

EXPERIMENTAL STUDY OF THE GATED SPILLWAY OF THE SHAHRYAR DAM IN IRAN

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ABSTRACT

Shahryar dam is currently under construction on the Qezel Owzan River (East Azerbaijan Province) in northwest Iran. An experimental study was led to check the good behaviour of the hydraulic structures during high return period floods. The present paper focuses on the gated spillway analyzing the flow behaviour from upstream towards downstream.

The gated spillway is oriented at 45° from the axis of the valley, creating a non uniform approach flow in the left bay of the gated spillway, with apparition of longitudinal vortex close to the left guide wall. To avoid these bad entry conditions, a vertical inclination of the left side wall reveals efficient to distribute uniformly the flow. Furthermore, this inclination allows increasing the hydraulic capacity for high water levels. This effect can be computed by adjusting the left side wall contraction factor.

Jets issued from the flip buckets were studied by picture analysis with the aim to define the impact zone in the plunge pool and to protect it against scour. The final design of the gated spillway includes, two splitters located on the flip bucket. Measurements have been carried out with and without splitters to highlight their effect on the jets in each bay.

Finally, the model allowed studying the plunge pool behaviour during floods. The jets issued from the gated and crest spillways create a complex and air entraining flow. Velocity and pressure measurements put in evidence the sensitive parts of the plunge pool to be protected against scouring.

Keywords: Extreme floods, Spillway, Flip bucket, Jets, Plunge pool

1 INTRODUCTION

Shahryar dam is currently under construction on the Qezel Owzan River (East Azerbaijan Province) in northwest Iran. It consists in a double curvature arch dam with a height of 135 m and a crest length of 204 m. High flood discharges expected on the river are important with $Q_{1'000}$ estimated at 5130 m³/s, $Q_{10'000}$ at 8400 m³/s and PMF at 14570 m³/s. To evacuate them, two spillways are designed: a free crest spillway in the centre of the dam following the curvature of the dam body, and a gated spillway located on the right bank preceded by an approach channel and equipped with three chutes and flip buckets (figure 1).

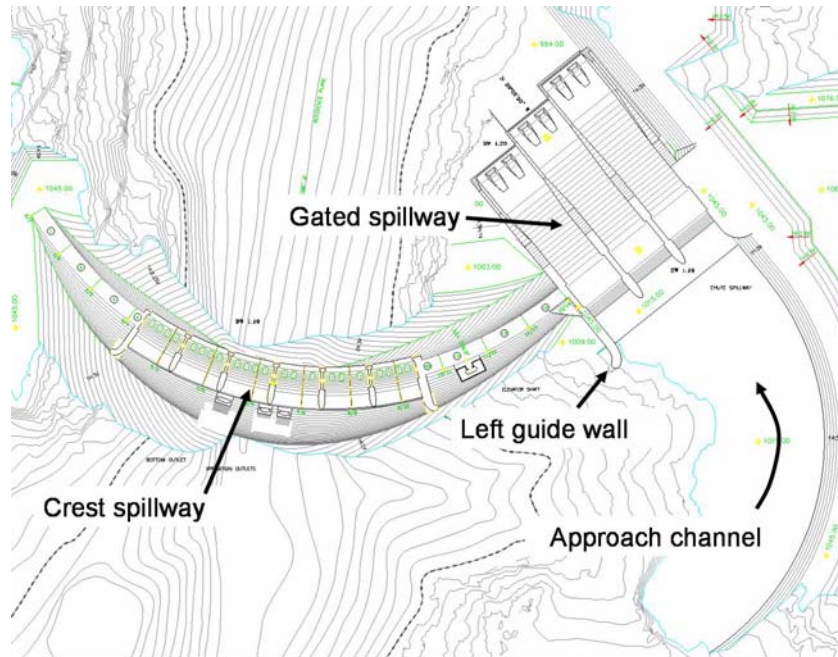


Figure 1 : Layout of works

The aim of the experimental study performed in 2005 is to verify the good behaviour of all hydraulic structures during high return period flood events. For this, the model includes a part of the reservoir, the dam body with both spillways, and the plunge pool. The control of the tailwater level is obtained thanks a movable weir. The crest and gated spillways are made of PVC and the topography, including the plunge pool, of a rigid cement covered structure (figure 2). The model is constructed with a scale factor 1:65 and operated with respect to Froude similarity, i.e. conserving the inertial and gravitational forces ratio.



Figure 2: Shahryar dam model in the laboratory

The present paper focuses on the gated spillway. It describes the flow behaviour from upstream towards downstream by the following stages:

- approach flow in the reservoir
- flow on the gated spillway and chute
- Jets trajectories and plunge pool.

