Simple Wave and Monoclinal Wave Models of Unsteady River Flow Surges

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Unsteady surface water flows occur in a variety of common situations that span the field of hydrology. Dam or ice jam failures, river-control operations, and rainfall/snowmelt runoff processes in watersheds all produce unsteady flows. River flow surges are a type of unsteady flow with particular importance to contaminant and sediment transport processes, and river ice processes. Longitudinal flow velocity and depth changes with time during passage of a flow surge are typically obtained with the *dynamic wave* model. Parameter variability and quasi-linearity of the dynamic wave momentum and mass conservation equations require a numerical solution. The simple wave and monoclinal wave models represent analytical solutions for special cases of the dynamic wave equations in uniform channels. These models are more intuitive and convenient to use than numerical solutions, and may provide a good description of flow surges. However, simple wave and monoclinal wave models are contrasting descriptions, which are not generally applicable to any given set of flow conditions.

The *simple wave* model of unsteady flow, described in detail by Abbott (1966) and Henderson (1966), neglects the bed slope and flow resistance terms of the dynamic wave momentum equation. Henderson and Gerard (1981) applied this model to surges resulting from the sudden release of ice jams. Beltaos (1995) emphasized the attractiveness of the simple wave model for jam release applications due to ease of use. However, applications of the simple wave model to date have generally relied on speculation regarding accuracy. The requirements of dominant inertia, with negligible resistance and bed slope, needed for accurate representation of unsteady flow by simple waves, are restrictive. In general the effects of bed slope and flow resistance increase and eventually become dominant with travel time and distance in free-flowing rivers. A general quantitative assessment of simple wave model accuracy is not available, and maximum time and distance scales of model application are not defined.

Ferrick and Goodman (1998) analyzed and compared analytical solutions for *monoclinal rising waves*. The monoclinal wave solution represents the wave profile separating initial and final steady state flow conditions that evolves in a uniform channel with downstream travel distance. Monoclinal waves have a constant profile shape and celerity, and satisfy the complete dynamic wave equations. The monoclinal wave model describes a flow profile that evolves over large time and distance, but most rapidly at high bed slope and flow resistance. Again, minimum time and distance scales for appropriate application of this model are not defined. Application of the simple wave and corresponding monoclinal wave models to river flow surges are depicted together in Figure 1, where the simple wave has evolved a shock front.

The objectives of this paper are to quantify the relationship between these contrasting models, to develop a general understanding of appropriate conditions for application of each model, and to test this analysis with data from case studies of flow surges. A dimensionless analysis is developed to quantify and better understand both differences and similarities between the inertia-dominated simple wave and resistance-dominated monoclinal wave models.

Dimensionless flow velocity and wave celerity parameters relate corresponding dimensional simple wave and monoclinal wave variables, allowing a general comparison of model predictions and assessment of similarities and differences. The effectiveness of the analyses developed to guide model application and that to compare the model predictions are tested with data from surges in laboratory dam break experiments and from field measurements that document hydropower and ice jam failure induced surges.