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Breakup Ice Control Structure with In-Channel Relief Flow

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A new concept in breakup ice control is presented. Current state-of-the-art breakup ice control structures (ICS) consist of piers that retain the breakup ice in the main river channel while passing relief flow via an adjacent floodplain. The ability to bypass flow around the structure is critical because it reduces upstream stage rise, the potential for ice blowout at the piers and ice jam failure. A major drawback with this approach is that many rivers with ice jam problems lack upstream sites with floodplains suitable for bypass flow. This paper introduces the concept of in-channel relief flow for ice retention at sites without floodplains. An L-shaped pier configuration is used, with transverse piers to stop the breakup ice run and longitudinal piers to maintain an ice-free flow relief channel along one side of the jam. The concept was developed as a possible means of preventing under-ice scour associated with ice jams that form naturally in the lower Grasse River (McShea et al., 2005). The DynaRICE ice-hydraulic numerical model (Shen et al., 2000) was used assess the feasibility of the concept and optimize general design parameters.

1. Introduction

Over the last several decades, breakup ice control technology has evolved to pier structures that retain the breakup ice in the main river channel while passing relief flow via an adjacent floodplain (Lever, 2000). The ability to bypass flow around the structure is critical as it reduces upstream stage rise and hydrostatic head, which can lead to ice blowout between piers and ultimately ice jam failure. Also, conveying the water flow via the floodplain allows the jam to ground and transfer ice forces to the bed instead of the piers.

The one major drawback with state-of-the-art ICS design is that many rivers with ice jam problems lack suitable upstream sites for ice retention with adjacent floodplains. One option that has been tried is to pass the entire breakup discharge beneath the jam that forms behind piers in the main channel. Recent physical model tests at CRREL revealed limitations of this approach however. Experimental results indicated that the maximum discharge at which such a structure will retain ice is about half that of an equivalent structure with floodplain relief flow. Also, to resist ice blowout due to the large hydrostatic head, the piers must be spaced more closely, resulting in a less aesthetic and more costly structure that is more likely to catch debris and interfere with other uses of the river.

This paper presents the concept of in-channel flow relief for breakup ice retention at sites with no floodplains. An L-shaped pier configuration is proposed, with a transverse row of piers to stop the breakup ice run in the conventional manner, and a longitudinal row of piers to maintain an ice-free flow relief channel along one side of the jam (Fig. 1). The concept was developed under the Grasse River ice control evaluation as a possible means of preventing under-ice scour associated with ice jams that form naturally in the lower Grasse River.

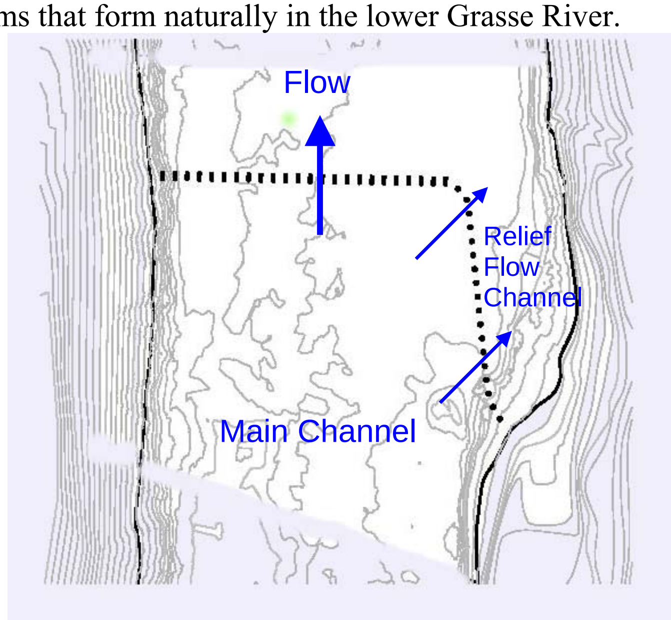


Fig. 1. Example of pier ICS with in-channel relief flow.

The DynaRICE two-dimensional unsteady ice hydraulic model was used to evaluate the effect of various design parameters on the upstream ice jam profile, the under ice flow area and under-ice water velocity.