2 APPROACH FLOW IN THE RESERVOIR

The upstream velocity field was measured using Particle Image Velocimetry (PIV, Kantoush, 2006) for high return period floods (Q_{10^000} and PMF). This measurement technique applied onto the physical model permits to highlight the general surface flow from the model discharge supply (two perforated pipes separated from the reservoir with a permeable curtain for flow distribution) to the spillways. Figure 3 presents the results of upstream surface velocity measurement for Q_{10^000} .

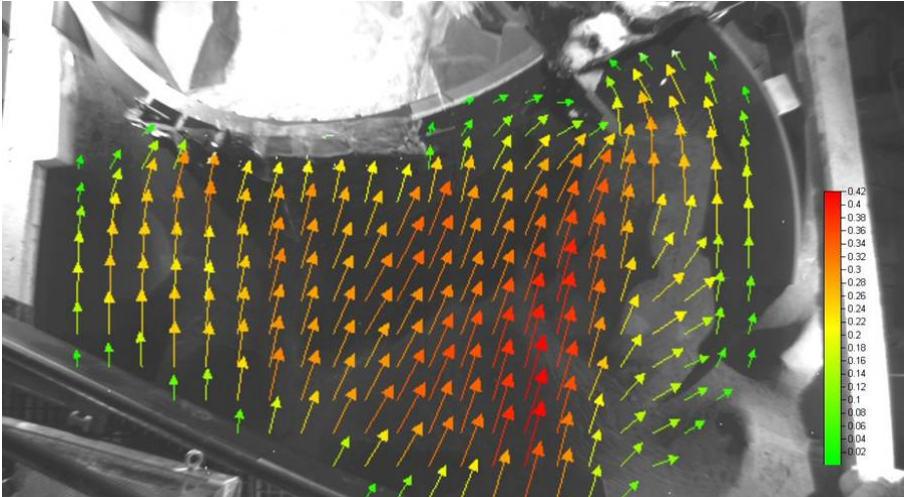


Figure 3: Upstream velocity field for Q_{10^000}

For high return period floods, with discharge higher than $5^000 \text{ m}^3/\text{s}$, the three gates of the spillways are fully opened and the bays evacuate a significant part of the total discharge representing 86 % for Q_{1^000} , 70% for Q_{10^000} and 58% for PMF. The gated spillway is directed at 45° from the axis of the valley. This leads to a small approach area and imposes high velocities to reach the weir with streamlines oriented on the axis of the spillway. Finally, the flow has to be redirected to the axis of the spillway. This involves an important turn around the left guide wall and a consecutive flow contraction. The next chapter deals more precisely with the hydraulic behaviour at the entry of the gated spillway.

3 GATED SPILLWAY AND CHUTE

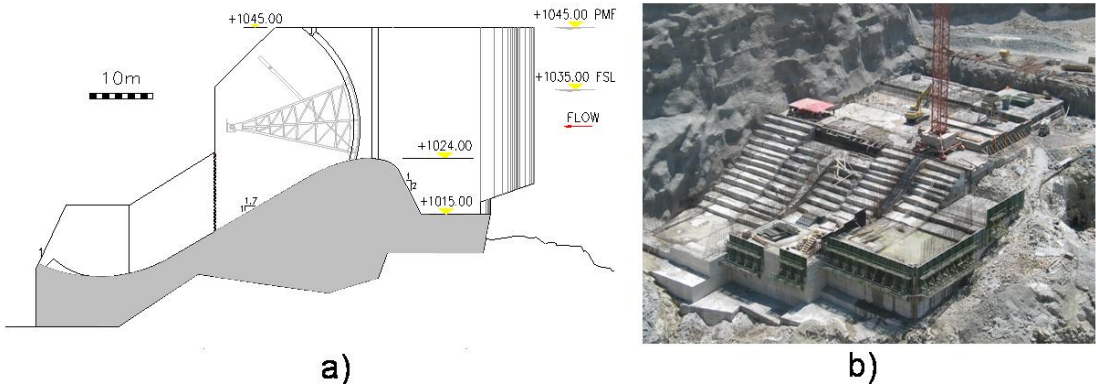


Figure 4: a) Side view of the gated spillway left bay b) Gated spillway under construction

The gated spillway is composed of three bays equipped with gates. Each bay is composed of a standard ogee crest followed by a chute, ending by a flip bucket with splitters. The three bays have a different geometry (length and flip bucket level).

3.1 FLOW BEHAVIOUR ON THE LEFT BAY

The approach flow is rather uniform for the middle and right bays (2 and 3 on figure 5). Nevertheless, due to the inclination of the gated spillway axis, the streamlines are strongly incurved at the entry of the left bay. Consequently, the flow is strongly disturbed close to the left guide wall and in the entire left bay (1). The contraction of the flow involves a separation zone with apparition of a longitudinal vortex. This causes perturbations and shock waves interacting with the waves issued from the left middle pier. Consequently, the flow over the chute and flip bucket is also perturbed and non uniform (figure 5).

