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BULKING EFFECTS AND AIR ENTRAINING MECHANISM IN ARTIFICIALLY AERATED SPILLWAY FLOW

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The 400 m long, 70.6 m wide Foz do Areia Spillway is one of the first throughly tested high velocity chutes provided with aerators to avoid cavitation. In operation since June 1980, the 10,000 m^3/s spillway has been subjected to floods up to 8,800 m^3/s (8,240 m^3/s daily average). It has performed flawlessly. The aeration system was closely observed during the floods and performance curves could be experimentally determined, see figure 1.

Besides the air entrained through the aerators indicated in figure 1 an intense aeration process along the free surface of the flow was also noticed downstream from each aeration ramp. It was realized that the aerators not only cause an air dragging effect along the lower nappe, but that the sudden pressure change in the water together with the inertial effects along the essentially free fall jump downstream from the ramps intensify the turbulence and the air mixing process along the upper nappe as well[1].

A preliminary evaluation of the global aeration effect can be gathered from the final bulking of the flow at the flip bucket exit. Water depths estimated from photographs, see figure 2, were compared with unaerated computed water depths. Table 1 illustrates the results obtained for different water discharges.

If the average flow velocity is considered unaffected by the air concentration, and air compressibility is disregarded, the bulking effect measures the amount of air in the mixture:

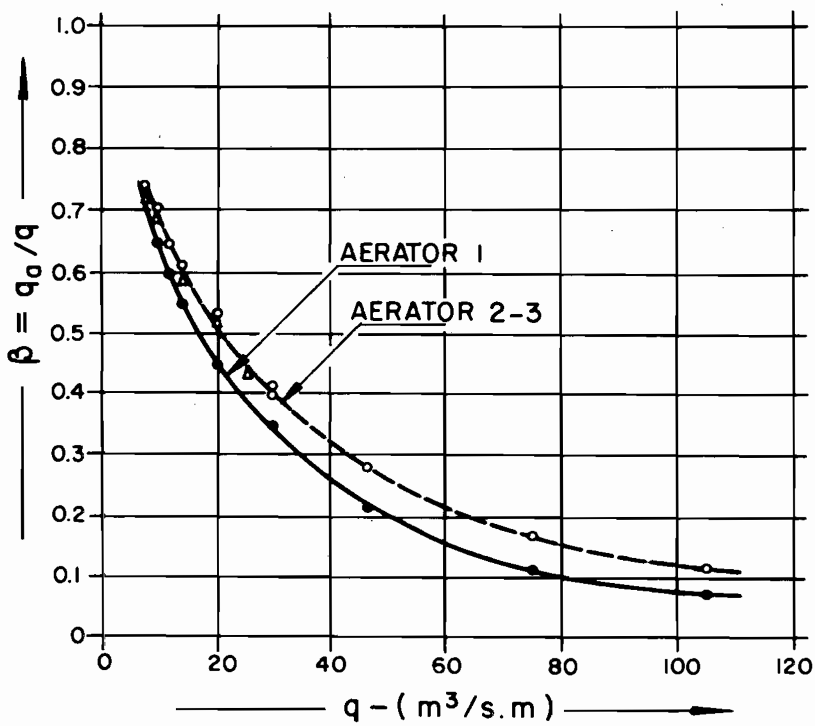

Fig. 1 - Foz do Areia spillway - Performance curves of the aerators[2].

$$\frac{h}{h_t} = 1 + \beta \qquad (1)$$

where:

h = observed depth of the air-water mixture.
h_t = theoretical depth of the unaerated flow.
β = q_a/q, dimensionless relation between air and water flow.

Actually, the effect of the pressure within the flow should be taken in consideration when evaluating the bulking due to air entrainment. Expression (1) should preferably read

Fig. 2 - Foz do Areia spillway - Flow conditions at the flip bucket exit.

TABLE 1

COMPARISON BETWEEN THE AIR ENTRAINED THROUGH THE AERATORS AND THE FINAL BULKING OF THE FLOW

Q (m^3/s)	q $m^3/s.m$	h m	h_t m	(a) $h/h_t - 1$	β - aerators 1	2	3	(b) Σ β	(a)−(b)
1 470	20.82	1.20	0.73	0.64	0.45	0.53	0.53	1.51	− 0.87
3 300	46.74	2.20	1.28	0.72	0.22	0.29	0.28	0.79	− 0.07
5 300	75.07	3.45	1.85	0.86	0.12	0.17	0.17	0.46	+ 0.40
7 400	104.8	4.6	2.45	0.88	0.07	0.12	0.12	0.31	+ 0.57
8 500	120.4	5.0	2.76	0.81	0.07	0.11	0.11	0.29	+ 0.52

$$\frac{h}{h_t} = 1 + \frac{P_a}{p}\beta$$

in which

p_a = atmospheric pressure.
p = average absolute pressure within the mixture.

