# Discussion of "Case Study of Prototype Hydraulic Jump on Slope: Air Entrainment and Free-Surface Measurement" by Zhongtian Bai, Ruidi Bai, Rongcai Tang, Hang Wang, and Shanjun Liu

Hubert Chanson

Professor in Hydraulic Engineering, School of Civil Engineering, Univ. of Queensland, Brisbane, QLD 4072, Australia. ORCID: https://orcid.org/0000-0002-2016-9650. Email: h.chanson@uq.edu.au

https://doi.org/10.1061/(ASCE)HY.1943-7900.0001916

The original article presented a challenging and interesting case study of hydraulic jump in a real-world application and discussed a number of very relevant practical considerations. In this discussion, it is argued that some air-water results showed differences from traditional air-water flow results in the laboratory for a number of reasons, including different inflow and boundary conditions. In turn, one needs to be careful with some definitive conclusions, especially based on one flow condition with a Reynolds number close to some of the largest laboratory studies to date.

The authors did well to discuss the use of phase-detection needle probes in the field and the associated practical considerations. During field studies, needle probe sensors may be damaged by quartz particles and small debris, as previously discussed at the Aviemore Dam spillway (Keller 1972; Cain 1978) and reported in several laboratory studies conducted with high velocities (Low 1986; Cummings 1996; Gonzalez 2005). Furthermore, the water quality, including salinity and presence of surfactants, may adversely affect the signal outputs of phase-detection electrical probes (Timkin et al. 2003; Chanson et al. 2006; Salter et al. 2014), including the air-water flow properties in hydraulic jumps (Reif 1978; Pothof et al. 2013). Importantly, the single-threshold technique applied by the authors might not be the best phase-discrimination method in the presence of adverse water quality effects (Jones and Delhaye 1976; Chanson et al. 2002). A double-threshold technique, a differentiation technique, or a combination of signal thresholds and gradient threshold could be more suitable, although some validation would be required. For example, a combination of signal thresholds and gradient threshold might be performed successfully for the probe signal shown in Fig. 2(a) of the original article. Simply, "the signal processing [of phase-detection needle probes] is not trivial, even in simple steady one-directional flows" (Chanson 2020).

The case study was conducted in a B-jump, i.e., a hydraulic jump down a sloping chute immediately downstream of a sluice gate. Such jumps are also common in some standard culverts with drop inlets and in minimum-energy-loss culvert inlets operating under less than design flow conditions (Fig. 1). Several studies showed that both the boundary conditions and inflow conditions significantly affect the air-water flow properties in hydraulic jumps. Resch and Leutheusser (1972) demonstrated some seminal differences in hydraulic jump rollers with identical inflow Froude numbers between partially and fully developed inflow conditions, the former likely corresponding to the case study inflow. Mignot and Cienfuegos (2011) showed that turbulence production was primarily confined to the developing shear layer in the case of partially developed inflow, with Chanson and Brattberg (2000) arguing that the free-surface velocity immediately upstream of the roller is the most relevant velocity scale. Thandaveswara (1974) and Stojnic et al. (2021) presented air-water data in hydraulic jumps located downstream of a steep chute, showing the significant role of pre-air entrainment. That is, the inflow aeration modified the hydraulic jump roller characteristics, including its length and the air diffusion process. In horizontal channels with partially developed inflow, several studies investigated the effects of large bed roughness (Pagliara et al. 2010; Felder and Chanson 2018; Bahmanpouri et al. 2019). The experimental observations showed a drastic modification of both roller flow patterns and air-water flow properties. Fig. 2 presents a comparison in terms of the vertical distributions of void fraction and dimensionless frequency for three data sets measured for a similar Froude number $Fr_1$ at comparable dimensionless locations $x/d_1$ from the roller toe (Table 1). That is, the case study (B-jump) data are compared to classical hydraulic jump data (smooth invert) (Chachereau and Chanson 2011) and measurements in a horizontal hydraulic jump with artificial bed roughness (Felder and Chanson 2018). The comparative results showed markedly different trends, aeration levels, and fragmentation rates. Such differences were most likely linked to the different boundary conditions because all the data (in Fig. 2) were collected with similar dual-tip phase-detection probes and characterized by some partially developed inflow (Table 1). Simply, any true comparison of air-water flow properties in hydraulic jumps must be based on data sets with comparable boundary and inflow conditions.

