Sessions on the hydraulic resistance of ice covers and ice jams (A and B): some reflections

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After hearing the six contributions on this subject at the workshop it seems worthwhile to discuss the attributes of the various measures of hydraulic resistance and how they might best be employed in ice covered channels. However, in considering this point, it became evident that first an important distinction with regard to channel type should be kept in mind. With regard to resistance it would seem there are two classes of channel:

1. simple channels
2. complex channels

the distinction being based on the following two parameters:

1. the relative roughness of the reach (e.g. the ratio k/R)

and

2. the planform of the waterway.

A stream with a high relative roughness (say 0.5) <u>or</u> a highly tortuous planform would be classified as 'complex'; otherwise it is simple.

The significance of the distinction is that for a 'simple' channel, it is feasible to determine the composite roughness of the channel from a knowledge of the individual ice cover and bed roughnesses; this is not so for a complex channels. In the latter case the composite resistance must be assessed empirically and directly on the basis of the overall characteristics of the reach. In this sense a large deep river, a man-made channel or a laboratory flume would be classified as simple, whereas a wide, shallow, braided, ice-covered channel, with tortuous, dividing waterways and irregular ice accumulations, would be classified as complex.

It is suggested that this distinction should govern the type of research measurements and analysis, and the use of these measurements for design.

Measures of resistance

The above channel classification has an influence on the most appropriate measure of resistance in each case.

Simple Channels: As mentioned above, in these channels it is feasible to determine a composite roughness from a knowledge of the roughness of each portion of the boundary. For this purpose it is very desirable that the roughness (or resistance) measure used be simple, physically meaningful and, importantly, as independent as possible of other geometry effects. With these characteristics such a roughness parameter can be extrapolated to situations other than that from which it was derived.

The only roughness parameter in current use that satisfies these requirements is the equivalent sand grain roughness, or simply the hydraulic roughness, k.

The Manning 'n' is also reasonably independent of geometry effects, although less so than k, and is as simple. However, it is not nearly as successful as k in conveying a 'feel' for the roughness involved, particularly for the uninitiated.

The other choices - the dimensionless Chezy 'C' and the friction factor f -- are far too sensitive to the flow geometry to be of use in characterising surface roughness.

Therefore, of the four parameters, the hydraulic roughness k is much preferred.

Complex channels: In such channels it is not practicable to fabricate a composite roughness from the separate bed and ice cover roughnesses because of the many complexities involved such as frazil accumulation, large relative roughness and so on. It would seem that the only practicable option for these channels is to use a composite roughness assessed directly from field measurements made in similar circumstances, both geomorphic and climatic.

In such channels, although the use of k to express the resistance is still much preferred because of its generality and its ability to convey an immediate feel for the 'roughness' involved, it doesn't particularly matter which of the four resistance parameters is used.

Measurements of Roughness

In simple channels the ice cover roughness can and should be isolated from the other causes of resistance. The most satisfactory and universal method to do this is to deduce the hydraulic roughness from measurements of the velocity profile normal to the surface of interest. This has the advantage of providing a local measure of the ice roughness that is little effected by other portions of the cover, which may have a different roughness.

If the other causes of resistance (for example bed roughness, non-uniformities) are known beforehand - from open water measurements, for example - the ice cover roughness can be determined from a measurement of the composite roughness of the ice covered flow. However, this method assumes that the ice cover is homogeneous over the reach.

These measurements will usually be made over a short reach to ensure the roughness being measured is reasonably homogeneous. For complex channels, on the other hand, the resistance measurements should be made over a long reach - long in the sense that the heterogeneities are 'homogeneous'. This generally requires a reach length of about 20 channel widths.

Roughness information currently required for ice covered channels

1. Measurements of 'k', in the field and laboratory, for various ice roughness types in simple channels. The published results should be accompanied by photographs of the roughness and details of the circumstances of the measurement.

2. Field measurements of the ice-covered resistance of complex channels. In this case the published results must be accompanied by photographs of the channel under open and ice-covered conditions, typical cross-sections and details of the climatic circumstances. A compilation of such measurements could then be used much as the open water Manning 'n' compilations are used now.

Contributions by the papers presented in the session.