Along the flip bucket, that effect could be particularly important as floor pressures due to the curvature of the flow may reach values 8 to 10 times the normal hydrostatic pressure. The resulting high pressure gradient normal to the flow in the flip bucket and the fast rate of variation of the pressure field should influence the depth actually observed at the flip bucket exit. Nevertheless, the results of Table 1 do point out that for higher flows the total bulking far exceeds the effect that could be presumed from the air been entrained through the three aerators. It seems worthwhile to investigate the evolution of the air entrainment process along the spillway chute.

A set of reasonably good photographs of the spillway existed for discharges of 1,470, 5,300 and 8,500 m^3/s as exemplified in figure 3, 4 and 5. From those photographs it was possible to sketch the profiles of the free water surface, as shown in figure 6. Naturally, errors can be impor-

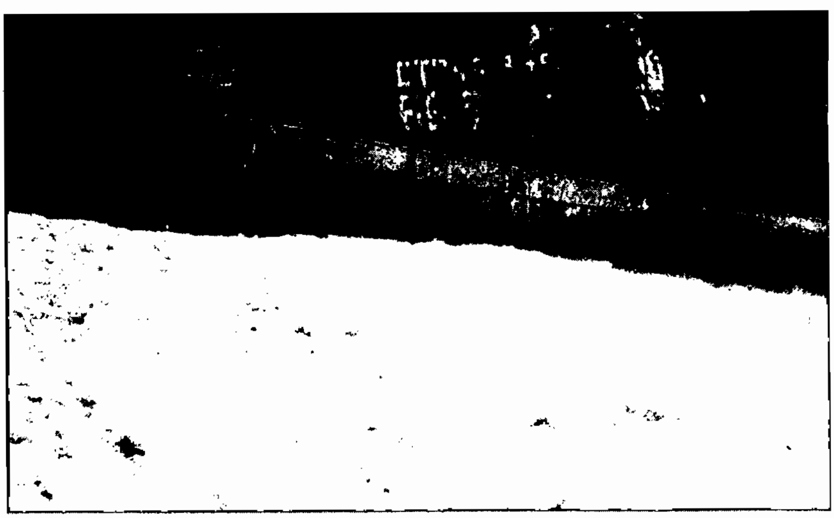

Fig. 3 - Aerator N° 2 Q = 1 470m^3/s.

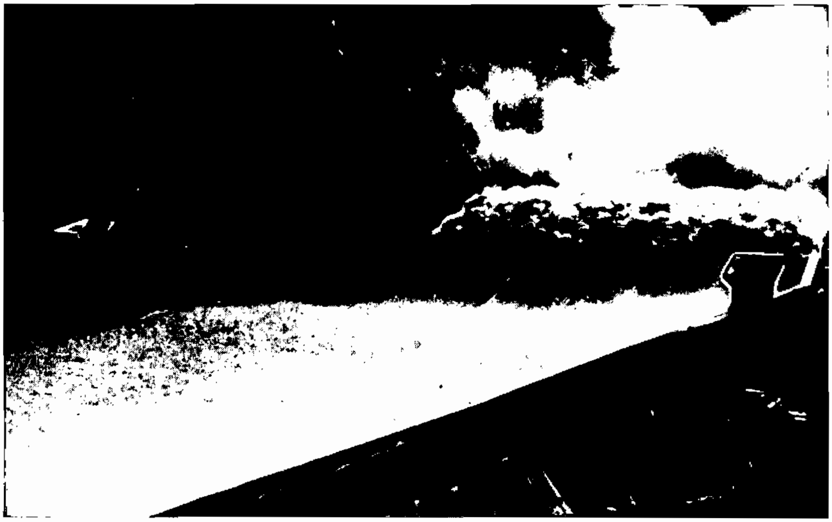

Fig. 4 - Aerator N° 3 Q = 1 470m³/s.

