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AIR-WATER FLOW PROPERTIES IN HIGHLY UNSTEADY FLOWS

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ABSTRACT

Recent catastrophic events caused by tsunamis, storm surges, flood waves, and the failure of dams (*e.g.* in Ukraine and Libya) have shown to be a significant threat to densely populated coastal communities. Interactions with built environments can lead to violent wave impacts that may have severe consequences, including significant infrastructural damage and potential loss of life. The frequency of these water-related disasters is increasing globally due to climate change and sea level rise, resulting in a rising demand for deeper knowledge related to the physical processes of such hazards.

The dynamic behaviour of these type of wave phenomena is described by long-period, high translatory waves, where the on-shore propagation or inland inundation is associated with sudden free-surface deformations. This results in a steeping of the slope at the leading edge, causing non-linear flow behaviour to prevail and inducing the wave to collapse. The breaking process generates a breaking roller at the wave front, containing a rapidly fluctuating mixture of air and water, associated with a strong recirculation. The high degree of air-water interaction in these unsteady flows has a significant impact on the flow properties as it influences many dynamic processes, including viscous and surface tension effects at air-bubble level, as well as larger scale gravitational effects associated with the turbulent flow and eddy formation (Brocchini and Peregrine, 2001). New innovative measurement techniques have allowed experimental studies to more precisely quantify the air-water interactions in multiphase flows. However, most experimental research focused on air-water flow properties in hydraulic jumps and other steady flows (*e.g.* spillway flows, plunging jets). Currently, limited research is available for unsteady flows and mostly based on small datasets and limited flow conditions. This lack of availability and diversity of experimental data restricts the understanding of how these multi-phase flows behave under different conditions, hence the need for future research.

In this context, this experimental study quantifies the level of aeration and its distribution under various flow conditions. The analogy with dam-break waves is commonly used to study the behaviour of long-period, highly unsteady waves that characterise tsunami and storm surge events (Chanson et al., 2003). Therefore, new sets of experiments were conducted in the hydraulic laboratory at the TU Delft, considering dam-break wave propagation over changing tailwater depths. The dam break waves were generated in a flume 14.5m long, 0.4m wide and 0.5m high, using a lift gate system. The rapid opening of the gate causes a sudden release of a body of water which generates a bore wave propagating downstream. Different flow conditions were obtained through variation of the initial still tailwater level, h_0, at the downstream side of the gate, while maintaining a constant impoundment depth, d_0, of 0.4m for all tests (i.e., $0.04 < h_0/d_0 < 0.16$). The different flow characteristics are summarized in Table 1, with Froude and Reynolds numbers defined as $Fr = U/\sqrt{gh_0}$ and $Re = (\rho U h_0)/\mu$, respectively.

The moving flows are investigated using three Acoustic Displacements Meters (ADMs), leading to a quantification of the wave profiles and celerity. In addition, an array of four phase-detection conductivity probes are sampled at 100 kHz to quantify the air-water characteristics, capturing the presence of air or water associated with the different levels of conductivity (i.e. low conductivity = air; high conductivity = water). The unsteadiness of the flow required a large number of repetitions, to obtain physically meaningful and statistically reliable results (Wüthrich et al., 2022). Therefore, a total of 200 repetitions were conducted for each flow condition, where a reference probe was located at a fixed elevation 2mm above the initial water level to allow for the synchronisation of all tests. The remaining probes were placed at various elevations in the vertical direction and shifted to cover 13 different elevations, while each elevation was sampled for 50 repetitions. Data analysis

involved statistical approaches, including ensemble-average techniques, leading to the estimation of the main air-water flow properties. The results include a quantification of the void fraction, the number of air-water interfaces and distributions of the bubble chord time/length. Data showed a strong influence of tailwater level on both the number of interfaces and the void fraction, associated with the decreasing Froude number (Table 1). For all flow conditions, a local maximum of interfaces appeared slightly above the initial water level, indicating the presence of a turbulent shear layer, in line with previous observations in hydraulic jumps. Overall, these results support the development of this new methodology to investigate air-water flow properties in highly unsteady flows, providing a deeper understanding of the air-water flow parameters within the breaking roller.

Table 1. Test program - flow conditions

flow condition	impoundent depth d_0 [mm]	tailwater level h_0 [mm]	h_0/d_0	Fr	Re
FC1	400	16	0.04	5.4	$0.34 \cdot 10^{-5}$
FC2	400	32	0.08	3.6	$0.64 \cdot 10^{-5}$
FC3	400	48	0.12	2.8	$0.93 \cdot 10^{-5}$
FC4	400	64	0.16	2.4	$1.22 \cdot 10^{-5}$

Figure 1. Recirculating air-water mixture in breaking roller

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