INFLUENCE OF STILLING BASIN GEOMETRY ON FLOW PATTERN AND SEDIMENT TRANSPORT AT FLOOD MITIGATION DAMS

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Abstract Recent flood events in Japan and social conditions have shown the need for improved flood mitigation (retention) dams along the rivers. In response, a research project is established to study updated 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. In the frame work of a research project, the FMD individualized and characterized for three parts, inlet upstream of the dam, outlets, and stilling basin with downstream reach of the dam. The approach appeared efficient to help flow and sediment practitioners, and ecologists work together, and find technical solutions complying with both flood mitigation and biodiversity preservation requirements. The present paper analyses the stilling basin design of flood mitigation dams with different configurations. The design of stilling basin geometry of flood mitigation dams in view of clear water flow is different when considering of suspended and bed loads transport. 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 study investigates the influence of the shallow basin geometry on flow and sediment deposition patterns. The effects of the geometry were investigated with systematic physical experiments, numerical simulation, and field data. This allowed identifying the optimal stilling basin shape of the flood mitigation dam that dissipate more energy, minimizes the deposition and reduces the number of horizontal recirculation cells. The results help to understand the influence of geometry on the flow stability, sediment deposition and flushing process in order to design the stilling basin geometry. The prediction of sediment profile lies in the prediction of flow pattern and, in turn, sediment deposits were able to change the flow structure.

Keywords: Flood mitigation dam, flood retention dam, dry dam, submerged hydraulic jump, stilling basin, Masudagawa dam, Miami Conservation District, ecosystem continuity.

INTRODUCTION

There are a wide range of hydraulic engineering solutions have been constructed for centuries to provide flood protections. These traditional approaches predominately utilize hard engineering solution to protect from overflows and ensure quick outflow of flood volumes. Rivers are channelized, diverted, straightened and corseted in levees, with little or no thought for river dynamics and biodiversity preservation. Recently, this is widely criticized (E.U. Commission, 2004). Firstly, accelerating the flow often results in turbid water discharge and significant erosions in downstream reach. Secondly, multipurpose dam interrupt the continuity of natural sediment patterns and change the flow regimes at the downstream reaches of reservoirs, hence causing erosion or deposits. And finally, the consequences on ecosystems are often disastrous. How to both protect citizens from floods and biodiversity from flood-management schemes is very important issue (Geilen et al., 2004). In Japan, numbers of new multipurpose dam construction projects are very limited.

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. Its bottom outlets are installed at the original river bed to facilitate the sediment transport during flood and flush out the deposited sediment at the end of flood. Therefore, FMD have less influence on reservoir sedimentation than a storage dam. 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.

Current General Definition and Classifications of FMD Dams designed only for the purpose of flood control have different definitions and classifications. In USA they are called "Dry dam", in Europe "flood retention basins", ("*Hochwasserrückhaltebecken*" in German), in Japan "in stream flood control dam" (*Ryusuigata dam*, Japanese), others "flood mitigation dam". Several definitions for the same hydraulic structure in different countries and languages are given. Such a loose defining FMD into one definition and one category frequently leads to legal disputes and misunderstandings between practitioners and the public. A classification scheme for FMD is therefore timely and urgently required to assist communication. There are various useful scientific attempts that are of potential relevance for a new engineering classification system. There is a need for detailed design and operation guidelines coupled with research on biodiversity enhancement, reliability, economics, and social acceptance.

A classification system is therefore needed to allow clear communication between stakeholders such as politicians, planners, engineers and environmental scientists. The absence of a universal definition and classification scheme for FMD leads to confusion about the status of individual structures and their functions. Scholz and Sadowski (2009) proposed a conceptual classification model based on 141 sustainable flood retention basins (SFRB) including 75 diverse wetland systems in the River Rhine Valley, Baden, Germany. Six SFRB types were defined based on the expert judgment of engineers, scientists and environmentalists. The German flood retention basin guidelines (ATV-DVWK 2001) distinguish between passive and automated, and small, medium and large sized flood retention basins. In Germany the complete design and therefore the design flood discharges (DFQ) and flood water levels (FWL) are depending on the classification of the basins in the four classes very small, small, medium and large basins. The classification according to (DIN 19700-12/2004) takes into account the height of the dams and the reservoir volume. The classification for flood retention basins according to mentioned code is given in (Fischer and Haselsteiner, 2008). Flood retention basins may also be either online or offline with respect to the local stream. Finally, the type of outlet is occasionally used as a classification criterion. Eighty flood retention basins contribute significantly towards minimizing flood hazard especially in small watersheds in the Land of Styria in the republic of Austria. Basins have been classified as small, medium and large according to capacities range from 5,000 m^3 to 1,650,000 m^3, the dam heights are between 2.0 m and 24.5 m. Sumi (2008) has classified FMD based on outlet arrangement: 1) installing regulating gates in bottom outlets or not and 2) securing continuity of the river through these outlets or not. 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.