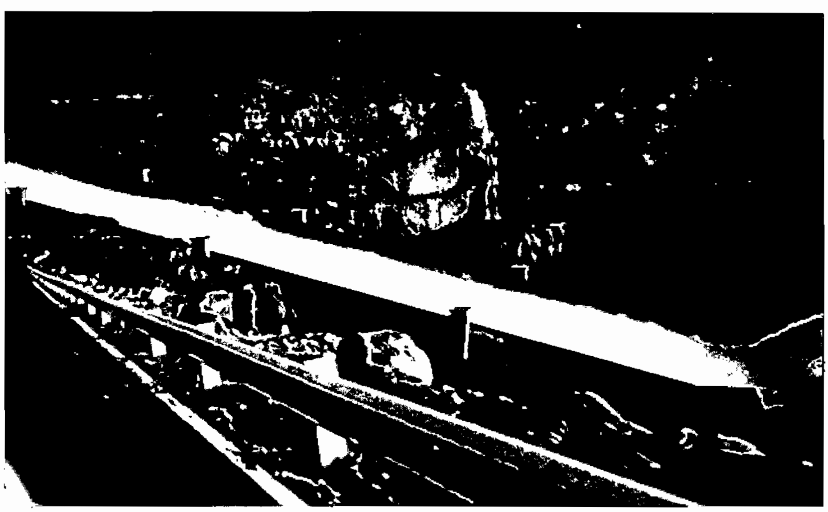

Fig. 5 - General view of the spillway Q = 5 300m³/s.

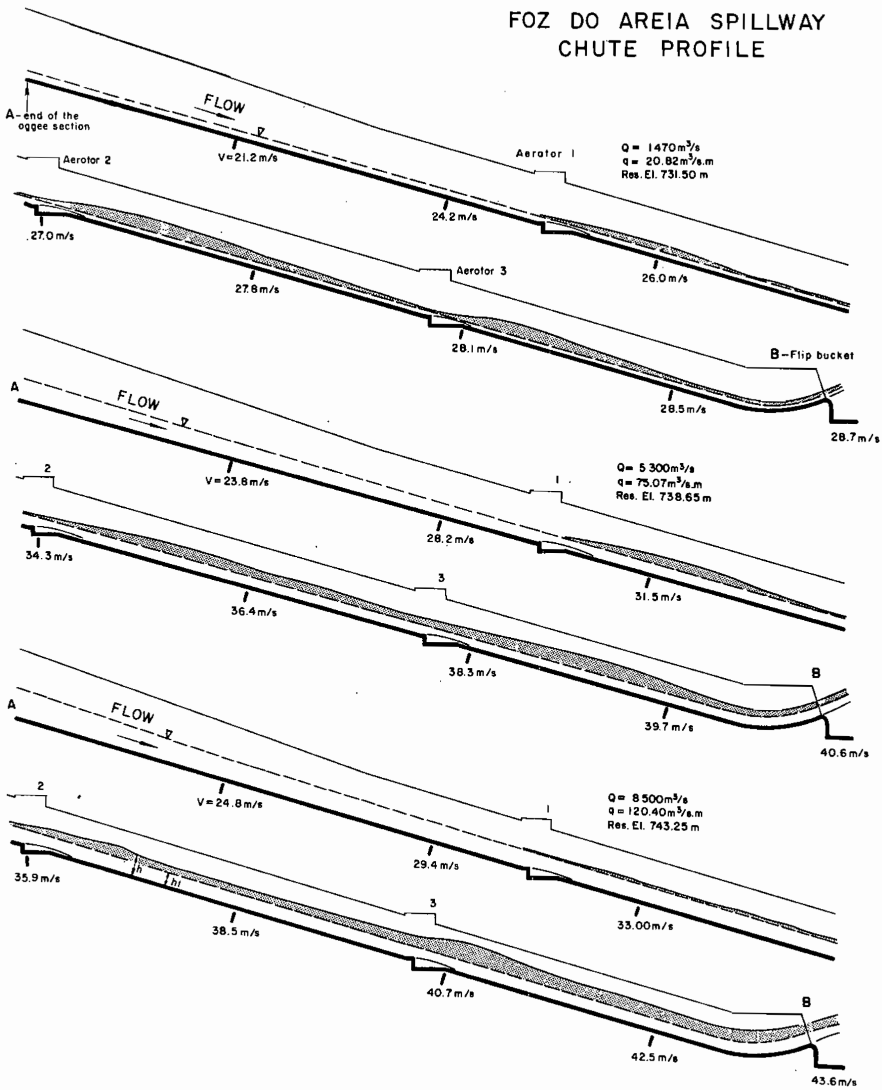

Fig. 6 - Observed free surface profiles.

