FLOW RESISTANCE IN ICE-COVERED ALLUVIAL CHANNELS

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ABSTRACT: This paper describes the influences of floating level ice covers on flow and bed-load transport in alluvial channels and proposes a semi-empirical procedure for calculating flow resistance in such channels. The procedure can be applied in conjunction with several existing methods for estimating flow resistance in alluvial channels under open-water conditions. Previously, cover influence was poorly understood, with the consequence that flow-resistance calculations for ice-covered alluvial channels entailed an inordinate amount of guesswork. The cover influences described herein were determined from the results of experiments conducted with a laboratory flume. The main findings of the flume experiments are that ice covers increase flow depth, decrease bulk flow velocity, increase dune length, and significantly decrease bed-load transport rate. Additionally, it was found that sediment transport relationships developed for open-water flow are applicable to ice-covered flow provided they are used in conjunction with estimates of actual bed shear stress. The proposed flow-resistance procedure enables such estimates to be made.

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INTRODUCTION

Ice-cover presence complicates the relationship between flow depth and discharge for alluvial channels in frigid winter environments. Not only are the flow-resistance characteristics of the ice cover uncertain, but cover presence likely alters the flow-resistance characteristics of the bed by modifying bed-form geometry. Exactly how an ice cover affects bed-form geometry and, thereby, bed resistance is not well understood. Evidence from prior studies on ice-covered flow appears inconclusive.

The lack of a reasonably accurate method for estimating flow resistance in ice-covered alluvial channels hampers reliable regulation and analysis of flow in such channels. Consequently, important questions concerning, for example, hydropower-station operation, transport and fate of pollutants, or flood levels in frigid environments have remained unsatisfactorily addressed. The current practice for estimating flow resistance in ice-covered alluvial channels is to assume either that the bed resistance coefficients (i.e., Manning, Chezy, or Darcy-Weisbach coefficients) do not change with ice-cover presence, or that the flow-resistance behavior of the bed can be determined by approximating an ice-covered flow as a composite of two noninteracting flow layers, with only the lower layer of flow affecting the bed. Neither assumption is sound for natural alluvial channels, which predominantly have dune beds. Flow drag on dunes contributes a substantial part of alluvial-bed resistance. However dune morphology is influenced by the full flow depth.

This paper proposes a semiempirical method for calculating flow resistance in ice-covered alluvial channels. The method is based on dimensional analysis backed by results from experiments with a laboratory flume and a reinterpretation of findings from prior studies. The experiments also included measurements showing the influence of cover presence on bed-load transport rate. Smith and Ettema (1995) and Yoon et al. (1996) present supportive diagnostic information showing how cover presence modifies the mean and turbulence properties of the flow field over dunes. The material presented here is fully documented by Smith and Ettema (1995).

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PRIOR STUDIES

Fig. 1 illustrates the principal variables associated with flow in an ice-covered alluvial channel. By imposing a solid boundary on the upper surface of flow, cover presence increases channel resistance to flow and redistributes the flow over its depth, as indicated and confirmed by the few prior studies of ice-covered flows in alluvial-bed channels. However, prior studies are inconclusive as to whether and how cover presence affects the dimensions and geometry of alluvial bed forms and, thereby, bed resistance. Some studies report no discernible effect, whereas others do.

The writers have identified four prior laboratory studies investigating flow in ice-covered alluvial channels. The studies are summarized in Table 1, which reveals one reason for the inconclusive prior findings concerning ice-cover influence on alluvial bed-form geometry and bed resistance. The prior studies investigated different ranges of bed regimes; i.e., beds with dune, ripple, or mixed morphology. Viewed in the context of Fig. 2, which shows the influence of different bed regimes on open water flow resistance, it is evident that flows producing different bed forms would respond differently to the imposition of an ice cover. The additional solid boundary of a cover increases flow resistance and thereby reduces mean flow velocity and increases flow depth. In accordance with whether the bed regime is in ripple, dune, or mixed regime, Fig. 2 suggests that cover presence may either negligibly or substantially alter bed-form geometry and bed resistance. The relationship shown qualitatively in Fig. 2, which indicates the relationship between flow depth and mean flow velocity for a loose-bed channel, is discussed more quantitatively later in this paper, when the results of the present study are presented and related to those of the studies listed in Table 1.

Two additional factors also may have contributed to the inconclusive findings: different techniques used to measure and determine representative bed-form lengths and heights; and

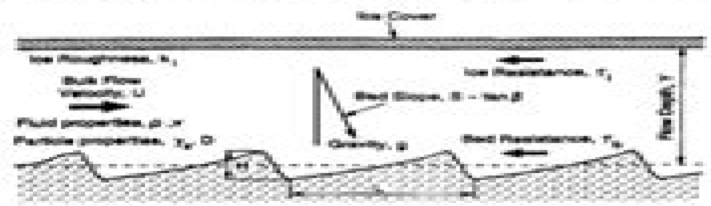

FIG. 1. Variables Influencing Flow in Ice-Covered Alluvial Channels

J. Hydraul. Eng., 1997, 123(7): 592-599

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Daryl B. Simons,Everett V. Richardson

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