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COMPARISON OF CHUTE AERATOR EFFECT ON STEPPED AND SMOOTH SPILLWAYS

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ABSTRACT

Bottom chute aerators are installed to prevent cavitation damages and they have been studied in detail on smooth spillways. In parallel, stepped spillways became widespread in the past decades. Research has shown that stepped spillways may be endangered even more by cavitation than smooth spillways, particularly for high unit discharges. As a consequence and besides issues of energy dissipation, the unit discharge of stepped spillways is usually limited to lower values than on smooth spillways. In order to overcome that limitation, flow aeration – mainly at the beginning of the chute – is necessary. Until now only fragmentary guidelines exists for the design of such aerators.

Systematic tests with bottom chute aerators on stepped spillway are performed on a physical model. A deflector is used to separate the jet from the bottom in order to produce slight negative air pressures. A horizontal slot located in the vertical face of the first step allows for air supply underneath the flow. In addition of the global air entrainment by the aerator, the local air concentrations are spatially measured downstream of the deflector. The resulting air concentration distribution allows the investigation of air transport and detrainment as well as the streamwise average and bottom air concentration. The present paper discusses a test with a typical aerator and compares it with a reference test without aerator and a test on a smooth chute with a similar aerator.

Keywords: Aeration, Air concentration, Air entrainment, Cavitation, Stepped spillway

1. INTRODUCTION

Aerators are built on spillways to protect them from cavitation. They have been extensively investigated in terms of global air entrainment coefficient (Koschitzky 1987; Chanson 1988; Rutschmann 1988) as well as streamwise air transport and air detrainment (Kramer 2004; Pfister 2008). In parallel, stepped spillways are common on roller-compacted concrete dams. Stepped spillways have an increased cavitation risk due to the roughness of the steps. Frizell et al. (2013) derived critical cavitation indices of 0.3-0.4 for a mild slope and 0.6 for a steep slope which is higher than the critical value of 0.2 for smooth chutes (Falvey 1990). Amador et al. (2009) suggest limiting the velocity to 15 m/s which corresponds to a unit discharge under 15 m^2/s for steep stepped chutes. Pfister et al. (2006) and Schiess Zamora et al. (2008) were the first to study stepped spillway aerators by varying the flow conditions for a fixed aerator geometry.

2. HYDRAULIC MODEL

Tests were carried out on a physical model at the Laboratory of Hydraulic Constructions of EPFL (Figure 1a). The steep prismatic channel had a width of 0.5 m. For the herein presented experiments, it had a length of 6 m, a slope of φ=50° and steps with a height of s=0.06 m. The transition between the pressurized flow of the water supply system to a free surface flow in the channel was made by a jetbox. It allowed the independent variation of flow depth h_0 and Froude number $F_0=V_0/(gh_0)^{0.5}$, with V_0=approach flow velocity and g=gravity acceleration. Unit discharges up to q=0.486 m^2/s could be generated.

The aerator consisted of a deflector without offset. The deflector angle α and height t used for the tests are given in Table 1. Air was supplied under the jet through a 0.02 m high horizontal slot in the vertical face of the first step. An air chamber with wide dimensions to avoid head losses – that would influence the jet length – was located behind the slot and underneath the flow. The unit air discharge q_a entrained was measured by a thermoelectric anemometer (Schiltknecht, Switzerland) located in the air duct supplying the chamber to determine the air entrainment coefficient $\beta=q_a/q$. The aerator was located at 0.46 m distance from the jetbox in order to be able to test small Froude numbers. The bottom of the channel was smooth upstream of the deflector (Figure 1b). The jet length L was measured visually.

A two-tip fiber optical probe (RBI Instrumentation, France) was used to measure local air concentrations in the flow. It uses the difference of refraction index between air and water phases to determine in which phase the tips are, at a sampling rate of 1 MHz. The probe was fixed on an automatic positioning system that allows movement along the streamwise axis x and the depth axis z (Figure 1b). The origin of the axes is the lip of the deflector at the pseudo-bottom level. All vertical profiles are measured at a step edge.