2. Grasse River Case Study

The primary purpose of breakup ice control structures built to date has been to prevent ice jams and ice jam flooding. Typically, an ICS retains the breakup ice run at a location upstream of the traditional ice jam problem area. More recently, breakup ice control has been considered as a means of preventing ice jam scour. An example is the lower Grasse River at Massena, NY. Within this 11-km-long, 120-m-wide, 5-m-deep, relatively quiescent reach, a 230-m-long pilot test cap was built in 2001 to contain contaminated riverbed sediments. In March 2003, breakup ice jam that formed in the lower Grasse River caused under-ice scour of some of the cap material and underlying sediment. Based on field observations and the DynaRICE computer simulations, the 2.4-km-long jam was about 5-m-thick at its toe, 2-m-thick in its mid section and caused a maximum stage rise of about 3 m (Fig. 2). Average discharge during the event was about 185 m^3/s and the final ice jam volume was about 300,000 m^3. Review of historical data, a hindcasting analysis, a tree scar survey, and geochronology of riverbed stratigraphy all indicate that the 2003 ice jam was an extremely rare event (Alcoa, 2004). The 2003 ice event was therefore used as a base line in the evaluation of various ice retention alternatives.

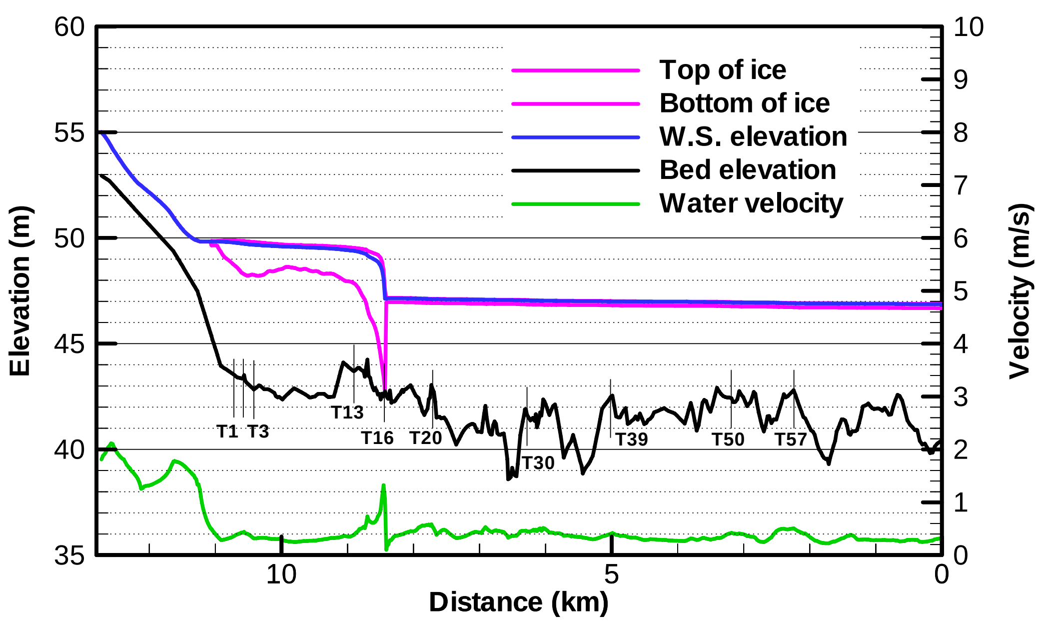


Fig. 2. Profile of March 28, 2003 ice jam on lower Grasse River by DynaRICE model.

A number of potential ICS sites were evaluated both in the lower river and the section of river upstream of the Massena rapids know as the upper river. A technically feasible site for a conventional ICS was identified on the upper river about 8 km upstream of the 2003 ice jam site. The structure would occupy a relatively uninhabited stretch of river with a large floodplain ideal for bypass flow. DynaRICE and HEC-RAS (US Army, 2000) simulations indicated that the ice accumulation behind the piers would be stable and not excessively thick (≤ 2.5 m). Calculated under-ice water velocities were moderate (≤ 1.2 m/s) and about 70 percent of the flow was expected to bypass the jam via the floodplain. Analysis of breakup chronology, ice sources and the numerical simulations indicated that ice retention at the upper river site would sufficiently reduce the ice volume reaching the lower river to avoid recurrence of a 2003-like ice jam scour event. In response to community concerns identified with the location of the upper river site, an evaluation was conducted to assess the feasibility of siting an ICS in the lower river.

