Effect of Spilling from Adjacent Orifices on the Velocity Field and Pressures in Front of Needle Stop-Logs

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In this study, the effect of spilling from neighboring sluice gates on stop-logs was experimentally investigated on a 1:65 physical scale model comprised of a double arch dam, a reservoir area, six spillway orifices and two stop-logs. Two types of measurement were performed: 2D velocity field in approach flow zone at the central horizontal plane of the orifices using two 0.5 MHz long range UVP transducers and dynamic pressures acting on the needle stop-logs at nine relevant positions using piezo-resistive pressure transmitter. The results showed that the pressure acting on the needle stop-logs followed hydrostatic distribution and velocity magnitudes in the zone of the needle stop-log are low and mostly unaffected by the spilling of the neighboring sluice gates.

Keywords: Stop-logs, pressure, velocity field

1. Introduction

Stop-logs are temporary hydraulic structures placed to close openings in order to perform maintenance work. In case of multiple spillway openings, maintenance work is usually performed sequentially in order to ensure passage of flood events. In this study, the effect of spilling from neighboring sluice gates is studied experimentally on the 1:65 physical scale model of Kariba Dam [1-3]. The Kariba Dam, commissioned in 1959, is located on the Zambezi River between Zambia and Zimbabwe, Africa. It is a double curvature arc dam, 128 m high, 617 m long. The dam spillway consists of six submerged sluice gates 8.8 m high and 9.5 m wide with a total spilling capacity of 9'000 m^3/s. Due to the decades of exploitation, the spillway orifices and gates were damaged. In order to repair damaged spillway orifices, needle stop-log are planned for blocking the spillways temporarily during the repair works. The temporary stop-logs are held in place by hydrostatic forces acting upon them and are sealed using a membrane on its upstream face. Therefore, it is necessary to ensure that the needle stop-log surface is not exposed to negative pressure since it could lead to its dislodgment. In order to assess the effect of spilling on stop-logs, two type of measurements were carried out, namely pressure measurements on the stop-logs and velocity field in the approach zone of the gates.

2. Experimental facility and instrumentation

All experiments were carried out at the Laboratory of Hydraulic Constructions (LCH) of EPFL, Switzerland. The physical model (Figure 1) consists of a reservoir area of 190 m by 220 m horizontally and of 100 m vertically, the Kariba dam with its crest and complete set of spillway sluices (six), the free falling jets, the complete plunge pool and the tailwater zone with two power house outlets. The physical model is constructed with geometrical scale factor of 1:65 and the model is operated following Froude similitude and therefore the maximum discharge for the entire spillway of 9'000 m^3/s in prototype corresponds to 264 l/s in the model. Needle stop-logs were manufactured using 10 mm thick PVC plates with variable dimensions corresponding to the appropriate sluice and the stop-logs were placed and sealed to gates (Figure 1).