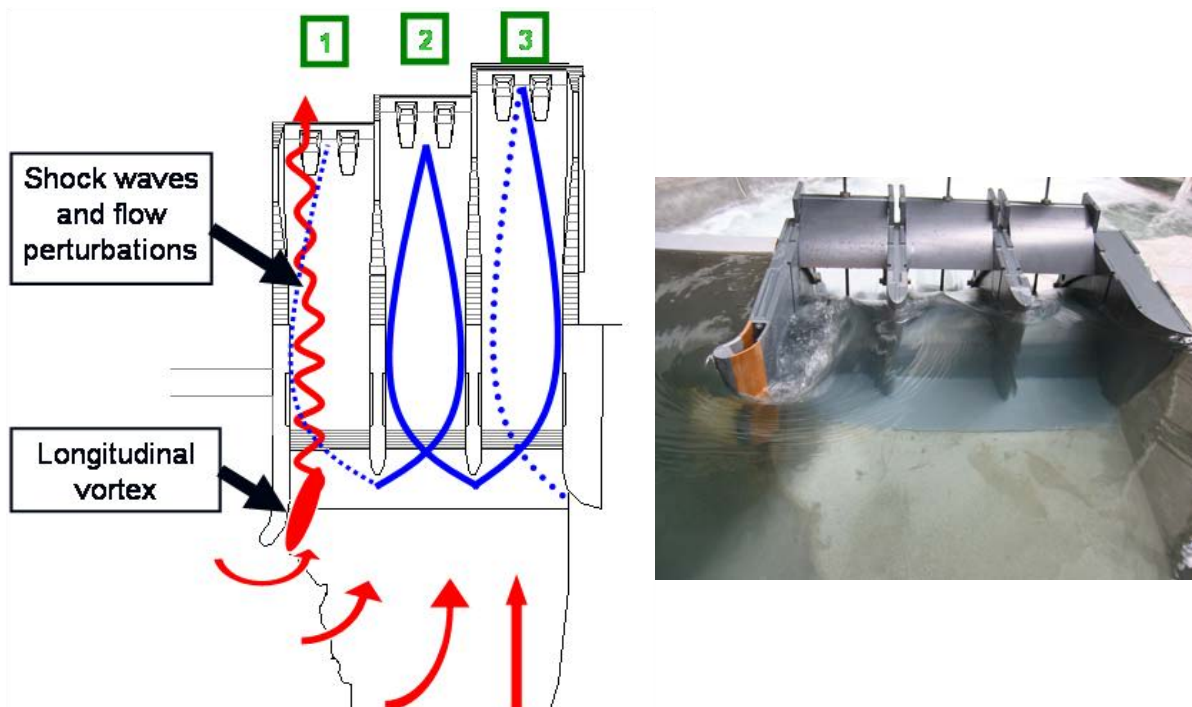


Figure 5: Flow behaviour on the gated spillway with vertical left guide wall

3.2 INFLUENCE OF THE LEFT GUIDE WALL GEOMETRY

Considering the approach flow perturbations described previously and the disturbances generated on the chute, alternative solutions were proposed and tested on the model. Using movable and flexible elements, the research for a good shape showed that a longitudinal inclination of the nose of the left guide wall allows improving the approach flow conditions. The nose inclination of the side wall like the prow of a ship contributes to a better flow distribution. Consequently, the separation zone is no more concentrated on one vertical line (figure 6). Shock waves are reduced and the horizontal vortex is eliminated. Furthermore, the interaction with the waves issued from the left middle pier is also reduced (blue line on figure 6). Figure 7 compares the flow conditions using top view pictures between a vertical wall (initial geometry) and an inclined wall (51° inclination from the horizontal).

