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NUMERICAL MODELING OF AIR ENTRAINMENT IN STEPPED SPILLWAYS: A COMPARISON OF RANS AND DES

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Abstract. This study investigates the numerical modeling of air entrainment in stepped spillways by employing two distinct turbulent closures: a Reynolds-Averaged Navier-Stokes (RANS) closure and a Detached Eddy Simulation (DES) closure. These closures are coupled with a Volume-of-Fluid method to capture the position of the free surface. The RANS simulation is based on a three-phase mixture formulation and the compressible formulation of the $k - \epsilon$ model and a criterion based on a balance between disturbing energy and stabilizing energies to determine the regions where air is entrained. The DES model is based on the Spalart-Allmaras model, and no sub-grid model is used for the dispersed air phase. Both methodologies demonstrate excellent agreement with the experimental data. While the RANS model requires more user input and is sensitive to calibration parameters, the DES model delivers satisfactory results without requiring any calibration. The current stage of development of the RANS model, it provides information regarding bubble concentration and level of bulking. In contrast, the DES model not only provides this information but also captures the bubble size distribution and rate of entrapped to entrained air. Although the DES model offers some advantages, it comes at a higher computational cost, approximately $\mathcal{O}(10^3)$ times that of the RANS model, with a corresponding cell count $\mathcal{O}(10^2)$ times higher. It should be noted that the DES model still presents limitations concerning the sub-grid scales: Special treatment of the interfaces at bubble scale are required to avoid bubbles of unrealistic densities. Both techniques exhibit strengths and weaknesses that make them suitable for different applications. The future research directions for both model types are also highlighted.