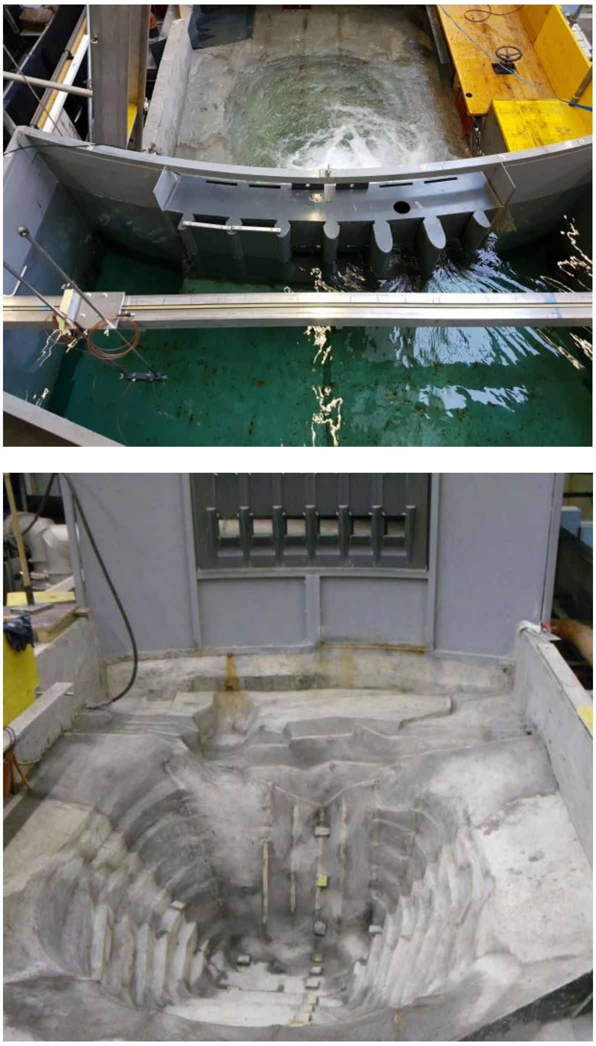

Figure 1. Physical model at LCH, view from upstream of Kariba dam orifice spillways with two stop-logs (top), view from downstream of the plunge pool towards the dam (bottom).

Each of the stop-log is equipped with 9 pressure taps (Figure 2), 15 mm long with 8 mm diameter which are pierced with a 2 mm micro tube. On each pressure tap, tubes with inner diameter of 8 mm were placed and connected to a multiplexer. The outlet tube of a multiplexer was connected to a piezo-resistive pressure transmitter for dynamic pressure measurement. The piezo-resistive pressure transmitter is of flush diaphragm type (Baumer, Switzerland) with an acquisition range between +/- 0.1 bar with an accuracy of +/- 0.001 bar. Pressures were collected at a sampling rate of 1 kHz for 66 s. The transmitter was calibrated before pressure measurements and the tubes were purged before each measurement.

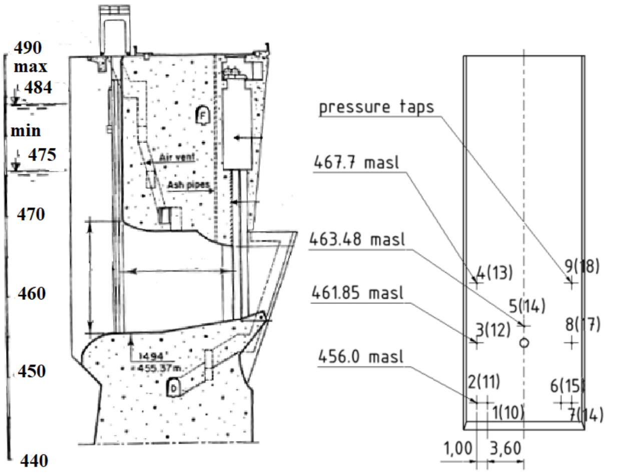

Figure 2. Sluice gate cross-section (left) and pressure taps position and designation-values in brackets correspond to second stop-log plate (right).

Velocity measurements were performed using a non-intrusive Ultrasound Doppler Velocity Profiler (Metflow, Switzerland). 2D velocities were recorded in the approach zone of the dam covering an area of 33.8 m by 156.0 m using two 0.5 MHz long range transducers with active diameter of 40 mm.(Figure 3). The transducers were placed horizontally in a frame (Figure 3) so that the beam axis formed a mutual angle of 60°.

Figure 3 UVP sensors, frame and carriage

The vertical position of the transducers axis was kept constant at the centre axis of the sluice opening corresponding to 462.3 meters above sea level (masl). The frame, which was attached to a carriage (Figure 3), was moved in 49 positions transversally across the width of the reservoir (with a step of 3.25 m) in which velocity profiles were recorded. The position of the carriage was measured with Leica D150 laser distometer with an accuracy of +/-1 mm. In such a way, a diamond shaped grid presented in Figure 4 is formed. In each intersection recorded velocity components were extracted from the corresponding velocity profiles giving 2D velocity components.