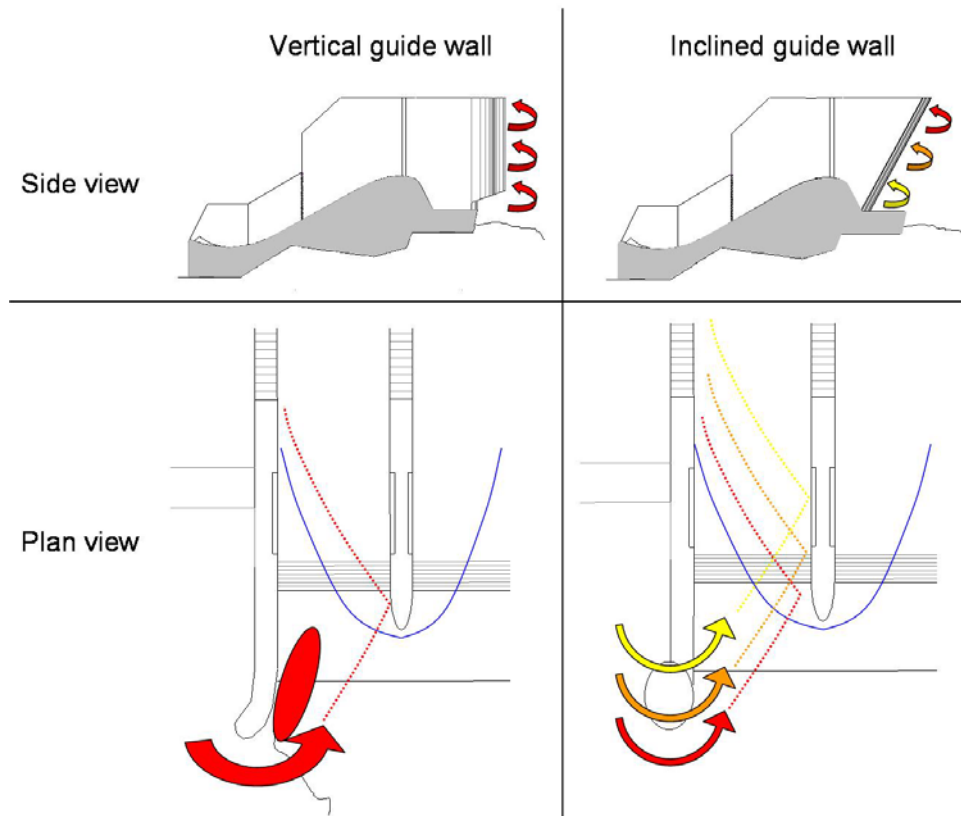


Figure 6: Influence of the left guide wall geometry on the flow behaviour

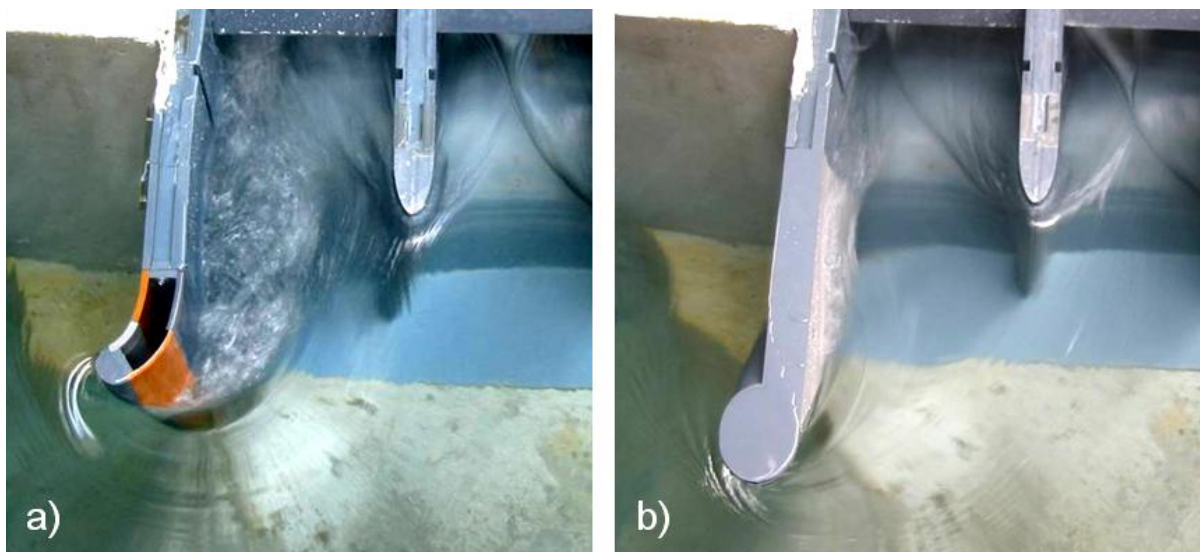


Figure 7: Comparison of flow conditions using vertical wall (a) and inclined wall (b)

Several solutions have been tested considering different inclinations, radius of pier nose and distance from the ogee crest. It appeared that the higher the inclination, the better the flow behaviour. In the same way, but with less important influence, the higher the radius, the better the flow conditions, with a weaker separation zone. To decrease the vulnerability of this wall against seismic load cases and to facilitate its construction, the inclination has to be reduced as far as possible. With a 60° inclination, small perturbations persist for $Q_{10'000}$ and PMF. To avoid them while conserving this inclination, a horizontal curvature of the entire wall is efficient for the very high return period floods. Figure 8 illustrates the flow behaviour close to the left guide wall for different geometries.

