Manning Friction in Steep Open-channel Flow

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Abstract: The Manning friction in steep open-channel flow is calculated directly from numerical simulation for several channel geometries including the flow through the meandering river. The results covering a full range of Froude number from Fr = 0.2 to Fr = 3.0 are correlated with the size of the macro roughness and the flow depth. A new correlation for the flow resistance in steep channel is proposed to replace the traditional formulation using the Manning formula.

Keywords: Turbulence Modeling, Wave Radiation, Manning Friction, Open Channel Flow, Computational Hydraulics.

1 Introduction

The navigation of waters around rocks and boulders in mountain stream is a process that is unique and distinctively different from the slow flow through large rivers. In steep channels, the flow changes rapidly from subcritical to supercritical at the control sections. Significant energy dissipation occurs in the hydraulic jumps as the supercritical flow returns to its subcritical state. The steep mountain stream shown in Fig. 1 (a) is an example. The resistance to flow is traditionally parameterized using the Manning coefficient of friction n. The validity of the Manning formula however is not justifiable when the dimensions of the roughness are comparable to the width of the river.

In this paper, the flow resistance due to the macro roughness is determined directly from numerical simulations. The calculations are carried out using the shallow-water equations and the periodic boundary conditions for a variety of channels including the flow through meandering rivers. Fig. 1 (b) shows one flow through a uniform array of blocks that were obtained from the numerical solution of the shallow water equations. The simulation begins with a layer of water initially at rest on a slope. The flow down the slope increases under the influence of the gravity. It eventually reaches a quasi-steady state. The flow rate of this quasi-steady state is used to evaluate the overall flow resistance including the drag coefficient $\mathrm{C_d}$ as shown in Fig. 2 (a) and the equivalent Manning coefficient n_{macro} for the overall resistance as shown in Fig. 2 (b). The macro coefficient n_{macro} is dependent on the water depth in a manner clearly in violation of the Manning formulation.

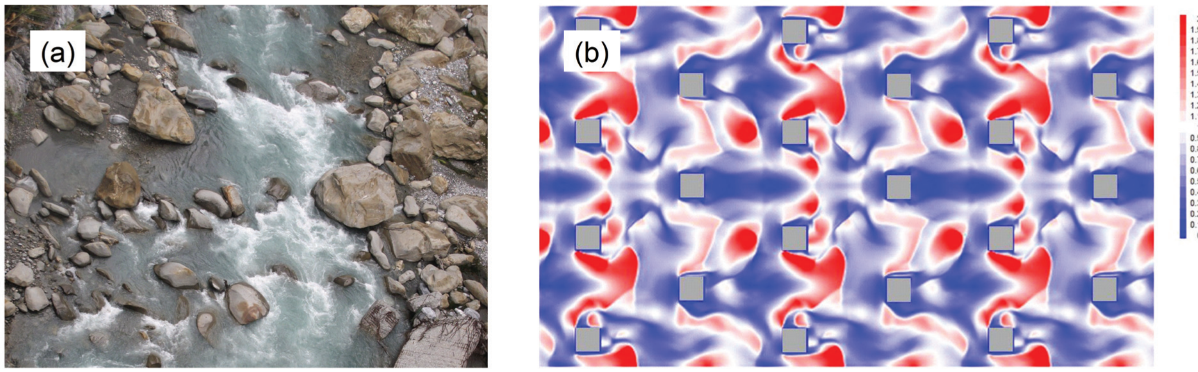

Figure 1: (a) The transition from subcritical (Fr < 1) to supercritical flow (Fr > 1) in steep river with the white waters marking the location of the jumps. (b) The passage of subcritical (blue) and supercritical flow (red) through periodic array of blocks.

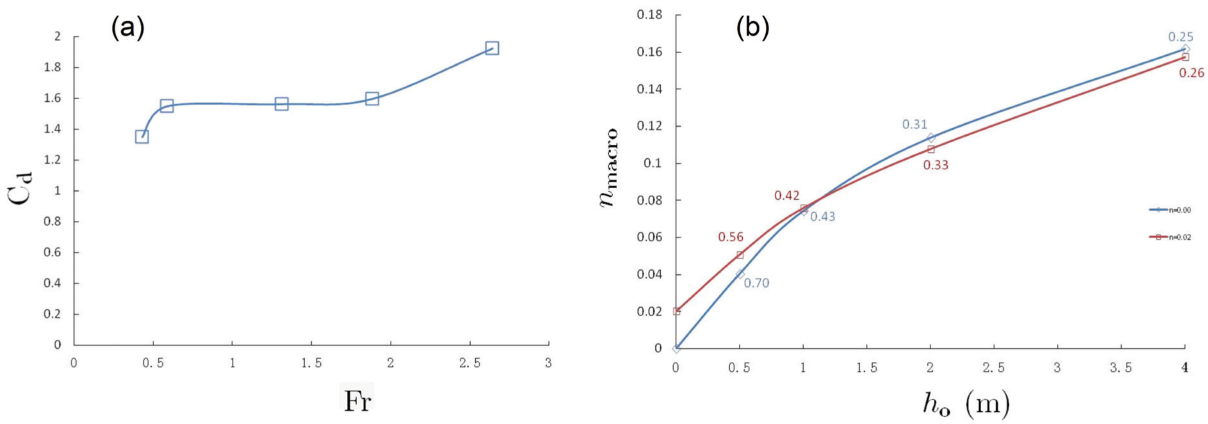

Figure 2: (a) The drag coefficient C_d and its dependence on the Froude number Fr. (b) The overall Manning coefficient of friction n_{macro} on the averaged water depth h_o. The label on the side shows the averaged Froude number in the channel.

2 Conclusion

The macro resistance to flow in channel of steep slope has been calculated by the direct numerical simulation using the shallow-water equations. Beside the flow resistance, the numerical simulations also provide the drag force and moment acting on the macro roughness. This data base is generated to develop a conceptual model of rock-and-boulder transport along the streams of steep slope.

References

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