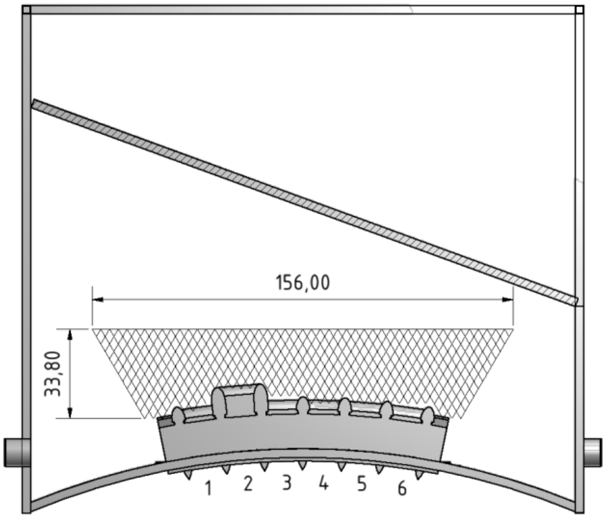

Figure 4 Velocity measurement grid and sluice gate designation

No particular seeding was used during velocity measurements since acoustic scattering was satisfactory. Water used in the model was a part of a large recirculating system of the laboratory and it contained impurities which enhanced acoustic scattering.

Each velocity profile was sampled 512 times with 64 repetitions that corresponds to a sampling frequency of around 15 Hz. The maximum depth was set to 750 mm and velocity bandwidth was therefore ±730 mm/s (± 5.89 m/s in prototype). In some cases, in particular in the zone of the open gates, velocity exceeded the maximum velocity bandwidth and aliasing effect was observed. In such cases, tailor-made Matlab® code was used to post process velocity profiles. All results are presented up-scaled with a scale of 1:8.06 for velocities and 1:65 for pressures in meters water column (m WC) following Froude similitude.

3. Test program

The physical model tests were conducted with two gates closed using stop-logs. In total three configurations were investigated: 1) Sluice no. 5 and 6 closed with stop-logs; 2) Sluices no. 3 and 4 closed with stop-logs; 3) Sluices no. 1 and 2 closed with stop-logs (see Figure 4). Herein only the second configuration will be presented since other configurations yield similar results. For each configuration, four different scenarios were tested, in which four other gates (that are not closed using stop-logs) were either completely open or closed (Table 1). Each scenario was then tested for three water levels namely 475.5, 482.0 and 488.5 masl.

Table 1: Definition of test scenarios where C is closed, O is open and S.L. is stop-log.

	Gate No					
Scenario	1	2	3	4	5	6
I	C	C	S.L.	S.L.	C	O
II	O	C	S.L.	S.L.	C	O
III	O	C	S.L.	S.L.	O	O
IV	O	O	S.L.	S.L.	O	O

4. Results

Up-scaled mean pressures P_{mean}, standard deviation σ and corresponding hydrostatic pressures P_{HS} for scenario IV at water level 488.5 masl for 18 pressure points (pressure taps 1-9 correspond to stop log at gate No. 3 and 10-18 at No. 4) are given in Table 2. Since results for other configurations and scenarios yield similar results and due to space limitation they are not presented herein. For all tested scenarios and water levels time averaged pressures on stop logs follow hydrostatic pressure distribution (Table 2). Standard deviations of pressure readings for all tested scenarios and water levels are below 0.15 m WC and are less than 1% of water depth. These results were supported with visual observation made during the tests. In the zone of the stop-logs, water surface is smooth, horizontal and undisturbed by the spilling of adjacent sluices (Figure 5 and 6). No negative pressure has been observed in the physical model.

Figure 5. Model in operation for scenario IV at 488.5 masl, view of the approaching zone from the right side.

