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Interactions between a Developing Boundary Layer and the Free-Surface on a Stepped Spillway: Hinze Dam Spillway Operation in January 2013

by

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Summary

On a chute spillway (Fig. 1), the flow is accelerated by the gravity force component in the flow direction. For an ideal fluid flow, the flow field may be deduced from the solution of a Laplace equations combined with the Bernoulli principle (VALLENTINE 1969). In a real fluid flow, however, friction losses occur. At the upstream end, a turbulent boundary layer is generated by bottom friction and it develops in the flow direction. When its outer edge is close to the free-surface, the turbulence next to the air-water interface may induce some exchange of air and water between the atmosphere and water flow. Basically the free-surface breakup and air entrainment occur because the turbulent shear stress is greater than the surface tension force per unit area resisting the interfacial breakup (ERVINE and FALVEY 1987, CHANSON 2009). Once some air is entrained within the bulk of the flow, the break-up of air pockets occurs when the tangential shear stress is greater than the capillary force per unit area (HINZE 1955, CHANSON 2009). Downstream of the inception point of free-surface aeration, the flow is fully-developed and rapid free-surface aeration is observed (CHANSON 2001). Far downstream the flow will reach uniform equilibrium and for a given discharge any measure of flow depth, air concentration and velocity distributions will not vary along the chute.

In the developing flow region, the flow consists of a turbulent boundary layer next to the invert and an ideal-fluid flow region above. The water surface is un-aerated, often brown because of the suspended sediment matters. The inception point of air entrainment is characterised by some strong interactions between the flow turbulence and the free-surface. These were documented during the operation of the Hinze dam spillway on 29 January 2013. The head above crest was 3.8 m corresponding to a discharge per unit width of $q \approx 14$ m^2/s ($Re = \rho \times q/\mu = 1.4 \times 10^7$). Some video movies were taken with a Pentax™ K-7 equipped with a Pentax™ lens SMC FA 31mm F1.8 AL Limited (HD movie 30 fps) and Pentax™ K-01 with a Pentax™ lens SMC DA 18-

135mm F3.5-5.6 ED AL [IF] DC WR (HD movie 60 fps). The video observations highlighted the surface scars immediately upstream of the inception point. These scars are believed to be evidences of elongated hairpin vortices generated by boundary friction, stretched by the main strain field. The scars were about 1.5 m to 1. 7 m in size. The median vortical ejection frequency was 2.5 Hz and the standard deviation was 0.87 Hz. The probability distribution function of surface scar production frequency was skewed with a skewed with a preponderance of short frequencies relative to the mean. (The mode was about 2.2 Hz.)

Next to the step cavities, frequent though random occurrences of events take place including outflows from the cavities into the main flow and inflows into the cavities with considerable exchange of fluid between the cavities and the external flow, and periods where the skimming cavity flows have no significant exchange of fluid (ELVARASAN et al. 1995, DJENIDI et al. 1999).

Keywords: Turbulent boundary layer, Free-surface flow, Air-water flow, Instabilities, Prototype flow.

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Fig. 1 - Photograph of the Hinze dam stepped spillway (Australia) shortly before completion (Courtesy of SEQ Water)