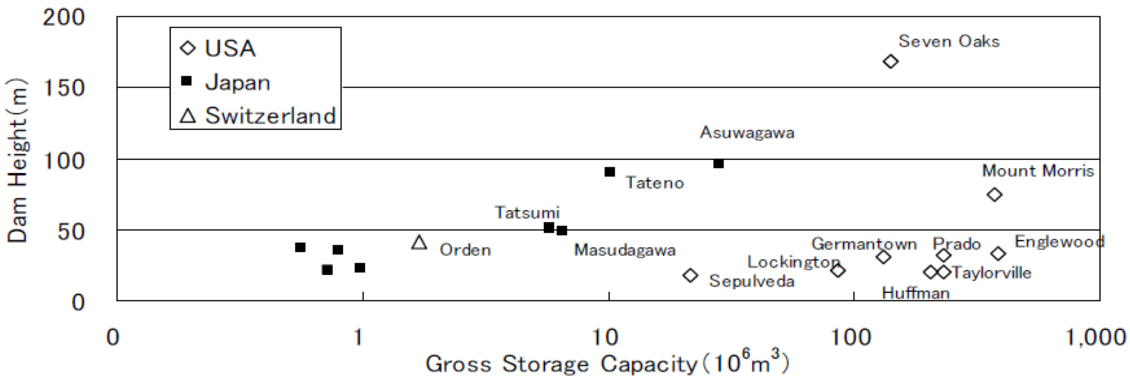

Figure 1 Gross storage capacity and dam height of FMD (Sumi, 2008).

In 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). Flood mitigation dams have several issues are summarized in Figure 2.

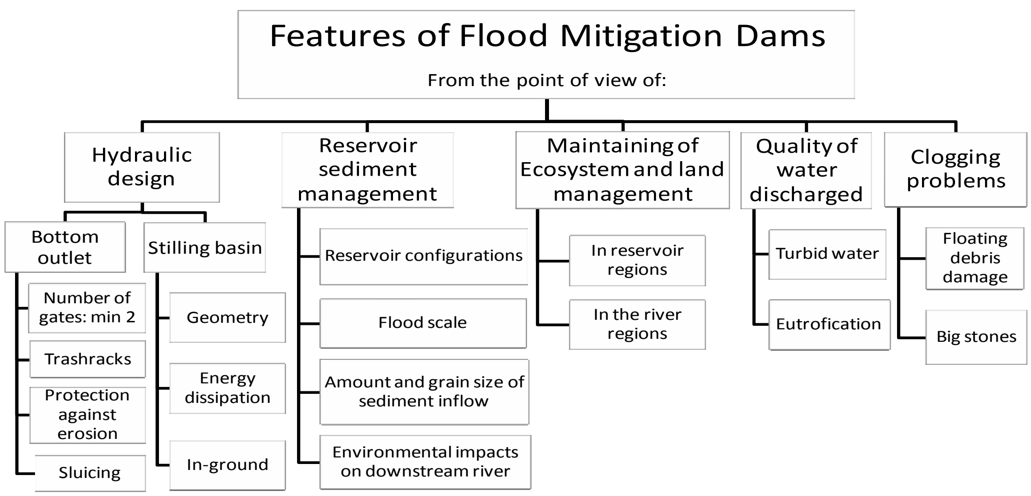

Figure 2 Features of designing and operating of flood mitigation dams.

The flexibility in the water levels within the reservoir is dependent on the probability of occurrence of Design Water Level (DWL) of 1/100 or 1/80. Therefore it is only indirectly dependant on the flood discharge within the river section. The retention effectiveness is based upon a flood event with varying occurrence probabilities. The annual recurrence for flood protection measures theoretically range from T = 5 to T> 100.

Finally some challenge aspects regarding the design, for instance number of dam outlets, and stilling basin dimensions are considered as specific design criteria respected unsteady flow and flexible water levels in the upstream reservoir. The stilling basin height and length shall be economically optimized by 3D numerical simulations, where the changeable water level and discharge are considered.

Design Methods of Stilling Basins and outlets of FMD The energy dissipation effectiveness of stilling basin is typically based on the probability analysis for possible water level, discharge rate, and the maximum velocity from the outlets. Flow separation and reattachment due to sudden changes in geometry in internal flow occur in many engineering applications such as in open channels, shallow reservoirs, groin fields and stilling basins. The occurrence of large-scale instabilities and consequent vortex formation in planar jets in various geometries has been studied by Kantoush (2008). In shallow flow both the limited depth and the bottom friction influence the development of the mixing layer (Kantoush et al. 2008a). A model was developed for obtaining the optimal dimensions of stilling basin and its appurtenances (Tung and Mays 1982).

In symmetrical geometries of stilling basins for a fixed and horizontal channel bed, and various expansions and aspect ratios, the hydraulic jumps have been classified by Rajaratnam and Subramanya (1968). Several ratios of the stilling basin width to the inlet channel width were analyzed by Sumi and Nakanishi (1991), which affect flow stability, necessary tailwater depth, and length for the hydraulic jump. A series of numerical simulations and compared with scaled laboratory experiments, to investigate the sensitivity of flow and sediment parameters were presented by Kantoush et al. (2008b).