Time averaged velocity vector plot superimposed on velocity contour line plot of time averaged velocity field in the approaching zone of the dam for scenarios I-IV at 475.5 masl and for scenario IV at 482.0 and 488.5 masl are given in Figures 7-12.

Table 2. Up-scaled time averaged pressure, standard deviation and corresponding hydrostatic pressures for scenario IV at 488.5 masl

Pressure tap	1	2	3	4	5	6
P_{mean} [m WC]	32.5	32.6	26.5	20.7	24.9	32.4
P_{HS} [m WC]	32.5	32.5	26.7	20.8	25.0	32.5
σ [m WC]	0.12	0.12	0.10	0.14	0.10	0.10
Pressure tap	7	8	9	10	11	12
P_{mean} [m WC]	32.6	26.6	20.8	32.5	32.5	26.6
P_{HS} [m WC]	32.5	26.7	20.8	32.5	32.5	26.7
σ [m WC]	0.09	0.11	0.14	0.10	0.09	0.09
Pressure tap	13	14	15	16	17	18
P_{mean} [m WC]	20.9	24.9	32.4	32.5	26.7	20.8
P_{HS} [m WC]	20.8	25.0	32.5	32.5	26.7	20.9
σ [m WC]	0.13	0.10	0.10	0.11	0.09	0.09

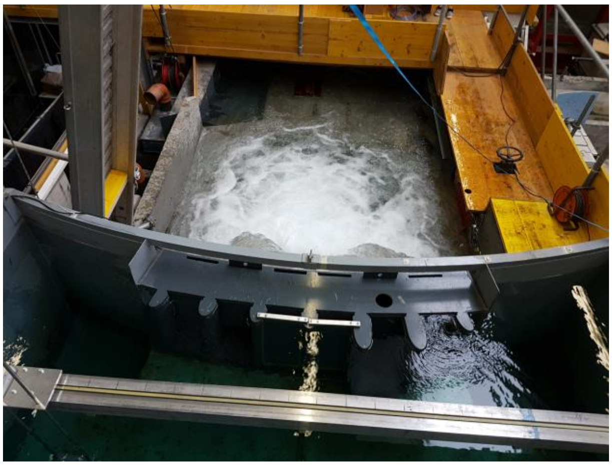

Figure 6 Model in operation for scenario IV at 488.5 masl, top view of the approaching zone.

Time averaged velocity magnitudes increase with the increase of water level as well as with the increase of the number of opened sluices. Velocity magnitudes in the zone of the opened sluices can reach up to 10 m/s. In the zone of the stop-logs time averaged velocity magnitude for scenarios No. I and II are below 2 m/s whereas for scenario III and IV they may reach up to 4.5 m/s (in the close proximity of the neighboring sluice no 5).

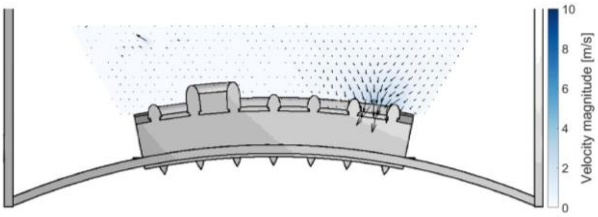

Figure 7 Time averaged velocity field in approaching zone of the dam for scenario I at 475.5 masl

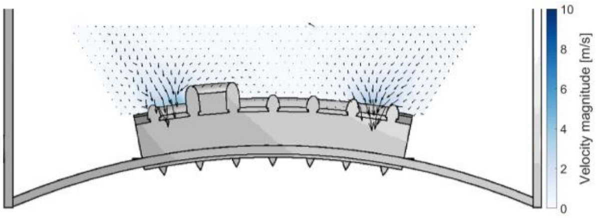

Figure 8 Time averaged velocity field in approaching zone of the dam for scenario II at 475.5 masl

