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SELF-AERATED FLOWS ON CHUTES AND SPILLWAYS

Closure by H. CHANSON[1]

The writer thanks the discusser (ANWAR 1994) for his interesting comments and information. The writer wishes to clarify three points : free-surface instabilities, calculations of the inception point of air entrainment and analogy between self-aerated flows and sediment-laden flows.

1- In his paper (CHANSON 1993), the author did not address the effects of free-surface instabilities (e.g. roll waves) on the location of the point of inception. He agrees with the discusser that free-surface instabilities and roll waves might induce free-surface aeration upstream of the position where the outer edge of the boundary layer reaches the free-surface.

For small discharges, it is known that the free-surface becomes unstable and is characterised by the formation of a series of roll waves (e.g. CORNISH 1910, KEULEGAN and PATTERSON 1940). Several criteria were developed to characterise the instability of uniform free-surface flows (CHOW 1959, ROUSE 1965). For turbulent flows, ROUSE (1965) predicted instabilities for $Fr > 1.3$ to $1.7 \sqrt{\cos\alpha}$ where Fr is the Froude number. For laminar sheet flow, CHEN (1993) showed that roll waves develop for $Fr > 0.527 \sqrt{\cos\alpha}$.

For the experiments of the discusser (fig. 2 of the discussion), the author estimates that the Froude number exceeds probably these critical values and roll waves are likely to develop. The development of free-surface instabilities and roll waves enhances the turbulence near the free-surface, and higher level of turbulence might induce self-aeration if equations (1) and (2) are satisfied. Air entrainment might appear upstream of the location where the outer edge of the bottom boundary layer reaches the free-surface if the free-surface instabilities are large enough.

2- The discusser compared his results with the calculations of WOOD et al. (1983). The writer wants to emphasise that the formula of WOOD et al. (1983) were fitted from KELLER and RASTOGI's (1975, 1977)

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calculations and that they were verified with model and prototype data obtained with steep slopes only (i.e. $\alpha > 40$ degrees) (fig. C-1).

The writer performed new experiments in a flat channel ($\alpha = 4$ degrees). The flume was made of planed wooden boards ($k_s = 1$ mm) and is 0.5 m wide. Velocity distributions were measured at various locations along the flume using a Pitot tube. The position of the inception point of air entrainment coincided with the location where the outer edge (δ_{99}) of the boundary layer reaches the free-surface. The Froude numbers at the point of inception ranged from 7.5 up to 10.5. The experimental results are shown on figure C-1 as well as the data of the discusser. Both set of data obtained with flat slopes (4 and 11 degrees respectively) indicate that the empirical correlation of WOOD et al. (1983) is not accurate for flat chutes. The writer believes that further experimental investigations are required to provide accurate predictions of the inception point on flat spillways.

3- The analogy between self-aerated flows and suspended sediment flows was extended recently by the writer (CHANSON 1994). In sediment-laden flows, and despite earlier controversies, the velocity distribution in the inner flow region follows the classical logarithmic profile (COLEMAN 1981, LYN 1988) and the Von Karman constant is 0.4. But suspended sediment is observed either to increase or to decrease the friction factor. Historical cases of drag reduction include observations of suspended silt flood flows in the Nile (BUCKLEY 1923), Indus (LACEY 1923) and Mississippi (McMATH 1883) rivers. A recent study (CHANSON and QIAO 1994) suggested that drag reduction in suspended sediment flows is observed only : (A) for starved bed flows or rising flood flows (i.e. with no sediment deposition), and (B) with micro-particles ($\varnothing < 0.1$ mm).

The writer believes that the subject is still open to discussion.

APPENDIX I. REFERENCES

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APPENDIX II. NOTATION.

Fr = Froude number defined as : $Fr = q_w/\sqrt{g\ d^3}$;

F* = Froude number defined in term of the roughness height : $F_* = q_w/\sqrt{g \cos\alpha\ k_s^3}$;

L_I = distance (m) from the start of the growth of the boundary layer to where it reaches the free-surface;

δ_{99} = thickness (m) of the boundary layer defined as the location where the velocity equals 99% of the free-stream velocity.

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Figure C-1 - Location of the point of inception L_I/k_s - Comparison between prototype data (Aviemore, Chastang, Douglas, Glenmaggie, Norris, Werribee), the discusser's data (ANWAR) and the writer's data (CHANSON)