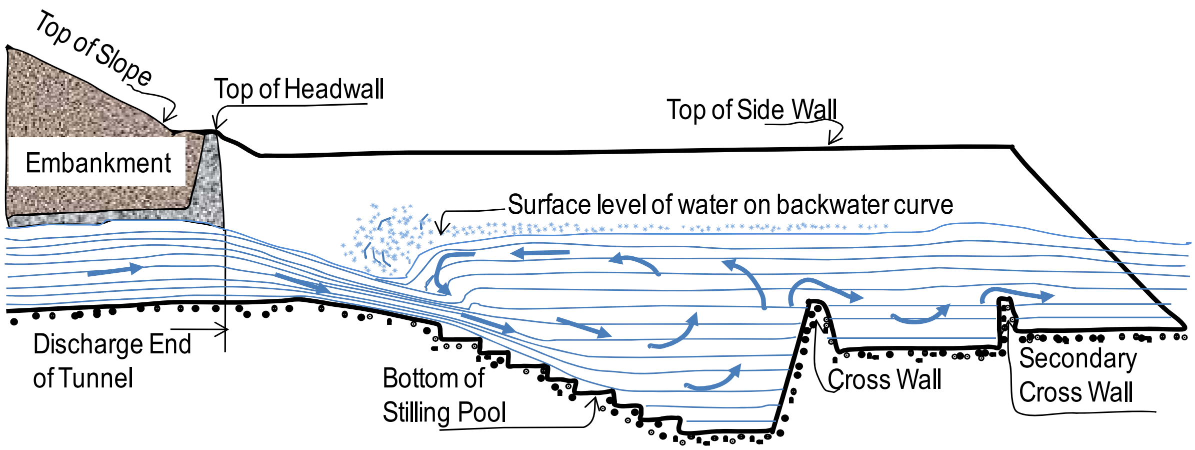

Figure 3 Concept of energy dissipation and flow pattern in stilling basin of Taylorsville dam longitudinal section of outlet works showing hydraulic jump.

According to the experience of MCD, Miami Conservation District, 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 3 shows in-ground stilling basin of Taylorsville dam of MCD. Stilling basins are external energy dissipaters placed at the dam outlet. These basins are characterized by some combination of baffle blocks and stairs designed to trigger a submerged hydraulic jump in combination with a required tailwater condition, assured by the secondary cross wall as shown in Figure 3.

Another example of stilling basin for Masudagawa dam, newly completed FMD in Japan is shown in Figure 4. Silts were installed for flushing sediment from the stilling basin and achieve fish passage functions. The stilling basin of Masudagawa dam dissipates the energy by hydraulic jump type equipped with an endsill to obtain appropriate tailwater depth. This type of energy dissipater is the most widely used in Japan where downstream water depth is usually small. The width of the stilling basin was designed according to the width of the downstream river (Kashiwai 2000).

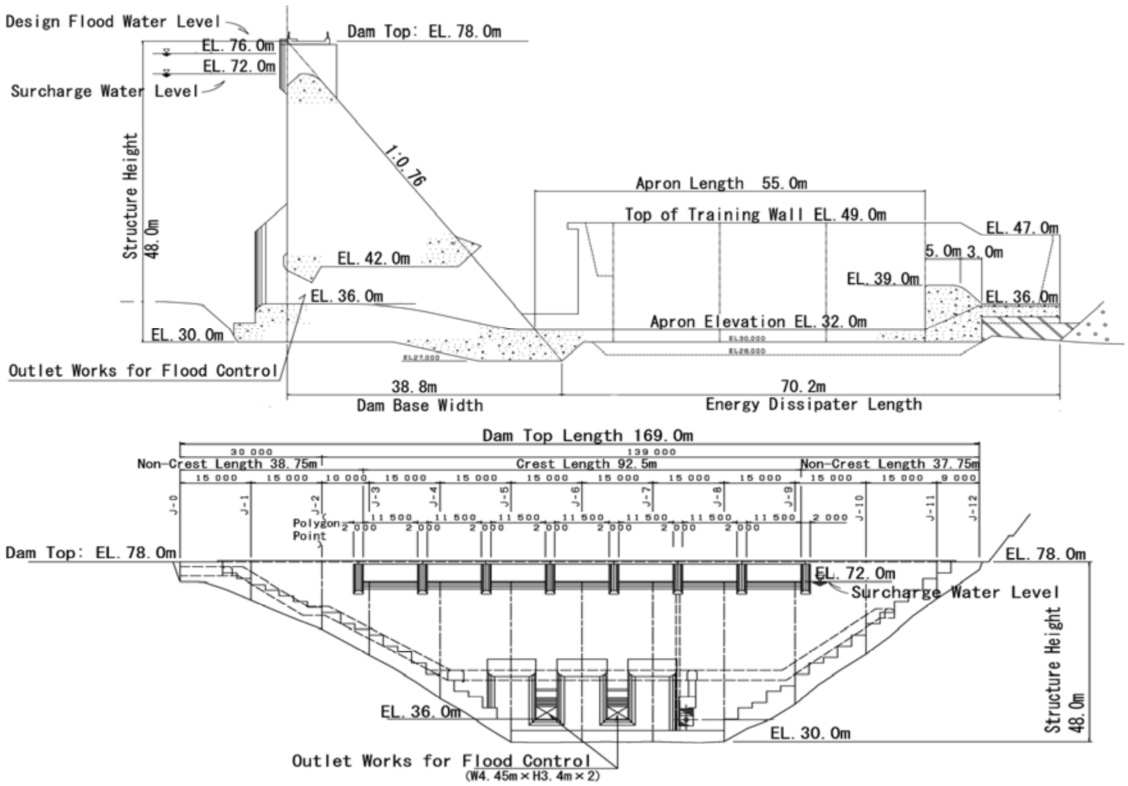

Figure 4 Configuration of stilling basin of Masudagwa dam.