Modelling two-phase flows is subject to scale effects. Using the Froude similitude, the viscous force represented by the Reynolds number $R_0=V_0h_0/\nu$ is underestimated and the surface tension force represented by the Weber number $W_0^{0.5}=V_0/(\sigma/\rho h_0)^{0.5}$ is overestimated, with ν=kinematic viscosity, σ=surface tension and ρ=density. The present tests respect the conditions $W_0^{0.5}>140$ and $R_0>2\text{-}3\cdot10^5$ required to minimize scale effects (Pfister and Chanson 2014).

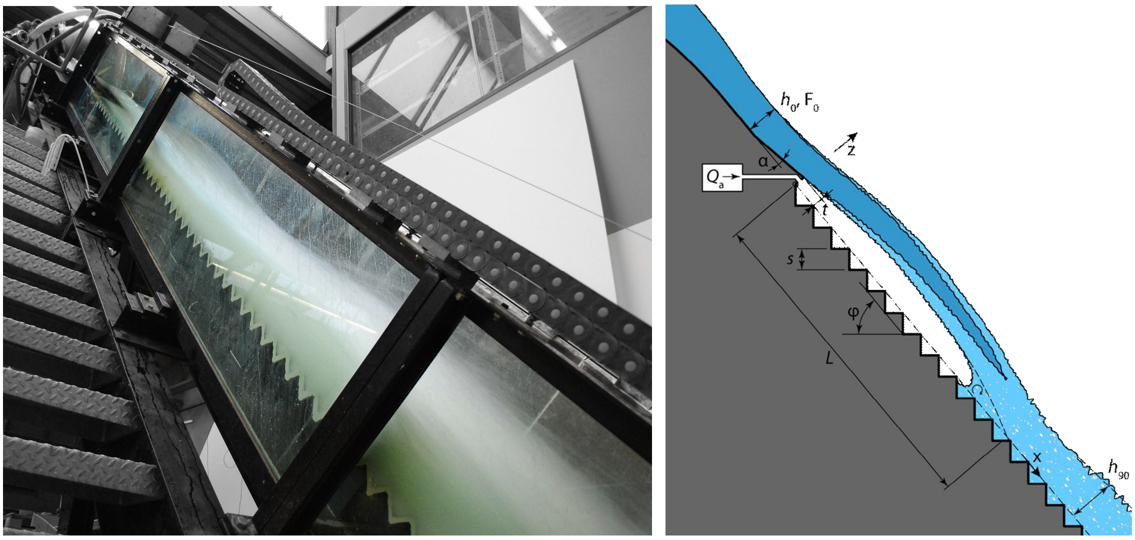

Figure 1. (a) Physical model at LCH, and (b) definition scheme.

3. RESULTS

The results of two tests performed on a stepped spillway, one without and one with aerator, as well as a third test of Pfister (2008) on a smooth spillway are compared here. Parameters for these tests were nearly identical (Table 1). The global air entrainment coefficient β, which is highly correlated to the Froude number for smooth chute (Pfister and Hager 2010), is similar for Test 2 and 3. The spatial resolution of the air concentration measurements was different for the stepped and smooth tests.

Table 1. Tests parameters and results

Test	φ [°]	α [°]	*t* [m]	h_0 [m]	F_0 [-]	*q* [m²/s]	β [%]	*L* [m]	R_0 [-]	$W_0^{0.5}$ [-]
1 - Stepped w/o aerator	50	-	-	0.075	7.5	0.481	-	-	$4.81\cdot10^5$	208
2 - Stepped w/ aerator	50	5.7	0.0150	0.075	7.5	0.483	22.1	1.43	$4.83\cdot10^5$	208
3 - Smooth w/ aerator	50	5.7	0.0133	0.080	7.4	0.522	23.1	1.22	$5.21\cdot10^5$	217

Looking at the air concentration distribution (Figure 2), Test 1, the reference test on a stepped spillway without aerator, shows that self aeration of the flow occurs after 0.85 m (bottom concentration $C_b>0.01$). The addition of an aerator (Test 2) produces significant changes in air concentrations along 0< x<2 m because of the jet. Downstream near the model end, starting at around x=3.5 m, Test 2 shows a slightly higher air concentration on the whole depth of the flow. The comparison of the stepped (Test 2) and smooth (Test 3) chute with an aerator shows little differences in the jet with a slightly larger diffusion of the lower surface for Test 3. Significantly higher air concentrations are present in the flow for the stepped spillway at x>1.5 m. The water depth is therefore higher for the stepped chute compared to the smooth chute, and similar to the reference (Test 1).