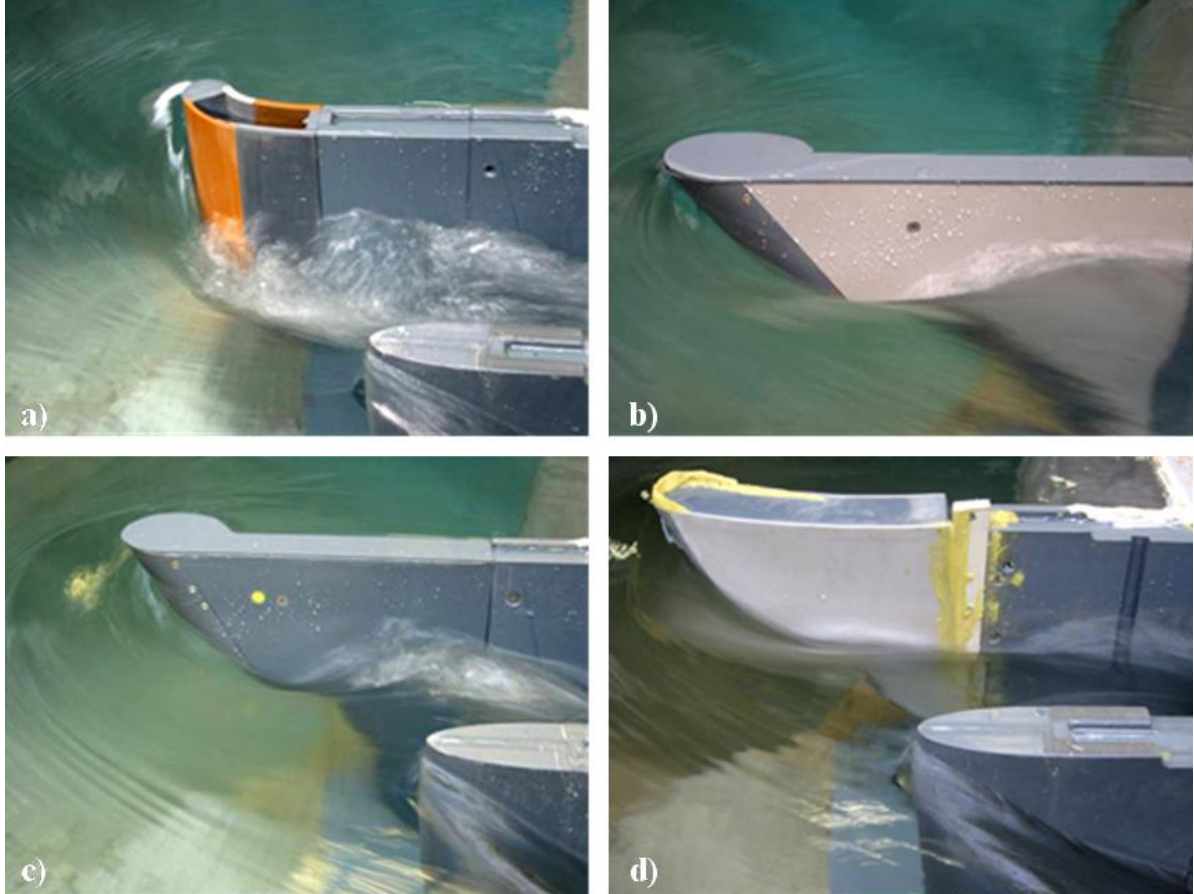


Figure 8: Flow behaviour for different geometries of the left guide wall:
a) Vertical wall (initial geometry) b) 51° inclination
c) 60° inclination d) 60° inclination with horizontal curvature

Optimization of the left guide wall geometry allowed improving the flow behaviour at the entrance of the left bay. Consequently, this improves the flow all along the chute down to the flip bucket. Furthermore, it permits to increase the gated spillway capacity for high return period floods. The hydraulic capacity Q of a free crest spillway is classically computed as:

$$Q = C_d \cdot b_e \cdot \sqrt{2g} \cdot H^{3/2}$$

where C_d is the discharge coefficient [-], b_e the effective width [m], g the gravitational acceleration [m/s^2] and H the upstream hydraulic head [m].

The effective width allows taking into account the lateral flow contraction due to the side walls and the piers. It can be expressed as:

$$b_e = b - (2 \cdot n \cdot K_p + K_L + K_R) \cdot H$$

where b [m] is the total width of the three bays, n the piers number and K_p , K_L and K_R the contraction factors for the piers, respectively the left and right walls. Contraction factors for the piers and the right wall were determined experimentally as constant value of 0.01 and 0.04 respectively. To take into consideration the separation zone with flow perturbations close to the left guide wall, the corresponding contraction factor has higher value, depending on the wall geometry. For the vertical wall, it was estimated at 0.20. This value reduces to 0.16 for 60° inclination and 0.10 for 51° inclination.