However, the flow width from the bottom outlet of Masudagawa dams shows a narrow flow width comparing with the width of the downstream river. Kashiwai explained that a horizontal recirculation cells were formed at the sides of the inflow jet where there is a big difference between the inflow width and stilling basin width. These recirculation cells accompanied with sediment are harmful, downstream flushing is hampered and the apron and training wall are subject to wear and damage for long periods. During the first and last stages of a flood when the reservoir water level is reduced, a huge sediment outflow will discharge. While the increasing reservoir water level, the velocity will increase and large sediment will be deposited in the reservoir. Therefore, it is possible to minimize the damage by stopping the horizontal recirculation cells in the stilling basin during the high water level conditions.

Another type of stilling basin shall be studies in order to reduce the cost. For instance, a plunge pool lined with rock riprap or other material to prevent excessive erosion of the pool area. Discharge from the plunge pool should be at the natural streambed elevation. Typical problems may include movement of the riprap, loss of fines from the bedding material and scour beyond the riprap and lining. If scour beneath the outlet conduit develops, the conduit will be left and separation of the conduit joints and undermining may occur. Separation of the conduit joints and undermining may lead to failure of the spillway and ultimately the dam.

Objectives and Target Research Project Design of stilling basin of flood mitigation dams such as Masudagawa dam is governed by several parameters such as: number of bottom outlets, approach Froude number, basin geometry, and tailwater level. The study is focus on how to use the findings of the basic research study about influence of geometry to define the stilling basin in flood mitigation dam. Case of study for stilling basin of Masudagawa dam is shown in Figure 5.

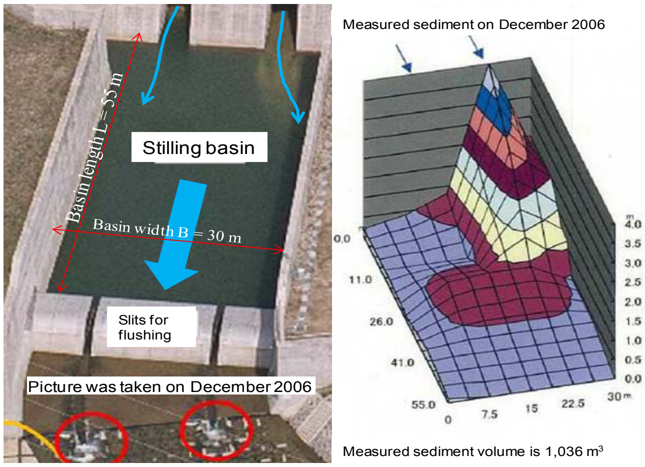

Figure 5 Masudagwa stilling basin (a) flow and deposition; (b) measured sediment and volume.

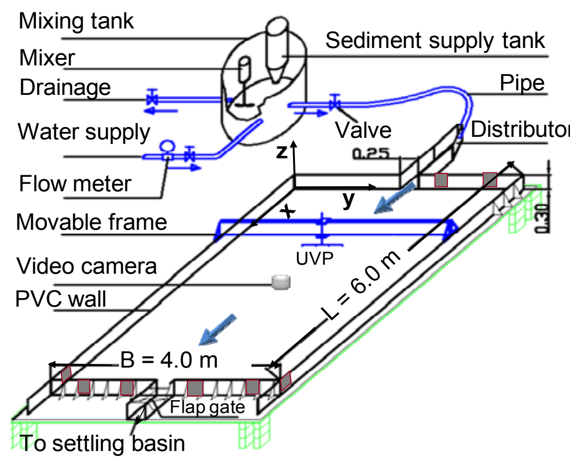

Figure 6 Schematic view of experimental facility installation.

A horizontal recirculation cells are formed at the sides of the inflow jet (Figure 5(a)). These recirculation cells accompanied with sediment are harmful. While the increasing basin water level, the velocity was increased and large sediment volume were deposited in the basin as shown in Figure 5(b). An asymmetric flow pattern with a low number of circulation cells is favorable to reduce the exchange processes between flow and sediment. Flow pattern with large stagnant zones allows a portion of flow to pass the basin in a time period less than the settling time. With the purpose of controlling the number of recirculation cells and deposition, the objective is also to gain deeper insight into the physical processes of sedimentation in shallow basins governed by suspended sediments. The findings will help designers of stilling basin of new FMD to decided appropriate geometry. To obtain an optimum design and operation of bottom outlets and stilling basin, 3D numerical modeling are carried out for different geometries. The main criterion for the different simulation is to find out which geometry dissipates more the energy and transport maximum volume of sediment over time.