Of the papers presented in the session those that had potential for contributing to the first need were those by Chee and Haggag, Gogus and Tatinclaux, and Tsang. Those that dealt with the second - the resistance to flow in complex ice-covered channels - were those by Burrel and Davar, Calkins and Witherspoon.

Summary Comments on Modelling Aspects

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It is apparent that many theoretical models exist for computation of resistance and conveyance capacity of ice covered rivers; the most significant differences are in the diverse assumptions in the formulations and correspondingly different results. Extensive field data appear necessary to check the applicability of the models, as general approaches or specific ones.

Some models have embedded conceptual modules which also need to be validated and refined on the basis of field research. Such improvements would be best achieved by development on a sound physical basis.

Finally, the comparison of models for effectiveness needs to be restricted to a common type of problem; the eventual criteria for model selection will emerge when studies are directed to finding 'Which Model is Best for What Type of Problem.'

Editors' note: The following reply to Michel's discussion (pp.182-189) on the paper "Observation and Analysis of Freeze-Up Ice Jams on the Peace River near Taylor" (pp. 162-181) was received late and could not be inserted in the appropriate place in the text.

Reply by T. Keenhan, U.S. Panu, and V.C. Kartha.

Dr. Michel notes within his discussion that the mechanism of ice formation on the Peace River resembles that observed in the past on the St. Lawrence River. From our observations on the Peace River and the details provided on the St. Lawrence River the ice formation mechanisms of the two rivers differ. The alternate freezing and thawing as reported on the St. Lawrence River did not occur within the Peace River study reach during the jam formation period reported and so did not contribute to formation of the jams. The daily temperatures during the period, as recorded in the neighbouring town of Fort St. John, are shown in the attached table.• Also shown is the sequence of jam formation.

The writers have observed that the frequency with time of ice jam formation, while dependent on hydraulic forces and ice strength, is greatly increased during cold weather periods when the amount of frazil ice production increases. During these period the upstream advance of the ice front towards W.A.C. Bennett dam is accelerated. The diveragence between the ice jam freeze-up mechanisms as reported on the two rivers illustrates the subtle differences in formation of ice jams in accordance with river characteristics.

Difficulties in analysis of the jams in the study reach arose due to uncertainty on the nature of the jams. Ice thickness measurements were not possible due to safety considerations, since the jams did not remain very long within the reach. A classification system incorporating the full spectrum of ice jams types by formation mechanism with supporting theory, based on data collected at numerous jams, would have proved invaluable. Since, for many site specific studies and particularly for studies of long river reaches, ice thickness measurements are not possible or practical, more intensive and selective data collection studies from which jam types can be classified are considered to be of the most benefit both on a short and long term basis.

TABLE: TEMPERATURES DURING STUDY PERIOD

Date	Daily Temperature (°C)			Ice Front	
1980	Max	Min	Mean	Location*	Comments
Feb 15	-28	-32	-30	42	Jam #1 Formed
16	-25	-30	-27-1/2	43	
17	-23	-24	-23-1/2	43	
18	-17	-25	-21	46	
19	-18	-20	-19	48	Jam #2 Formed
20	-16	-20	-18	49	Jam #3 Formed
21	-18	-20	-23-1/2	49	
22	-24	-32	-28	52	Jam #4 Formed
23	-25	-30	-27-1/2	53	
24	-20	-21	-20-1/2	56	
25	-16	-21	-18-1/2	58	Jam #6 Formed
26	-19	-25	-22	60	Jam #6 Removed
27	-17	-24	-20-1/2	57	Jam #5 Formed
28	-18	-28	-23	61	Jam #6 Reformed
Mar 1	-18	-22	-20	63	Jam #7 Formed
2	- 6	-12	- 9	63	
3	6	-15	- 4-1/2	60	Jams 6 & 7 Eroded Out
4	4	- 8	- 2	58	Jams 6 & 7 Washed Out
5	4	-20	- 8	56	

* - approximate distance in kilometres upstream of the B.C. - Alberta Border

** - approximate jam locations - Jam #1 - 42.2 km
2 - 45.9 km
3 - 48.7 km
4 - 52.3 km
5 - 53.5 km
6 - 57.5 km
7 - 59.6 km