Finally, the authors are correct to remind us of the absence of benchmark data sets for any investigations of scale effects affecting the air-water flow properties in large prototype stilling basin operating at large Reynolds numbers ($Re > 10^7$). Yet, a recent data set (Estrella et al. 2022) investigated the air-water flow properties in

**Fig. 1.** B-jump in a minimum-energy-loss culvert inlet at Stones Corner on March 30, 2017 (shutter speed = 1/200 s, $\alpha = 4°$).



J. Hydraul. Eng., 2022, 148(11): 07022006

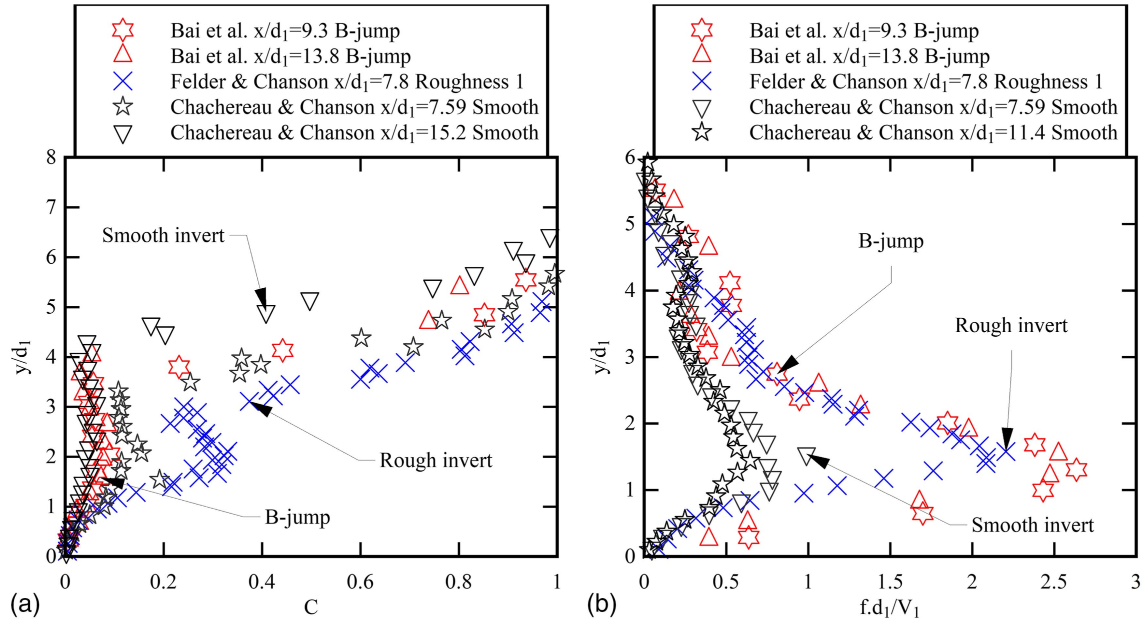


**Fig. 2.** Comparative distributions of void fraction $C$ and dimensionless bubble frequency $f \cdot d_1/V_1$ in hydraulic jumps with comparable inflow Froude number $Fr_1$ at similar dimensionless locations $x/d_1$ (Table 1): (a) void fraction; and (b) bubble frequency.