EXPERIMENTAL AND NUMERICAL MODELS

The complexities associated with predicting the flow and sedimentation pattern in various basin geometries are emphasis the need of combination of the numerical results with the physical one, which helped to deeply understand the physics and the process of the sedimentation in the shallow basins. Sixteen experiments with clear water and water-sediment mixture were performed in a facility (Figure 6) at LCH of the Swiss Federal Institute of Technology (EPFL). The experiments have been conducted in a rectangular shallow basin, with inner maximum dimensions of 6 m in length and 4 m in width. The inlet and outlet rectangular channels are both 0.25 m wide and 1 m long. The influence of different shallow reservoir geometries, with variable widths and lengths has been achieved experimentally. To investigate the effect of basin width on the flow and sedimentation processes, first the 6 m long basin was performed. The width was then reduced successively from 4 to 3 to 2, to 1, and to 0.50 m. In a second step the effect of basin length was examined by reducing the length of the rectangular shallow basin from 6 m to 5, to 4, and to 3 m successively. Crushed walnut shells with a median grain size d_{50} = 50 µm, and a density of 1500 kg/m^3 is used.

Two dimensional depth-averaged flow and sediment transport simulations representing the experimental set-up have been performed with the numerical model CCHE2D, developed by NCCHE (National Center for Computational Hydroscience and Engineering) based on a variant of the finite element method (Jia and Wang, 2001). The model was used to predict river flow patterns and related bed and bank erosion for both uniform and non-uniform sediment transport. Both depth-averaged *k–ε* and eddy viscosity turbulence closures are available. CCHE2D was used for its capabilities to simulate suspended sediment transport.

Applicability of a three-dimensional computational method is examined when using a standard Smagorinsky model and assuming that the free-surfaces are fixed free-slip boundaries (Ushijima et al. 2009). The governing equations were solved with a finite volume method with a collocated grid system. Computations are performed for two geometries, case−3×4 and case−6×2, in which a pair of the lengths (L, B) are (3m, 4m) and (6m, 2m), respectively. The depth of water is 0.2 m in both cases. The average inlet velocity u_0 is 0.14 m/s. Additional zones were set up on upstream and downstream boundaries to simulate the channels used in experiments, whose longitudinal lengths are both 0.5 m. directions are 160×160×8 for case−3×4 and 280×80×8 for case−6 × 2 including the four boxes on the corners. All boundaries are treated as non-slip walls except top boundary that is a fixed free-slip wall. The computations start from initial static flow field at t = 0 to t = 1,000 s, with increment $\Delta t = 2.5\text{x}10^{-2}$ s. Since the grid-scale flow fields are obtained at each time step, the averaged results are calculated from t = 800 to 1,000 s. More details about 3D simulation can be obtained from Ushijima et al. 2009.

RESULTS AND DISCUSSION

Flow pattern with and without sediment The flow features and large–scale structures were investigated by using LSPIV measurement technique. Figure 7(a) shows an overview of the velocity field and behavior of large-scale coherent structures in clear water. A plane jet issues from the narrow leading channel and enters straight ahead in the first half meter of the wider basin. Then, the main flow tends to develop in a curved way towards the right hand side over the next two meters until it touches and follows the right wall. When separating from the right wall, the main flow induces a recirculation zone.

A main large stable circulation cell is generated in the centre of the basin rotating anticlockwise. Furthermore, two small triangular cells are formed rotating clockwise in the upstream corners of the basin. Figure 7(b) shows the second flow feature developed with sediment entrainment. The addition of sediment decreases the mixing length or increasing the eddy size of the right corner gyre with time. The flow becomes more stable and symmetric as shown in Figure 7(b). As a result of ripple formation and suspended sediment concentrations, the flow field is completely changed as shown in Figure 7(a) and (b). The gyres in the upstream corners disappeared (Figure 8) and a pattern emerges rather symmetric with respect to the center line.

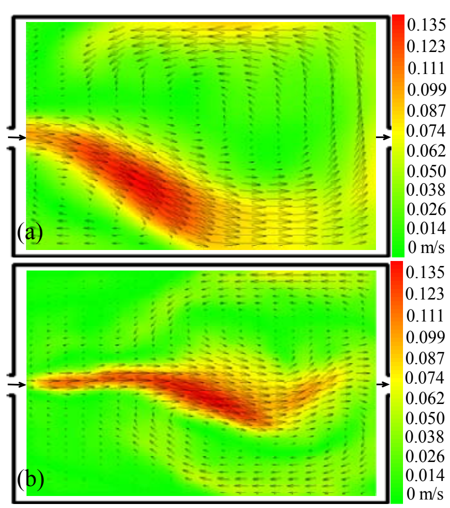

Figure 7 Time averaged flow pattern and velocity magnitude (a) clear water; (b) sediment entrainment flow.