Under normal flow conditions, the lower Grasse River, which lies in the backwater of the St. Lawrence River, has a very low water surface slope with average water velocities on the order of 0.05 m/s. This is due in part to an oversized channel resulting from past dredging to convey large hydro flows from the old power canal back to the St. Lawrence, before the construction of the Moses-Saunders Power Dam in the 1950's. Even at breakup discharges, average water velocity in the lower river is only about 0.5 m/s. Because of these relatively mild hydraulic conditions, ice retention was considered on the lower river, upstream of the 2003 ice jam site. Major drawbacks with retaining ice in this section of river are the high banks and the lack of floodplains for relief flow around the jam, which would form behind the piers. Because all flow must pass beneath the toe of the jam, high under-ice water velocities, ice blowout between piers and jam failure are possible.

3. Methods

The DynaRICE model was used to simulate ice retention behind piers at a number of sites on the lower river. Site selection was constrained by the need to contain the expected ice jam volume as far upstream as possible without affecting properties in Massena Village. This analysis is based on a representative site located about 1.2 km below the foot of the Massena Rapids. A number of cases were examined. Case 1, consists of a transverse row of piers across the river with no relief flow. Cases 2, 3 and 4 have longitudinal piers in addition to the transverse piers to simulate in-channel flow relief channels of lengths 60,100, and 200 m respectively. In these cases, the DynaRICE "ice boom" option is used to model the piers. This option imposes a fixed barrier to ice passage and the user specifies a maximum ice restraint capacity for this barrier. DynaRICE also has the capability to calculate ice forces acting on the boom as the simulation progresses. In these cases, the structure is assumed to be 100% efficient, in other words, no ice is allowed to get past. The "boom" does not obstruct water flow beneath and, in these simulations, ice erosion was not allowed. An earlier simulation with the actual pier geometry included in the model mesh produced an ice jam profile very similar to the profile calculated using the boom option. Because the boom option is computationally simpler, it was used to model the pier structure alternatives in this study. The water and ice inflow during the 26-hour simulation period were the same as those used for the baseline simulation of the March 2003 ice jam. Ice jam volume increase during the course of the simulations is more or less linear, reaching a maximum of 300,000 m^3.

4. Results

Results are discussed in terms of parameters used to gage performance such as ice jam thickness, under ice water depth, and under ice water velocity. Other parameters discussed are under ice flow area and the under ice water discharge split between the jam toe and relief channel.

The presence of in channel flow relief had little effect on the overall ice jam profile once a short distance upstream of the structure. Fig. 3 shows the no-flow relief ice jam profile to merge with the 100-m-long relief channel ice jam profile at a point about 200 m upstream of the structure. Similarly, the 60 and 200 m long relief channels affected only local ice jam thickness and had no effect on the upstream ice jam profile.

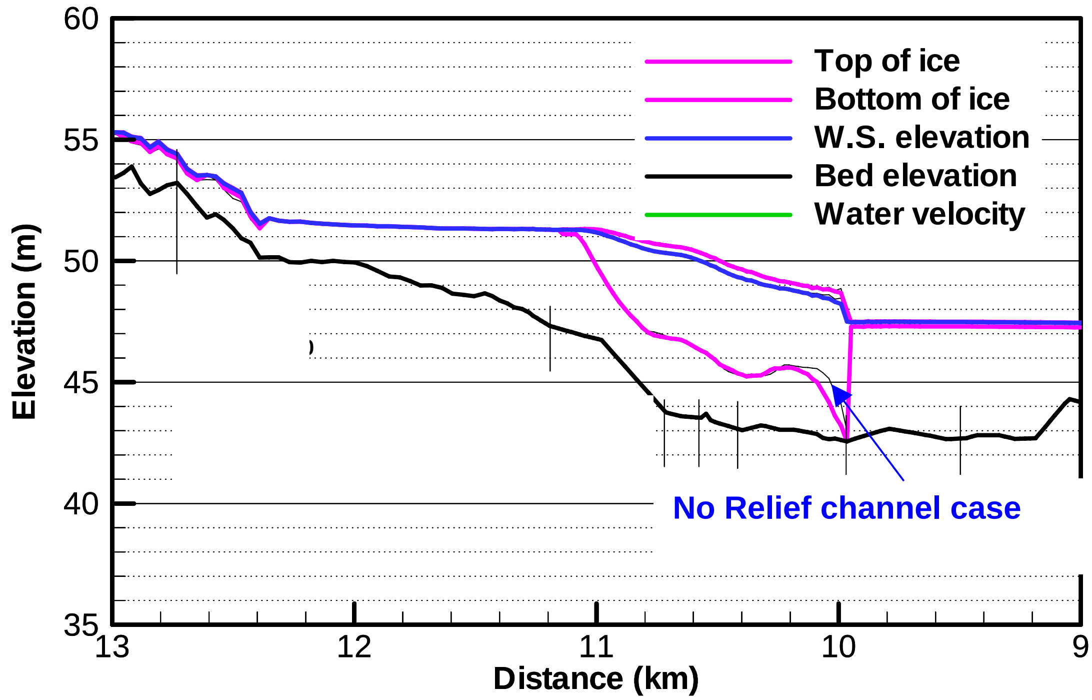


Fig. 3. Ice jam profiles, no-relief channel case compared to 100-m-long relief channel case.