**Table 1.** Comparative studies of air entrainment in hydraulic jumps with comparable inflow Froude number $Fr_1$ at similar dimensionless locations $x/d_1$

| Reference | Invert slope $\alpha$ | Invert conditions | $d_1$ | $Fr_1$ | Re | $x/d_1$ | Comment |
|---|---|---|---|---|---|---|---|
| Case study | 15.5 | Sloping concrete ($\alpha = 15.5°$) | 0.145 | 5.1 | $9 \times 10^5$ | 9.3, 13.8 | B-jump |
| Felder and Chanson (2018) | 0 | Artificial roughness 1 ($k_s \sim 12$ mm) | 0.045 | 5.5 | $1.6 \times 10^5$ | 7.8 | Rough invert |
| Chachereau and Chanson (2011) | 0 | PVC | 0.0395 | 5.1 | $1.3 \times 10^5$ | 7.6, 15.2 | Smooth invert |

weak hydraulic jump with Reynolds number between $0.08 \times 10^5$ and $3 \times 10^5$. At the largest Reynolds number, the results did show a sizable number of large bubbles, in amounts comparable to the case study. The finding was further consistent with other laboratory studies at higher Froude numbers (Chanson 2007; Montano and Felder 2020). In the present case study, the results might not be truly Froude-similar to past laboratory studies because of the marked differences in inflow and boundary conditions. Maybe the key outcomes are (1) a need for field measurements of air-water flow in large prototypes; and (2) the necessity for detailed air-water flow measurements in B-jump, to complement the present case study.

## Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

## Notation

*The following symbols are used in this paper:*

$d_1$ = inflow depth (m);
$Fr_1$ = inflow Froude number;
Re = Reynolds number;
$x$ = longitudinal distance (m) from the roller toe positive downstream;
$y$ = vertical distance (m) measured normal to the invert; and
$\alpha$ = angle between longitudinal invert slope and horizontal.

## References


Bahmanpouri, F., C. Gualtieri, and H. Chanson. 2019. "Air-water flow characteristics in hydraulic jump on pebbled rough bed." In *Proc., 38th IAHR World Congress*, edited by L. Calvo, 2040–2048. Madrid, Spain: International Association for Hydro-Environment Engineering and Research Publication. https://doi.org/10.3850/38WC092019-0557.

Cain, P. 1978. "Measurements within self-aerated flow on a large spillway." Ph.D. thesis, Dept. of Civil Engineering, Univ. of Canterbury.

Chachereau, Y., and H. Chanson. 2011. "Bubbly flow measurements in hydraulic jumps with small inflow Froude numbers." *Int. J. Multiphase Flow* 37 (6): 555–564. https://doi.org/10.1016/j.ijmultiphaseflow.2011.03.012.

Chanson, H. 2007. "Bubbly flow structure in hydraulic jump." *Eur. J. Mech. B. Fluids* 26 (3): 367–384. https://doi.org/10.1016/j.euromechflu.2006.08.001.

Chanson, H. 2020. "On velocity estimations in highly aerated flows with dual-tip phase-detection probes—A commentary." *Int. J. Multiphase Flow* 132 (10): 103330. https://doi.org/10.1016/j.ijmultiphaseflow.2020.103330.

Chanson, H., S. Aoki, and A. Hoque. 2002. "Similitude of air bubble entrainment and dispersion in vertical circular plunging jet flows." In *An experimental study with freshwater, salty freshwater and seawater*. Tokyo: Toyohashi Univ. of Technology.

Chanson, H., S. Aoki, and A. Hoque. 2006. "Bubble entrainment and dispersion in plunging jet flows: Freshwater versus seawater." *J. Coastal Res.* 22 (3): 664–677. https://doi.org/10.2112/03-0112.1.

Chanson, H., and T. Brattberg. 2000. “Experimental study of the air-water shear flow in a hydraulic jump.” *Int. J. Multiphase Flow* 26 (4): 583–607. https://doi.org/10.1016/S0301-9322(99)00016-6.

Cummings, P. D. 1996. “Aeration due to breaking waves.” Ph.D. thesis, Dept. of Civil Engineering, Univ. of Queensland.