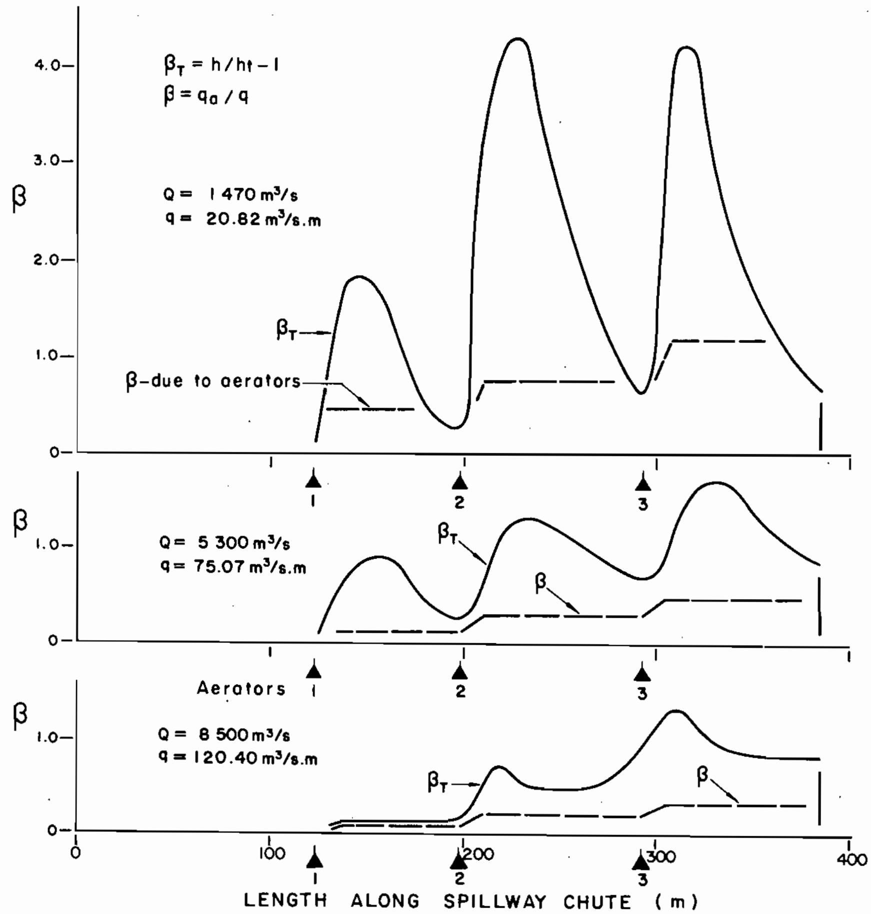

Fig. 7 - Evolution of β values along the flow.

tant as the water elevation had to be judged from sparse dimensional evidences in the photos such as the main dimensions of the aeration towers. However, approximate water profiles were developed which should be fairly representative of the actual water surface configuration.

Accepting the validity of expression 1, the water surface profiles furnish the corresponding β values along the chute, which are shown in figure 7, where the performance of each aerator is also identified.

It is to be noticed that essentially all entrained air is due to the action of the aeration ramps and not to the turbulence being generated at the boundary layer along the botton of the chute. Particularly for discharges of 5,300 m^3/s and 8,500 m^3/s the turbulent boundary layer would not have developed to the surface of the flow if aerators did not exist. Even for the discharge of 1,470 m^3/s, self aeration would start only about 200 m downstream from the ogee section, well beyond the emplacement of aerator N° 1.

From figures 6 and 7, several conclusions can be reached which help the understanding of the aeration phenomena:

— The entrainment of air occurs essentially along a strech 20 to 30 m long immediately downstream of each aerator.
— The proportion of air being entrained through the aerators proper is relatively modest.
— The main aeration mechanism seems to be related to the turbulence generated at the ramps and to the inertial effects in the essentially free fall jump following the aerator. Turbulence is not restrained by gravity along the free water jet which expands considerably. The resulting spray catches a great amount of air which is mixed into the water by the turbulent action.
— After the jump, gravity becomes again the main agent tending to move the air upwards through and away of the water. The settling of the intense spray back into the main water body results in an immediate reduction of the air concentration. Turbulence and gravity action tend to produce an equilibrated air concentration distribution further dowstream.
— For low specific discharges the spray mechanism is preponderant.
— For higher specific discharges, the effect of turbulence on air concentration becomes evident. As velocity and turbulence increase along the flow, air concentration tends to increase.
— The final bulking of the flow, especially for the higher specific discharges, is considerably greater than it could be reasonably expected from normal fully developed boundary layer turbulence.

The prototype evidence although sparse has contributed to the understanding of the mechanism of aeration of shooting flows. The above conclusions merit a more specific study for quantitative confirmation, ideally in other prototype structures as well. The effect of aeration on the energy dissipation process and consequently on the velocity of the flow constitutes also a question for further investigation.

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