Figures 4 and 5 shows a general decrease in under-ice water depth in the ice jam toe area as relief channel length increases. With the decreased flow depth, one might expect a corresponding increase in water velocity, but Figs. 6 and 7 show a general decrease in under-ice water velocity in the toe area with increasing relief channel length. This coincidental decrease in under-ice water depth and flow velocity occurs as the nearly grounded ice jam shifts water flow into the relief channel.

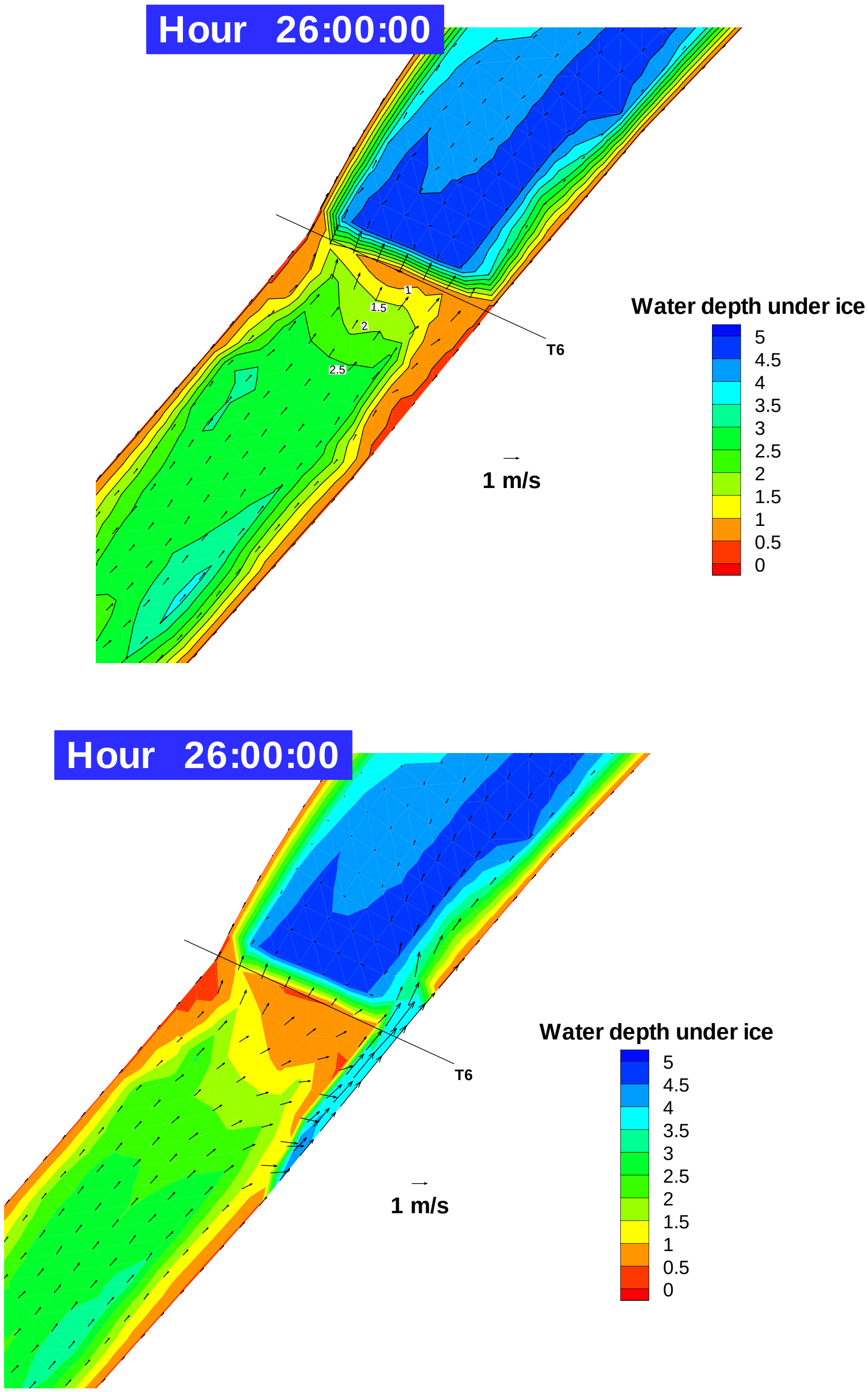


Fig 4. Water depth under simulated ice jams, no-relief channel case (top) compared to 100-m-long relief channel case (bottom).