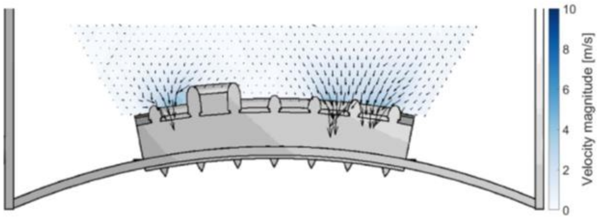

Figure 9 Time averaged velocity field in approaching zone of the dam for scenario III at 475.5 masl

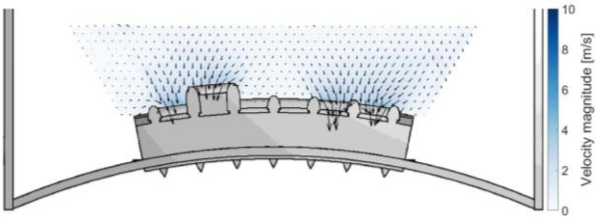

Figure 10 Time averaged velocity field in approaching zone of the dam for scenario IV at 475.5 masl

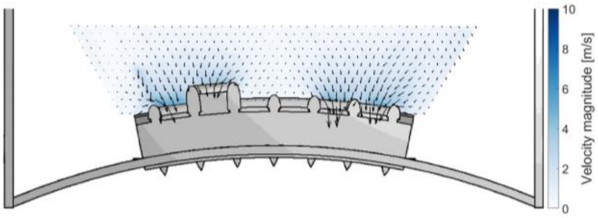

Figure 11 Time averaged velocity field in approaching zone of the dam for scenario IV at 482.0 masl (Table 1.).

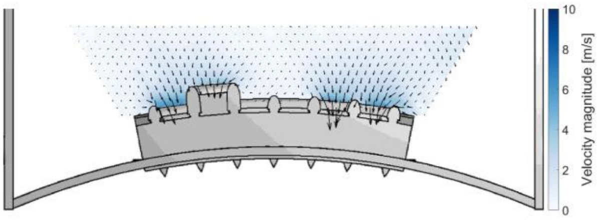

Figure 12 Time averaged velocity field in approaching zone of the dam for scenario IV at 488.5 masl

It can be noticed that mean velocity magnitude are low and mostly unaffected by the spilling of adjacent sluices. This observation is in agreement with visual observations and pressures measurements on the stop-log. Based on the above presented measurements it can be concluded that, for the tested conditions, stop-logs are very limited affected by the spilling effects of neighboring sluices.

5. Summary

Stop logs are temporary hydraulic structures frequently used to block the flow through a spillway or canal during routine maintenance. Needle stop-logs are held in place by hydrostatic forces acting upon them and therefore it is necessary to ensure that the stop-logs are not exposed to negative pressure. This study is based on an experimental approach using a 1:65 physical scale model of Kariba dam to investigate the effect of spilling from adjacent sluice gates on the velocity field and pressure in front of needle stop-logs. Two types of measurements were performed, namely dynamic pressure measurements on the stop-logs and velocity field in approaching zone of the dam. Two long range UVP transducers with an emitting frequency of 0.5 MHz were used to record 2D velocity field in the approaching zone of the dam. UVP sensors were place horizontally in a frame so that the sensors axis formed a mutual angle of 60°. The frame, which was attached to a carriage, was moved in 49 positions transversally across the width of the reservoir and by extracting the velocities components 2D velocity field was generated. No seeding was using during the velocity measurements since acoustic scattering was satisfactory. The physical model tests were conducted for three different configurations in which two gates were closed using needle stop-logs while remaining ones were either fully closed or fully open. Pressure measurements have shown that for all configurations time averaged pressure readings followed hydrostatic pressure distribution. Standard deviations of pressure reading were less than 1% of the available water depth and therefore it can be concluded that the needle stop-logs were not exposed to negative pressure for the tested conditions. Velocity measurements in the approaching zone of the dam have shown that velocity magnitudes in the zone of the needle stop-logs are low and mostly unaffected by the spilling of the neighboring sluice gates.

6. References

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