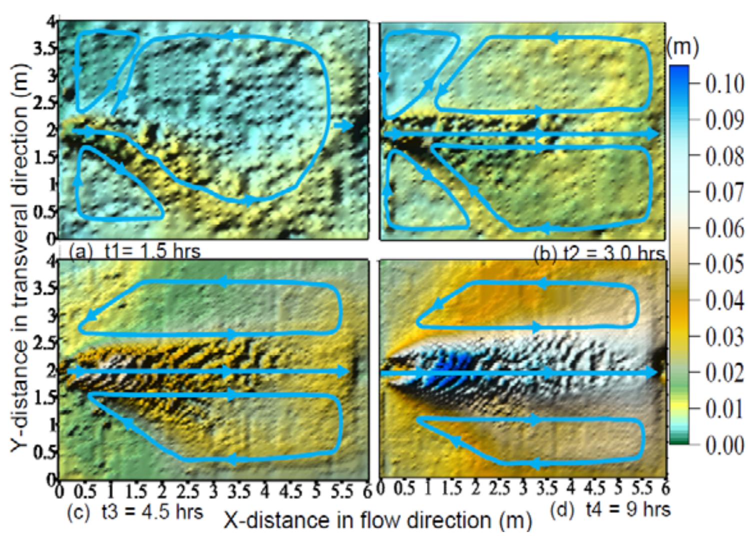

Figure 8 Long-term morphological evolution of deposition at 4 runs with Q =7.0 l/s, h = 0.2 m and sediment concentration C = 3.0 g/l.

The changes in the bed forms or effective roughness resulting from the sediment deposition can completely modify the overall flow pattern. As a conclusion, a strong interaction between flow field and bottom topography occurred in the basin inlet region with a quasi equilibrium state. There, most of the bed form features disappeared, as the deposition was fairly fast increased. Numbers of recirculation cells that exist in the basin have a strong influence on the flow and sediment deposition behavior. By increasing the numbers of cells the deposited volume of sediments in the basin increased. The bed morphology and the corresponding schematic flow field for the reference geometry are shown in Figure 8 for four different runs (1.5, 3, 4.5, 9 hrs) allowing a comparison of the long-term bed evolution in the rectangular basin. For all runs, two sedimentation behaviors were observed. First is the development of the sediment deposition developed with ripples formation concentrated on the right hand side till bed thickness deposition reaches up to 15% of the water depth as shown in Figure 8 (a). Then the sediment deposition concentrated along the centerline with relatively steep gradients near the inlet channel and the first part of the jet (Figure 8 (b)).

The footprint of the flow patterns was clearly visible in the morphology. However, the increased roughness height associated with mobile sediment may contribute to increase in shear velocity. A symmetric ripples pattern formed on the middle of the basin is clearly visible after 4.5 hrs (Figure 8(c)). After 9.0 hrs (Figure 8 (d)), the deposition on the center gradually increased generating a wider bed elevation underneath the jet centerline.

Influence Of The Basin Width Flow patterns and associated bed depositions after 4.5 hrs for reduced width basins of 3 and 2 m, are shown in Figure 9. The bed morphology for a reduced width of B = 3.0 m and 2.0 m have a uniform deposition rate over entire reservoir surface and symmetric ripple patterns as shown in Figure 9. During the first hour of the tests, the observed flow pattern was deviated to the right side. But, after two hours the asymmetric jet was flipped from right side to the left one as shown in Figure 9. The footprints of these previous stages of the flow patterns are clearly visible in Figure 9(a).As a result of the asymmetry flip flop from one side to the other, bed forms persisted throughout the alternately deflected jet.

An asymmetric flow pattern has been observed for all reduced width geometries. Hence, the reservoir width did not affect the asymmetric separation of the deflected jet. However, the size of center and the upstream corner eddies were in accordance with the width. By reducing the reservoir width, the decelerating of the deviated jet is reduced. Final deposition patterns were affected by the reservoir width, with more symmetric and uniform distributions on the entire surface, and concentrated deposits on both sides.

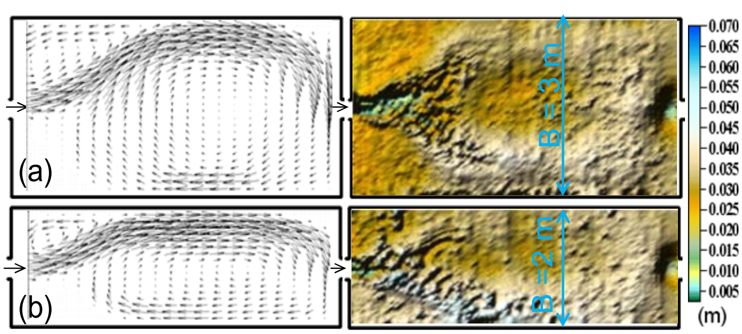

Figure 9 Flow patterns, (left) and evolution of deposition, (right) for reservoir width (a) B = 3.0 m, (b) B = 2 m, at 4.5 hrs.

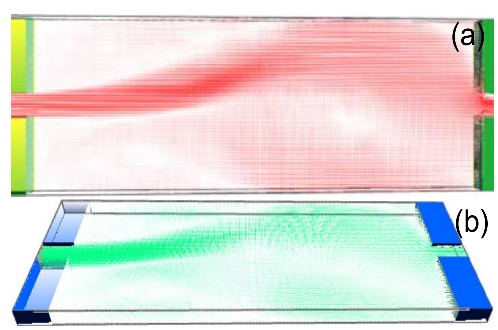

Figure 10 Predicted results on top boundary (case−6×2) (a) averaged 2D flow pattern (b) averaged 3D flow pattern.