A lower value of this coefficient means that the left bay is less perturbed and permits to increase the discharge for a given water level. Compared to the vertical geometry, at maximum water level in the reservoir, the inclined wall allows increasing the evacuated discharge by 180 m^3/s for the 60° inclined wall and 450 m^3/s for the 51° inclined wall.

Figure 9 shows the rating curve of the gated spillway during high return period floods for the three geometries described above.

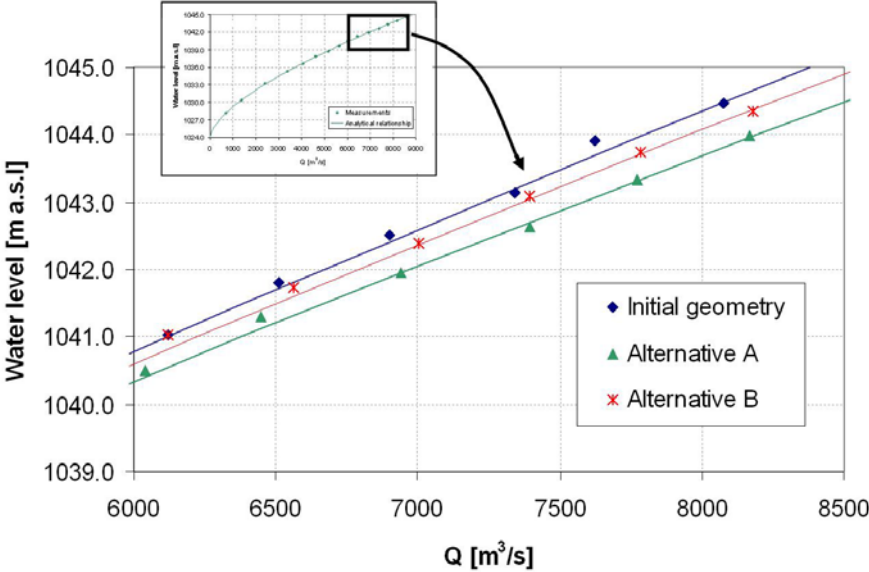


Figure 9: Gated spillway capacity during high floods for vertical left guide wall (initial geometry), 51° (alternative A) and 60° (alternative B) inclined walls

4 JETS AND PLUNGE POOL

4.1 JETS TRAJECTORIES

Jets issued from the flip buckets were studied by picture analysis with the aim to define the impact zone in the plunge pool and to protect it against scour. For this purpose, coordinates of about twenty points on the upper and lower limits of the jets trajectories were defined. These two points' series allowed calibrating the jet ballistic equation expressed as:

$$z = z_0 + \tan(\alpha)x - \frac{gx^2}{2V_0^2 \cos^2(\alpha)}$$

where x and z are the axis coordinates with origin at the takeoff point (see figure 10), α the takeoff angle, and V_0 the flow velocity before the flip bucket. The takeoff levels of the upper and lower lines are known. Calibration of the jet equation consists thus in the adjustment of the take-off angle and velocity. Measurement points close to the flip bucket permit to determine the take-off angle. From there, velocity is adjusted to obtain a good correlation over the entire length of the jet. It has to be quoted that for a constant discharge, the adjusted velocity for the upper line is superior by about 5 to 10% to the one for the inferior line. Figure 11 illustrates for the measurement issued from picture analysis and the analytical relation issued from calibration for $Q_{1'000}$.

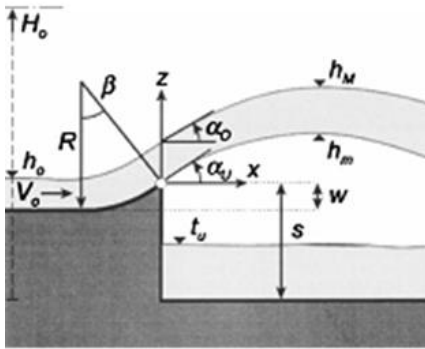


Figure 10: Definition sketch for a plane jet (issued from Heller and al., 2005)