Estrella, J., D. Wüthrich, and H. Chanson. 2022. “Two-phase air-water flows in hydraulic jumps at low Froude number: Similarity, scale effects and the need for field observations.” *Exp. Therm. Fluid Sci.* 130 (Jan): 1–21. https://doi.org/10.1016/j.expthermflusci.2021.110486.

Felder, S., and H. Chanson. 2018. “Air–water flow patterns of hydraulic jumps on uniform beds macroroughness.” *J. Hydraul. Eng.* 144 (3): 04017068. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001402.

Gonzalez, C. A. 2005. “An experimental study of free-surface aeration on embankment stepped chutes.” Ph.D. thesis, Dept. of Civil Engineering, Univ. of Queensland.

Jones, O. C., and J. M. Delhaye. 1976. “Transient and statistical measurement techniques for two-phase flows: A critical review.” *Int. J. Multiphase Flow* 3 (76): 89–116. https://doi.org/10.1016/0301-9322(76)90001-X.

Keller, R. J. 1972. “Field measurement of self-aerated high speed open channel flow.” Ph.D. thesis, Dept. of Civil Eng., Univ. of Canterbury.

Low, H. S. 1986. *Model studies of Clyde dam spillway aerators*. Research Rep. No. 86–6. Christchurch, New Zealand: Univ. of Canterbury.

Mignot, E., and R. Cienfuegos. 2011. “Spatial evolution of turbulence characteristics in weak hydraulic jumps.” *J. Hydraul. Res.* 49 (2): 222–230. https://doi.org/10.1080/00221686.2011.554208.

Montano, L., and S. Felder. 2020. “An experimental study of air–water flows in hydraulic jumps on flat slopes.” *J. Hydraul. Res.* 58 (5): 767–777. https://doi.org/10.1080/00221686.2019.1671512.

Pagliara, S., I. Carnacina, and T. Roshni. 2010. “Air-water flows in the presence of staggered and row boulders under macro roughness conditions.” *Water Resour. Res.* 46 (11): W08535. https://doi.org/10.1029/2009WR008834.

Pothof, I. W. M., A. D. Schuit, and F. H. L. R. Clemens. 2011. “Influence of surface tension on air-water flows.” *J. Hydraul. Eng.* 139 (1): 44–50. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000637.

Reif, T. H. 1978. *The effects of drag reducing polymers on the turbulence characteristics of the hydraulic jump*. Rep. No. EW-11-78, 50. Annapolis, MD: US Naval Academy.

Resch, F. J., and H. J. Leutheusser. 1972. “Le ressaut hydraulique: Mesure de turbulence dans la région diphasique” [The hydraulic jump: Turbulence measurements in the two-phase flow region]. *Jl La Houille Blanche* 1972 (4): 279–293. https://doi.org/10.1051/lhb/1972021.

Salter, M. E., E. D. Nilsson, A. Butcher, and M. Bilde. 2014. “On the seawater temperature dependence of the sea spray aerosol generated by a continuous plunging jet.” *J. Geophys. Res.: Atmos.* 119 (14): 9052–9072. https://doi.org/10.1002/2013JD021376.

Stojnic, I., M. Pfister, J. Matos, and A. J. Schleiss. 2021. “Effect of 30-degree sloping smooth and stepped chute approach flow on the performance of a classical stilling basin.” *J. Hydraul. Eng.* 147 (2): 04020097. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001840.

Thandaveswara, B. S. 1974. “Self aerated flow characteristics in developing zones and in hydraulic jumps.” Ph.D. thesis, Dept. of Civil Engineering, Indian Institute of Science.

Timkin, L. S., N. Riviere, A. Cartellier, and O. N. Kashinsky. 2003. “Performance of electrochemical probes for local void fraction measurement in air-water flows.” *Rev. Sci. Instrum.* 74 (8): 3784–3786. https://doi.org/10.1063/1.1596431.



J. Hydraul. Eng., 2022, 148(11): 07022006