# TWO-DIMENSIONAL ANALYSIS ON SOLID-LIQUID-PHASE FLOW IN AN OPEN CHANNEL WITH A RUBBLE MOUND GROIN

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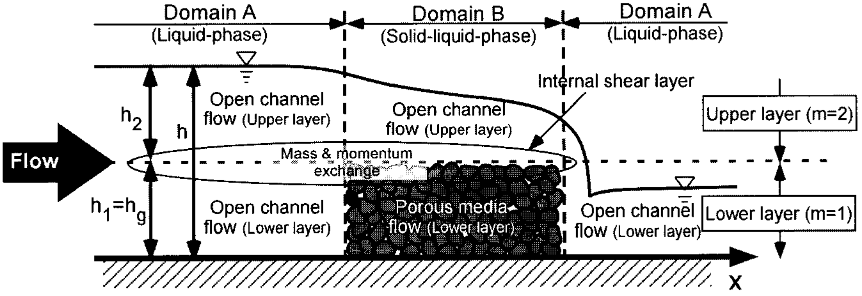


Fig. 1 Schematic side view of the flow system.

A two-dimensional numerical model was developed for describing the solid-liquid-phase flow in an open channel where a permeable rubble mound groin was installed. The computational domain in the analysis was divided into two regions, i.e. (1) a single-phase open channel flow and (2) a liquid-solid- phase flow consisting of an upper layer over the rubble mound groin and a porous media flow inside the groin. As shown in Fig.1 the whole domain was considered to have a two-layer structure with an interfacial boundary at the same level as the rubble mound's top surface. Momentum and mass exchange through the interface was taken into account by using the concept of entrainment velocity between the upper and lower layers.

Numerical analysis was conducted for an open channel flow with a single rubble mound groin installed perpendicularly to the bank, as shown in Fig.2. Numerical solutions for flow structures were obtained not only outside but also inside the groin.

Fig.3 shows an example of solutions for velocity vectors compared with the laboratory data, where the rubble mound is submerged ($h>h_g$: Case B-3). The analysis shows good agreement with the experiment not only for velocity but also water surface profile, effect of groin's porosity and grain diameter on the flow structure, etc.

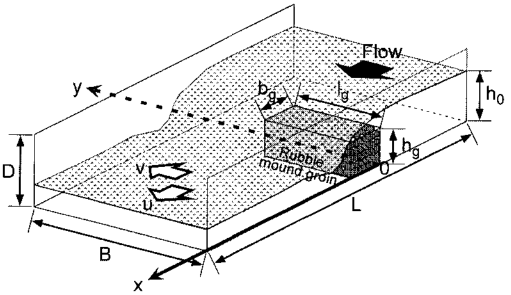
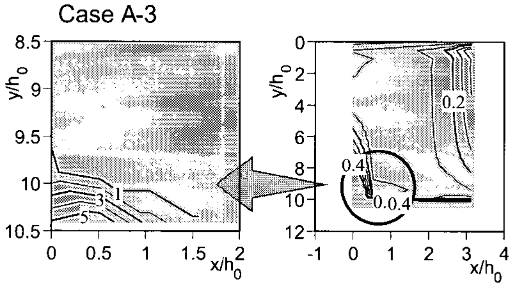
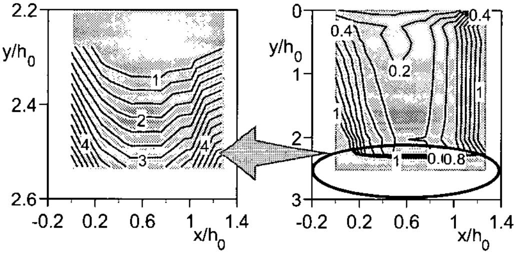


Fig. 2 Flow system with a rubble mound groin.



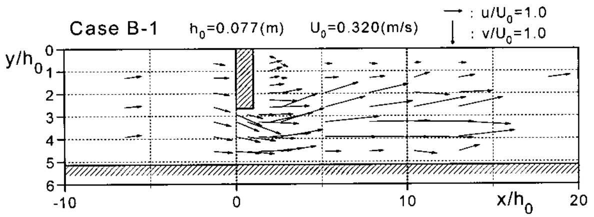
(a) $h<h_g$ (Case A-3)



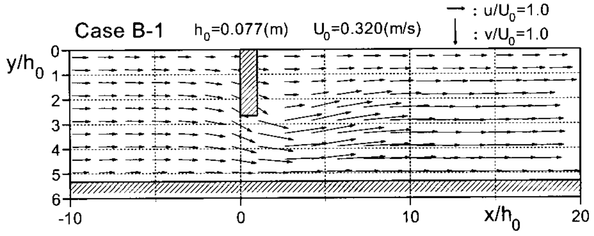
(b) Submerged groin ($h>h_g$: Case B-3)

Fig.4 Distribution of normalized drag force $\widetilde{F}_P$ in the groin.

The present model also provides solutions for flow force acting on the rubble mound $\widetilde{F}_P$. Fig.4 represents the horizontal distribution of dimensionless drag force in the groin. The figure shows that the drag force is particularly predominant around tip of the groin. This suggests that the structure is most likely to collapse around this area, and some countermeasures are required for reinforcing the groin. Another interesting feature is that in Case A-3 ($h<h_g$), the drag force reaches its maximum value around the upstream-side corner of the groin, while the maximum drag force is found on both sides of the corners in Case B-3 ($h>h_g$).

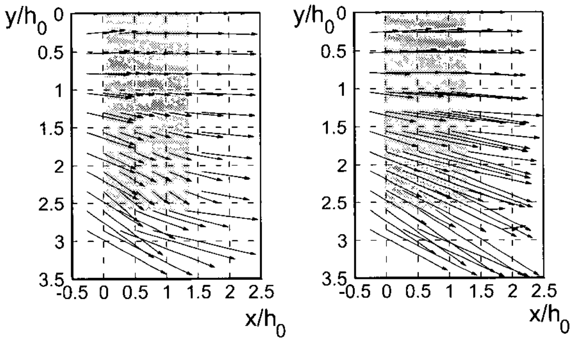


(a) Experiment



(b) Numerical solution

Fig.3 Velocity vectors ($h<h_g$: Case B-1).



(a) lower layer (in rubble mound) (b) upper layer

Fig. 5 Velocity vectors in and above the rubble mound ($h>h_g$).

Fig.5 shows the solutions of the velocity vectors above and inside the groin, where the velocity in the lower layer is an apparent velocity component ($U_S$, $V_S$). Since flow fields in the rubble mound are closely related with the turbulent structure that eventually plays an important role in environmental processes such as aeration, water purification, aquatic life habitat, etc., the present analysis provides flow property information that is useful in terms of environmental considerations as well as hydraulic design. This is one advantage of the present analysis, although the flow in the rubble mound can hardly be measured in a physical model.

The present analysis is expected to be a powerful engineering tool for performing suitable designs for rubble mound river structures that create a more desirable water environment in river courses.