Figure 10(a) shows the view of the calculated results in case−6×2, which are averaged values during the above time period. As shown in this figure, while 3D results are obtained in the predictions, 2D velocity fields on top boundaries are mainly used in the comparisons with experiments. On the other hand, Figure 10(b) shows the similar 2D flow patterns for case−6×2. In this case, non-symmetric patterns appear in both experiments and predictions. Whilst the main flows attach on the left-hand side in the computations, which is upside-down compared with experiments, it is not an essential problem, since the attached side is not deterministic depending on the instabilities in the flows.

Comparison of numerical and experiments with clear water of reduced width (B = 2 m) Figure 11 shows the predicted unsteady flow patterns for case−6 × 2 on the top boundary. As shown in that figure, the incoming flows impinge on the downstream side and then flows deviate to the left with three circulation cells. A clear organized eddy motions are found in the snapshots of Figure 11, the overall flow patterns are preserved until 1,000 sec. This results in the averaged velocity field shown in Figure 10(b), which is asymmetric similarly to the experiments shown in Figure 9(b). The development of non-symmetric flow patterns for case−6×2 is visible. As shown in Figures 11 (a) to (d), the initial average flow field is approximately symmetric, while a large circulating flow arises after around t = 250 s. and then the flow pattern become non-symmetric.

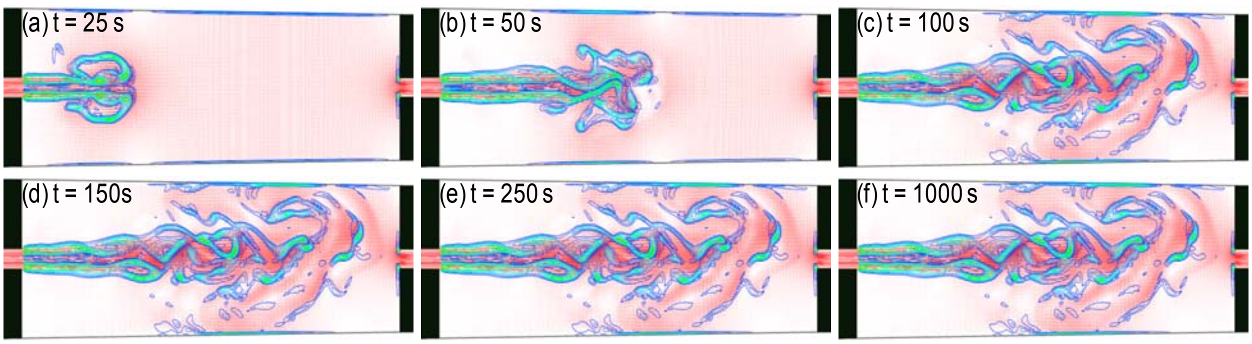

Figure 11 Predicted flow patterns and isolines for 2D vorticities on top surface (case−6×2).

INFLUENCE OF BASIN LENGTH

Influence of sediment transport The average flow field and the corresponding bed morphology contours after 4.5 hrs for the reduced reservoir length are shown in Figure 12. In the first ten minutes for reduced basin lengths with sediment entrainment, the flow is symmetric with one circulation cell on each side. The reduction of horizontal cells takes place with sediment transport. As sediment is added to the flow, the turbulence is reduced together with increasing roughness, cause an increase in velocity gradient when compared to clear-water flow. The turbulence was generated locally by the horizontal entrainment of a mixture into the basin with stagnant water. The jet pulse created a region of 3D turbulent flow, characterized by mixing and entrainment. Then the size of the turbulence increased rapidly. During the subsequent stage of sediment settled down, the horizontal motions are suppressed and the mixed region becomes flat and the motion becomes quasi vertical. Figure 12 (b) shows a high sediment deposition in the center under the jet and low deposition near the walls under the reversed jet.

Comparison of numerical and experiments with clear water of reduced length (L = 6, 3 m) The time-averaged of measured and computed flow fields are depicted in Figures 13 (a), (b) for reduced basin length of L= 6 and 3 m, respectively. Asymmetry disappears when the basin length is reduced less than 5.8 m, as illustrated by Figures 13 (a), (b). For a better approximation of turbulent eddies and jets formation, it is recommended to use a more detailed model for horizontal turbulence. For instance techniques such as Large Eddy Simulation or fully 3D approaches may be considered as shown in previous section 3D computational attempts.

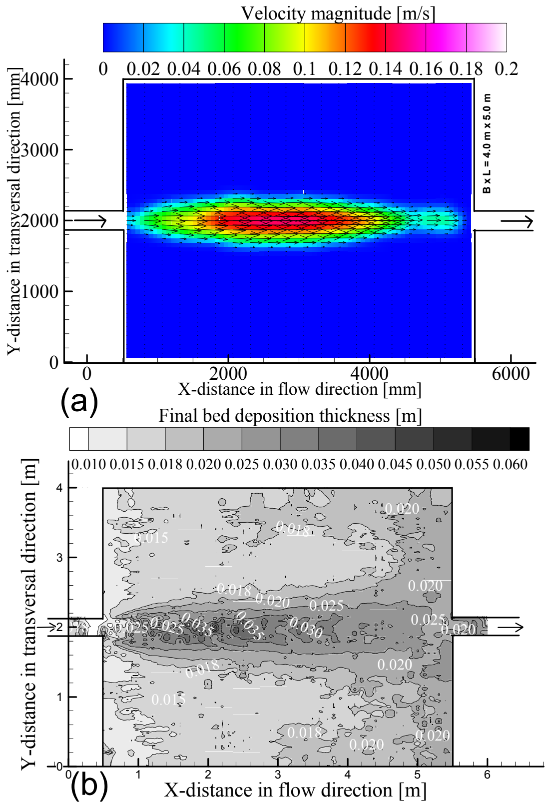

Figure 12 Flow pattern and bed deposition at 4.5 hrs of the reduced basin length.