The last air concentration profile measured shows that the higher air concentration of Test 2 compared to Test 1 occurs on the full depth (Figure 3). For the smooth chute (Test 1), the air concentration is less than 0.05 in the lower half of the flow.

The depth-averaged air concentration C_a is similar in the jet for Tests 2 and 3 (Figure 4a). From x=1.6 m, the average air concentration changes very little for the smooth chute whereas it rapidly doubles for the stepped chute. Average air concentration for uniform flow C_{au} with a slope of 50° is 0.61 according to Hager (1991) and 0.69 according to Chanson (1996) for smooth chutes. Test 3 has only a value of 0.25 for the last profile measured as it has not reached self-aeration. The roughness of stepped chutes does not affect C_{au} for skimming flow (Boes and Hager 2003). Values of 0.50 were measured for Test 1 and 0.59 for Test 2 which is slightly under the uniform flow values. Compared to Test 1, Test 2 shows less air concentration in the jet impact zone (x=1.5 to x=3 m), but more afterwards.

The bottom air concentration C_b (measured ~3 mm from the pseudo-bottom) for stepped chutes (Tests 1 and 2) quickly converge to values between 0.25 and 0.35 (Figure 3). The bottom air concentration for uniform flow C_{bu} is 0.20 for stepped chutes according to Boes (2000). The lowest value reached by Test 2 is 0.24 and is located where the jet impacts the pseudo-bottom. The bottom air concentration behavior is very different for the smooth chute (Test 3) where there is a rapid decrease towards concentrations under 0.01. Test 3 is far from uniform flow as C_{bu}=0.50 for smooth chutes (Hager 1991).