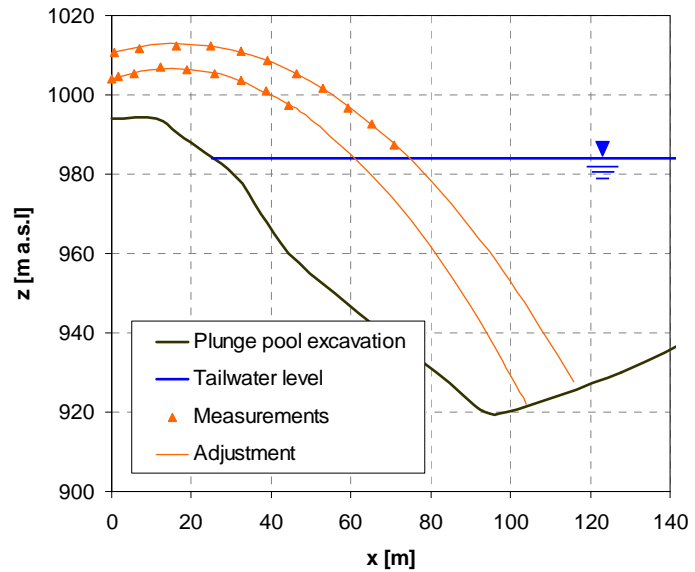


Figure 11: Measurements and adjustment of the jet trajectory for $Q_{1'000}$

4.2 INFLUENCE OF SPLITTERS

The final design of the gated spillway includes, for each bay, two splitters located on the flip bucket (figure 12). Measurements have been carried out with and without splitters to highlight their effect on the jets. Figure 13 shows the jet trajectories contour lines with and without splitters for Q_{100} , $Q_{1'000}$ and PMF.

This figure allows illustrating the efficiency of the splitters on jets trajectories for different discharges. This efficiency is higher for smaller discharges. For Q_{100} , the jet trajectory is clearly modified by the splitters, its body being bigger and its trajectory shorter. For PMF, the trajectories with and without splitters are almost the same. Calibration of the jet equation has also been carried out for the jets with splitters by adjusting the takeoff angle and velocity. This adjustment permits to highlight the splitters effect: a good correlation of the jet trajectory with splitters is only obtained when decreasing the outlet velocity V_0 with regard to the case without splitters. This decrease can be interpreted as the splitters head loss. The relative decrease of the kinetic term $V_0^2 / 2g$ in the case with splitters is about 22% for Q_{100} , 8% for $Q_{1'000}$ and only 3% for PMF. Splitters can thus be considered as effective for floods with a relative small return period. This efficiency becomes less marked for extreme floods.



Figure 12: General view of chutes, flip buckets and splitters

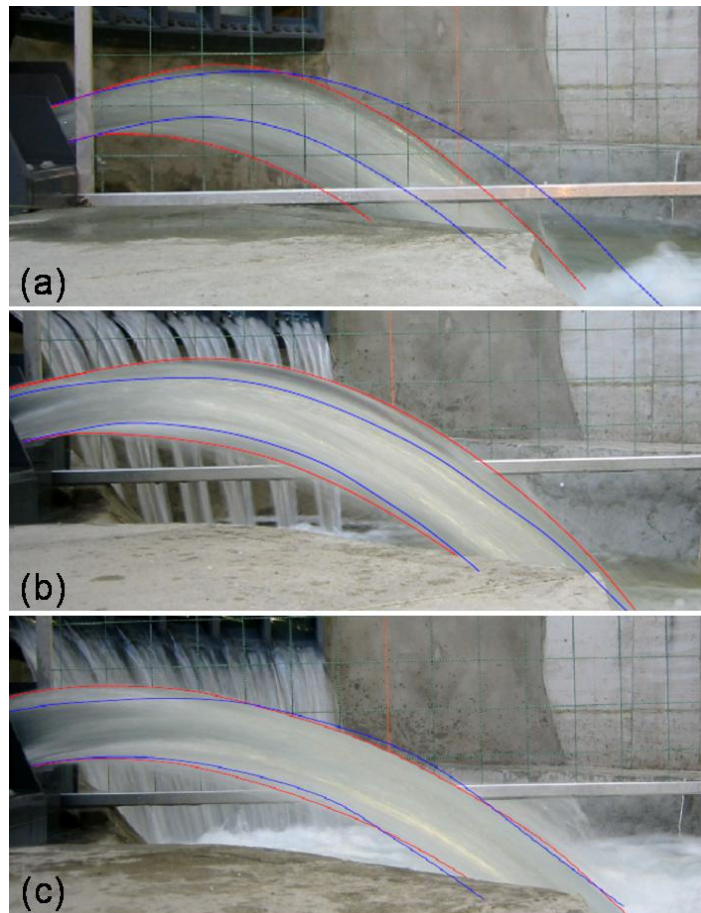
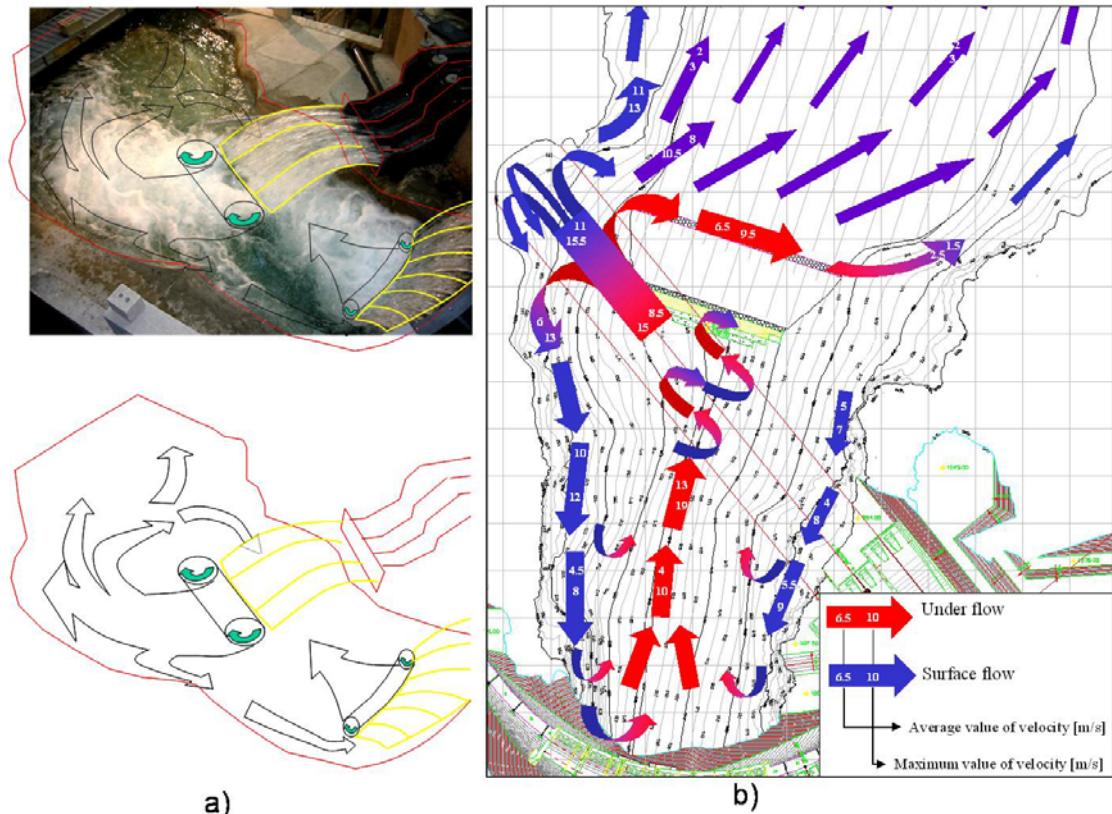