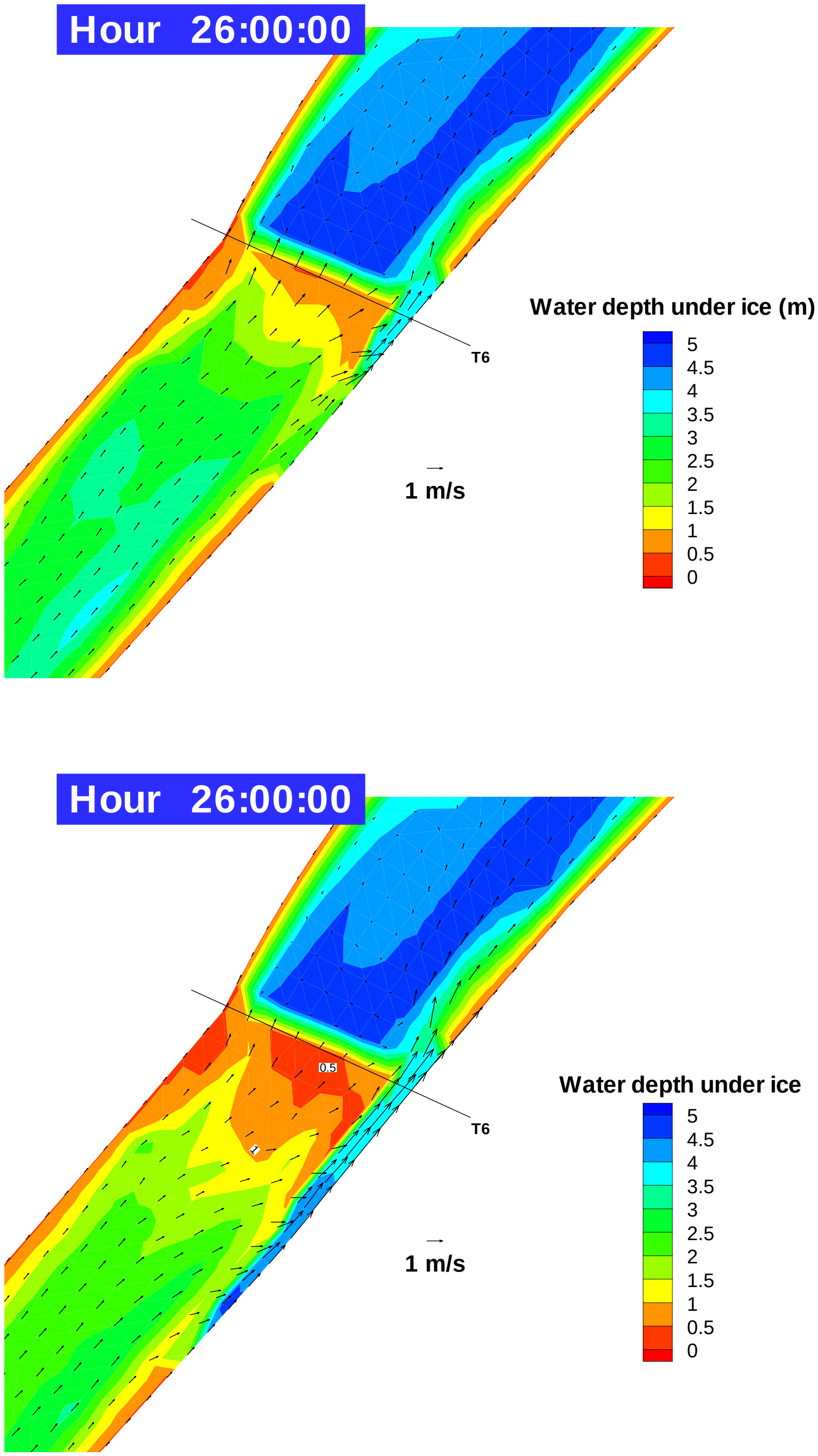
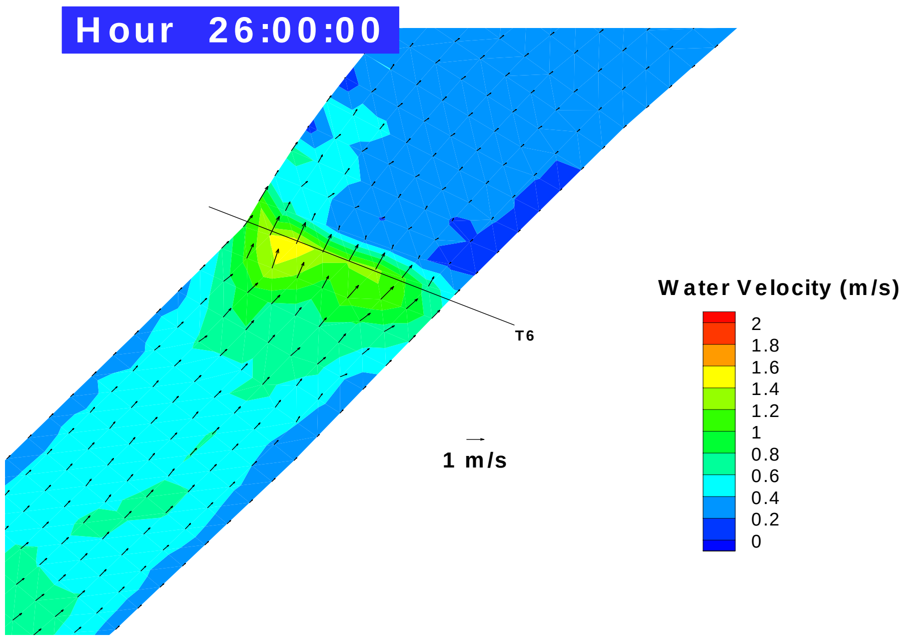