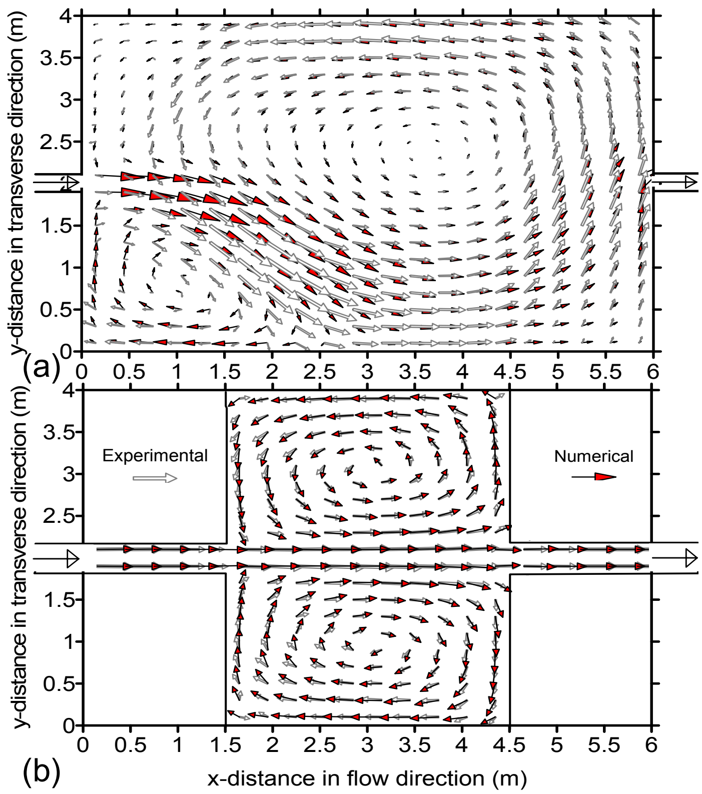

Figure 13 Comparison of velocity vectors measured and simulated.

DISCUSSIONS

Regarding the continuation of this research project the major goal is to find out which stilling basin criteria leads to minimum sediment deposition, erosion and cost; maxim flood retain and fish passage. This requires same methodology scaled model tests combined with unsteady 3D numerical modeling techniques that include the processes as observed in this study. In the present study, rectangular, triangular and hexagonal cavity type flows are investigated. The goal of this study is to better understand the physical processes involved in flow structure formation, particularly the interaction of recirculating flow and large coherent-eddy structures in the separated layer.

The focus of this paper is the influence of the shallow reservoir geometry on clear water flow patterns and the main mechanism controlling the asymmetric flow process of the jet entering the reservoir. The findings can be used to define the optimal stilling basin dimensions and flexible operation rules for FMD. Moreover, these findings allow reservoir designers to predict flow patterns and choose an appropriate geometry. Applications of the present paper are not restricted to shallow reservoirs; they can be extended to other shallow-flow related problems, such as jet flows. Flow fields with regions of flow separation and reattachment occur frequently in natural environments and hydraulic structures.

Numerical simulation of flows in the stilling basin of flood mitigation dam has to be checked for its consistency in predicting real flow pattern and sedimentation volume. Typical flow patterns may exhibit flow separation at the dam outlet, accompanied by recirculation area all over the stilling basin. The aim of the present research project is to study the influence of the geometry of a stilling basin on sediment transport and flow field numerically, focusing on in-ground basin behavior with sediment transport.

A series of numerical simulations are presented and compared with scaled laboratory experiments, with the objective of testing the sensitivity to different flow and sediment parameters and different turbulence closure schemes. Different scenarios are analyzed and some selected simulations are presented. To obtain an optimum design and operation of bottom outlets and stilling basin, 3D numerical modeling attempts are achieved for different scenarios.

The main criterion for the different simulation is to find out which geometry dissipates more the energy and transport maximum volume of sediment over time. This goal will be pursued with different geometries of stilling basin, according to the following procedure:

- Comparison of the flow patterns and sediment transport for different geometries;
- Definition of the geometrical parameters such as ratio of outlet width to the basin width or depth and the ratio of stilling basin length to the width;
- Design of the stilling basin geometry which creates less deposits and economically.

Although the geometry is symmetric, the flow pattern is asymmetric under certain conditions. The basin geometry influences the behavior of the large turbulence structures, and the flow is quite sensitive to the geometry shape. When suspended sediment is added to the turbulent flow over a plane bed and transported the study revealed: (a) the large coherent structures disappear compared to clear water flow, (b) depositions and flow structure remains asymmetric with reduced width of the reservoir and disappear when reducing the length of the reservoir.

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