Figure 13: Jets trajectories and contour lines with splitters in red and without splitters in blue
a) Q_{100} ; b) Q_{1000} ; c) PMF

4.3 PLUNGE POOL

Finally, the model permitted to study the plunge pool behaviour during floods. Jets issued from the gated and crest spillways create a complex and air entraining flow in the plunge pool. This behaviour was analyzed directly in the plunge pool by velocity measurements and qualitative considerations according to the jets trajectories and impacts (figure 4).

The gated spillway jets create a significant roller along their impact lines with high air concentration. Large masses of water are moving sequentially and water surface fluctuations are very important. Downstream of the impact zone, most of the water is flowing up along the valley slope. Then the flow is divided in two parts. The main one is turning on the right and leaving the plunge pool. This involves high velocities along the rock on the left side of the valley. The other part of the flow issued from the gated spillway jet is flowing back towards the dam. This return flow creates also important velocities along the left side of the valley before turning back under the influence of the crest spillway jet when reaching the dam. This qualitative description along with velocity and dynamic pressure measurements allowed putting in evidence the sensitive parts of the plunge pool to be protected against scouring.



a) General flow conditions in the plunge pool during floods
 b) Velocity measurements for PMF

Figure 14: Flow behaviour in the plunge pool

5 CONCLUSIONS

This applied study illustrates the hydraulic behaviour of a non-axed free surface gated spillway during floods. Different measurement techniques used on the hydraulic model permits to check the good behaviour and the efficiency of all significant elements for high return period floods evacuation. A special focus is oriented towards the improvement of the lateral guide wall geometry.

Other measurements which are not presented in this article were also carried out in order to investigate the dynamic effects on the gated spillway weir, the flip buckets, the splitters, and the plunge pool.

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REFERENCE

- Heller, V., Hager, W.H. and Minor H.-E (2005). “*Ski jump hydraulics*”. J. hydr. Engrg., 132(5): 347-355
- Kantoush, E., Bollaert, E., De Cesare, G., Boillat, J.-L., and Schleiss, A., (2006). “*Flow Investigation in a Rectangular Shallow Reservoir Using UVP, LSPIV and Numerical model*”. Proceeding of the 5th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering. ETH Zurich, Switzerland, ISBN 3-905609-29-0, pp. 129-133