Fig 5. Water depth under simulated ice jams, 60-m-long relief channel case (top) compared to 200-m-long relief channel case (bottom).



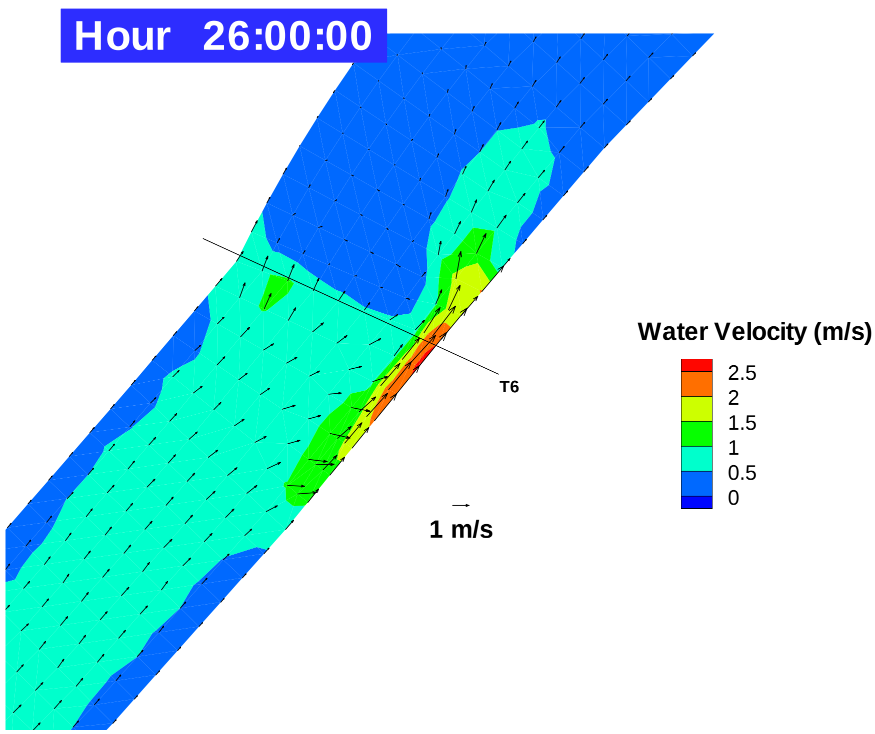


Fig. 6. Water velocity under simulated ice jams, no-relief channel case (top) compared to 100-m-long relief channel case (bottom).