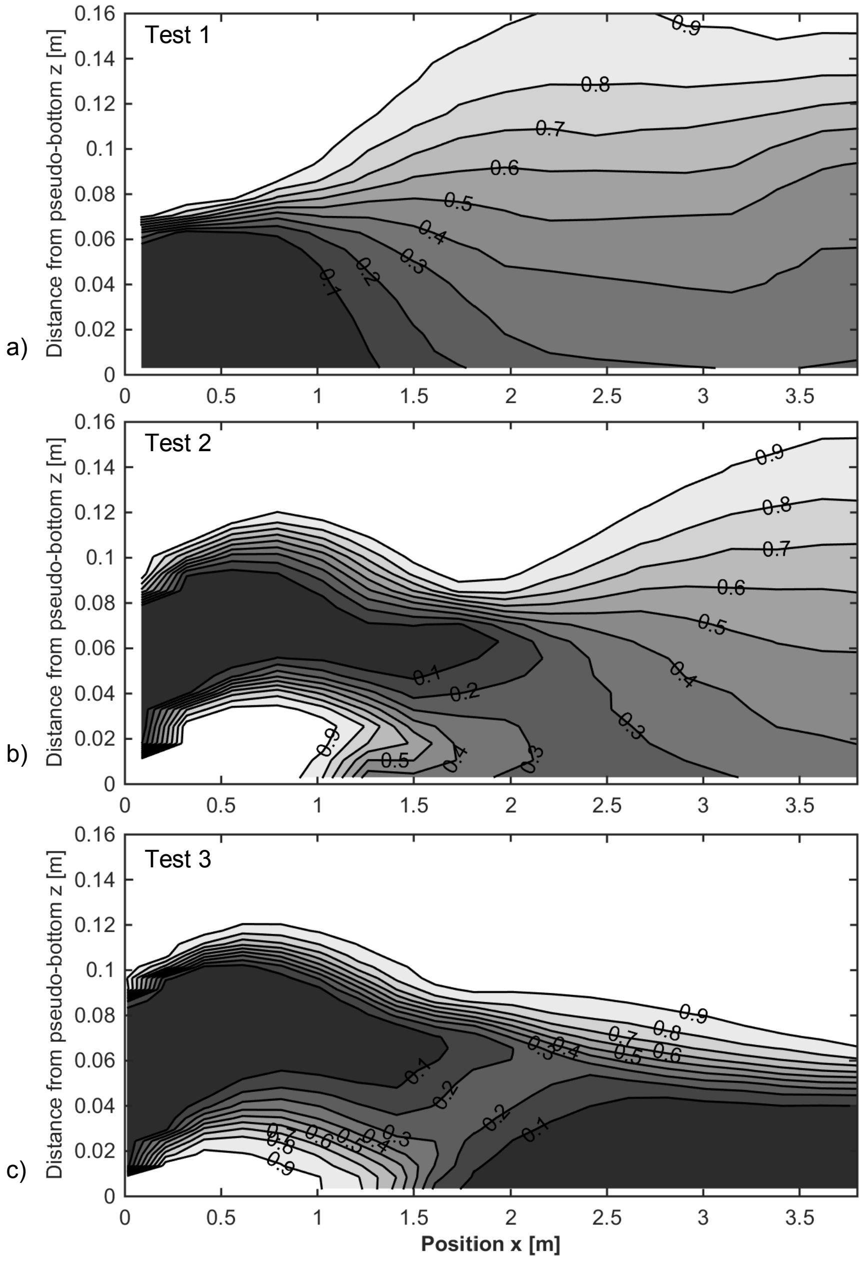

Figure 2. Air concentration distribution for (a) stepped spillway without aerator, (b) stepped spillway with aerator and (c) smooth spillway with aerator for similar flow conditions.

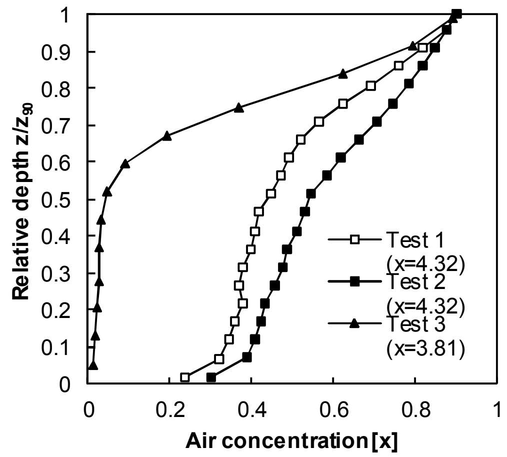

Figure 3. Most downstream air concentration profiles measured.

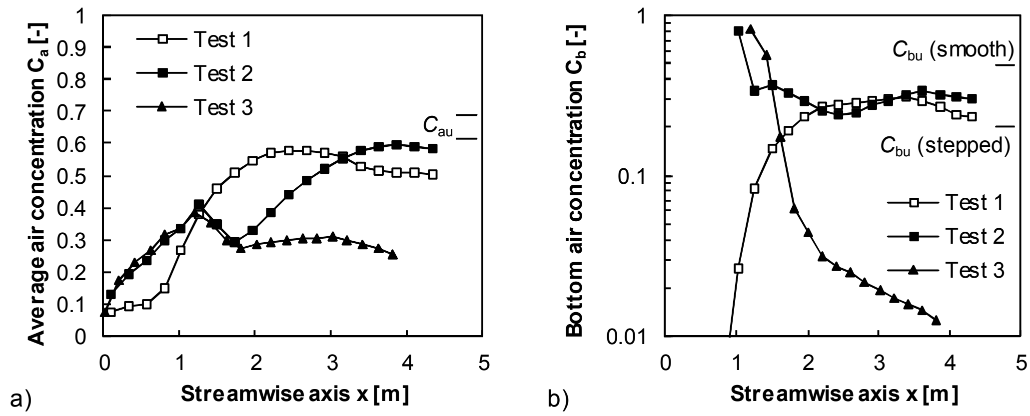

Figure 4. (a) Average and (b) bottom air concentrations.

4. CONCLUSIONS

First observations of a two tests performed among a systematic study on stepped spillways aerators were compared to a nearly identical setup on a smooth chute. The stepped spillways tests show significantly higher downstream air concentrations compared to smooth chute aerators, especially for the bottom air concentration. In addition, the bottom air concentration is maintained downstream of the jet impact and does not rapidly decrease, which suggests that one aerator would be sufficient for stepped spillways. Because self air entrainment occurs higher upstream on smooth chutes and given that cavitation risk appears at the beginning of the chute, an aerator might have to be placed high upstream. Further tests with lower Froude numbers need therefore to be analyzed.

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