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SIMULATION OF SKIMMING FLOW OVER MODERATE STEPPED SPILLWAYS USING SMOOTHED PARTICLE HYDRODYNAMICS

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Stepped spillways are mainly designed to act as energy dissipators and protective measures against cavitation damage. Although air plays a vital role in protecting the surface of this structure against this damage, it may be entirely absent or insufficiently present over the upstream reach of the chute, which is known as the non-aerated flow region, especially with skimming flow conditions (Chanson, 2002). The behaviour of the pressure, as a main parameter to predict the cavitation tendency, in the non-aerated flow region on moderate slopes has been the subject of only a limited number of research studies. Understanding the pressure pattern on the step faces under severe conditions is therefore an important aspect of improving the design of said structures. The current work is a numerical investigation which presents and describes the features of the pressure flow field on the horizontal and vertical faces of steps situated in the non-aerated flow region. The coordinate of the inception point, based on the predicted free water surface level and velocity profile at the outer edge of steps, and are also predicted and compared with the existing experimental results. These are examined under a range of flow rates typical of skimming flow regime on a stepped spillway of 1V:2H bottom inclination.

The present work applies the 2D SPHysics open source code as an implementation of the computational Smoothed Particle Hydrodynamics (SPH) method. This method is characterized by a pure meshfree and Lagrangian approach in which grids, used in grid based methods, are replaced by arbitrarily distributed particles carrying the fluid properties (Monaghan, 1989). This code solves the Navier-Stokes governing equations considering the fluid as weakly compressible which allows the explicit determination of the pressure flow field by solving an equation of state (Gómez-Gesteira *et al.* 2010). A cubic spline kernel is used as the interpolation function and a Verlet time integration scheme is adopted. The effect of the flow field turbulence is introduced using the SPS technique and the repulsive boundary condition is applied to generate the solid wall particles. Further, the moving least square approach is utilized to stabilize the pressure flow field and the first order kernel correction technique is used to achieve the consistency and normalization conditions of the kernel function. In this study the code is firstly validated against two existing experimental test cases, namely; flow over broad crested weirs carried out by Hager *et al.* (1994) and a stepped spillway of 1V:2H slope similar to the laboratory model of Meireles *et al.* (2009). Figure (1) plots the numerical velocity profiles predicted by the SPHysics code and the experimental results gathered by Hager *et al.* (1994) at $x/H_o = 0.5$, where x is the distance along the crest originating at its upstream corner, H_o is the approach total head with respect to the crest level, u is the horizontal velocity at distance y measured from the crest. Free surface profiles of

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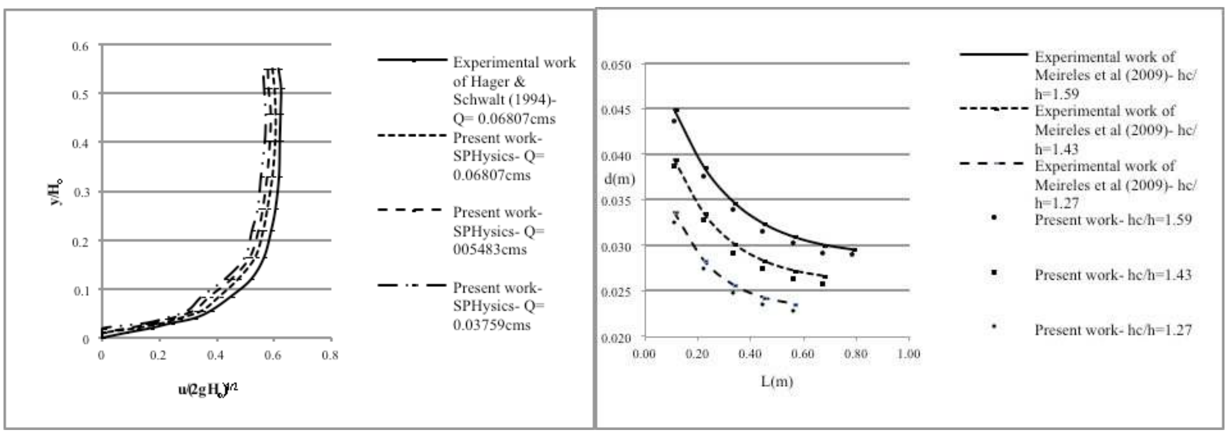
the experimental and numerical results of skimming flow over the stepped spillway model for three different discharge values represented by the dimensionless parameter h_c/h, where h_c is the critical flow depth over the crest and h is the step height, are shown in Figure (2). The validated code is then applied to predict the hydrodynamic pressures applied on the step faces under various discharges within the range of skimming flow.

The authors observed that the numerical results, in terms of free surface, velocity and pressure profiles, obtained from the current model are in reasonable agreement with the experimental results. This demonstrates the capability of the SPHysics code, as a particle based scheme, to accurately simulate the flow properties over stepped spillways. Furthermore, from the pressure profiles, on both faces of different steps in the non-aerated flow region, the positions of peak positive and negative pressure values are indicated. Negative pressure values are predicted at some boundary points close to top of the vertical step face with a maximum value at the upper point, whereas the pressure values along the horizontal face are almost positive with a maximum value located far from the step outer edge about 0.35-0.45 the whole length of the horizontal step face.



(a) (b)

Figure 1 (a) Non-dimensional horizontal flow velocity at $x/H_o = 0.5$ (b) free surface profiles along the chute in the flow direction

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