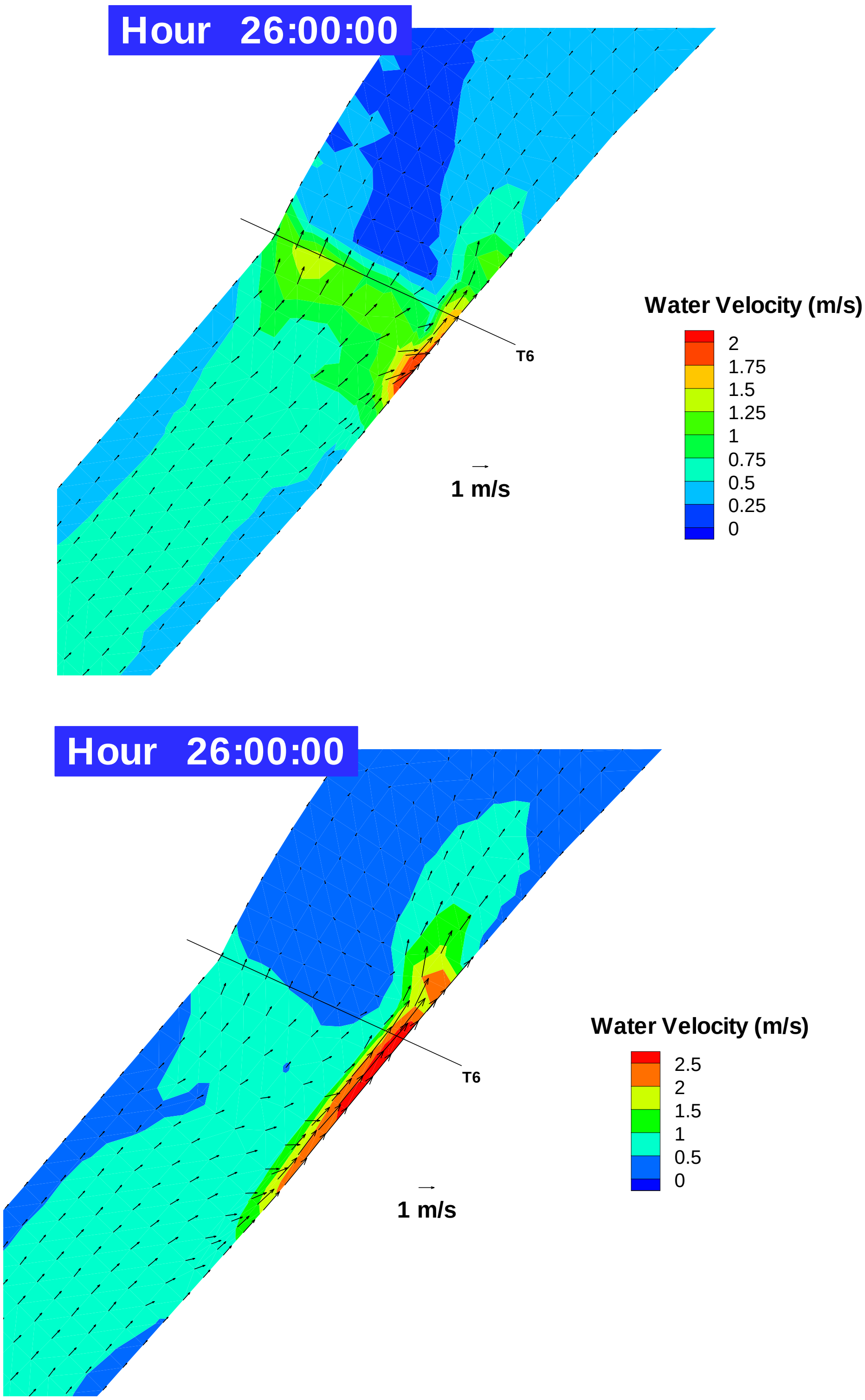


Fig. 7. Water velocity under simulated ice jams, 60-m-long relief channel case (top) compared to 200-m-long relief channel case (bottom).

An interesting result is that the total under ice flow area remains about 100 m^2 for all cases. Fig. 8 shows the under ice flow areas vs. time for the 100-m-long channel case with the relief channel area staying relatively constant while the ice jam progressively decreases the main channel flow area. The curves for the other cases are similar with a slight decrease in the final main channel flow area as relief channel length increases (Table 1).

