood mitigation dams should be investigated.

2- Outlets and gate operation: As measures to mitigate changes of sediment transport properties, the geometry of the outlet works and stilling basins should be further studied in order to smooth the fish and sediment passages at the end of the flood period. The most effective approach is to accept variability of the reservoir water level less frequently within a range that satisfies flood control plans. By expanding the cross-section of outlet works installed on the elevation of riverbeds, it is possible to raise the reservoir level less frequently. But, in Japan, the peak cut rate of flood at dam site is generally large, so in order to achieve a flood control plan, it is necessary to make the outlet works section small when the reservoir water level is raised. The measure that is considered at this time is to install large outlet works for sediment discharge and separate small outlet works for flood control, and switch over from the former to the latter during flood control. To rationalize equipment and simplify its operation during a flood, at normal times, a large cross-section ensures the movement of sediment, stream, and aquatic life. But for flood periods, discharge equipment that permits the operation of gates to reduce the flow section, thereby controlling the flood discharge, should be developed. In that sense, automatic gate in Styrian examples are one of possible solutions for small discharge.

3- Stilling basin and downstream reaches: To improve current design method of outlets and stilling basins effective dissipation of energy, optimal design of stilling basin leading to optimal geometry is required. The main question is what are the optimal SB configuration and upstream conditions to maximize the energy dissipation (ΔE), fish passage and minimize the cost? An optimal stilling basin geometry with acceptable flood risk therefore requires a holistic approach, addressing the flow parameters, design flood, upstream water level in the reservoir, dissipation energy, rivers, ecology and flood inundation as well as the human and socio-economic issues of planning, development and design.

Acknowledgements

Authors express their gratitude to Mr. Rudolf Hornich for his kind guidance in our field trip and participation to the symposium on Flood Mitigation Dams in Tokyo in 2010.

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