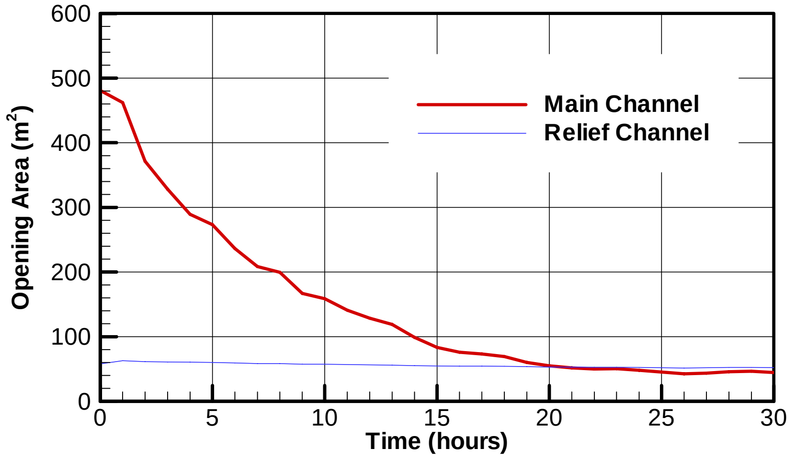


Fig. 8. Under ice water flow areas vs. time for 100-m-long relief channel case.

Table 1. Comparison of performance parameters for ICS alternatives

Case	*Under ice flow area (m^2)*		*Discharge (m^3/s)*		*Maximum velocity (m/s)*
	Main channel	*Relief channel*	*Main channel*	*Relief channel*	*Main channel*
1. No relief channel	100		180		1.6
2. 60-m-relief channel	50	50	90	75	1.5
3. 100-m-relief channel	47	50	65	110	1.1
4. 200-m-relief channel	40	55	50	132	0.8

As expected, the portion of the total under ice flow passing the jam via the relief channel increases with relief channel length. The 100-m-long relief channel conveys 62 percent of the under-ice water flow compared to 45 and 73 percent for the 60-m and 200-m-long relief channels respectively (Fig. 9 and Table 1).

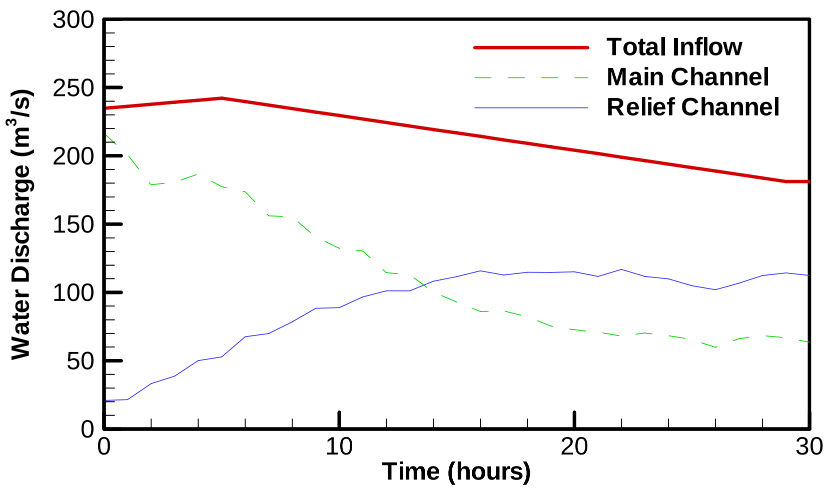


Fig. 9. Water discharge vs. time for 100-m-long relief channel case.

Under-ice water velocity serves as a predictor of ice erosion and the potential for ice blowout between the piers. A non-eroding under ice water velocity of on the order of 1.5 m/s is sometimes assumed for breakup ice jams (White, 1999). The eroding velocity approach has limitations however since it does not address effects of ice roughness or turbulence. Table 1 shows a decline from 1.6 to 0.8 m/s in main channel under ice water velocity between the no-relief channel to 200-m-long relief channel cases. Note that the maximum under-ice water velocities in the main channel fall below 1.5 m/s for the 100 and 200-m-long cases, indicating relatively stable ice conditions in the ice jam toe region.

5. Summary and Conclusions

A new concept in breakup ICS design is presented and evaluated using the DynaRICE ice-hydraulic numerical model. State-of-the art breakup ICS rely on an adjacent floodplain to bypass flow around an ice jam formed behind piers in the main channel. The in-channel relief flow concept would allow reliable breakup ice retention at sites without floodplains.

DynaRICE simulations indicate that the addition of the in-channel flow relief significantly decreases the maximum under-ice water velocities in the ice jam toe area, reducing the potential for ice blowout between the piers and ice jam failure. Based on these results, the 100-m-long relief channel was found to be a good compromise between cost and performance.

A parallel series of physical model tests would further improve confidence in the design concept. The study would investigate in detail the under-ice erosion processes in the vicinity of the piers.

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