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MODELING ICE JAMS IN RIVERS

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The results of modeling the effect of obstacle deepening on ice involvement under the obstacle have been presented. The Froude number has been used for modeling calculations.

Ice aggregates, diving jams, hummocking jams, jamming, Froude number

INTRODUCTION

There are two basic types of the jamming and hummocking processes among the great variety and complexity of the jamming phenomena in rivers:

1. Diving jams – formation of jam ice aggregates by entraining ice under the ice edge;

2. Hummocking jams – formation of jam ice aggregates during ice cover destruction in the process of ice hummocking and and ice jamming by ice suction, rideups, and pileups.

In the first case, the process of forming jamming ice aggregates is determined by the energy of flow, required and sufficient for ice diving and movement under the ice cover as far as the river part with reduced flow velocity, where ice hummocking is formed. The size of ice-floes forming hummocking jams does not exceed the flow depth. Formation of jamming by entraining ice under the ice edge is mainly observed when individual ice floes approach the ice edge in the parts of regulated rivers in the zone of thinning out of the reservoir backup, in the downstream reaches of a hydroelectric power station, as well as in the cases of accelerated movement of ice masses coming from the upper parts of the river during breakthrough of ice jams or debacle of tributaries. In addition, this type of phenomena is observed in the parts of rivers with significant destruction of ice cover when exposed to solar radiation (Rivers Don, Dnieper, Danube, Amur, Syr-Darya , etc.).

In northern rivers, jamming during ice hummocking is most widespread, caused by general destruction of ice cover when exposed to static and dynamic compression of ice fields.

Modeling involvement of slushed ice and ice under the edge of ice cover is a component part of studying ice jamming in rivers and a phase of experimental development of the methods of hydraulic regulation of slushed ice and ice transport. The modeling method may be used to determine conditions of drifting of ice floes of different planimetric sizes and thickness under the ice cover with different hydraulic parameters of the river flow [*Umirkhanov, 2011*].

THE CONDITION OF MODELING STUDIES

As similarity criteria during flow modeling, usually the dimensionless Froude number (Fr) and the Reynolds number (Re) are used. However, it is impossible to satisfy these criteria simultaneously, therefore Fr is used in modeling ice transit, which reflects the ratio between the gravity and inertia forces. Choosing the ice substitute material (ISM) is the greatest challenge for modeling jamming. In literature, a trend prevails for choosing ISM with specific gravity close to the specific gravity of ice $\gamma = 0.9$ g/cm^3. Most often, paraffin is used as ISM. Yet, nonwettabillity of paraffin plates by water to a certain degree affects their interaction with an obstacle and, given small scales of models, it may introduce significant distortions into the modeled phenomenon of ice entrainment under an obstacle. Such a defect takes place when another popular ISM – wood of different varieties – is used. Currently varieties of polystyrene and polyethylene are widely as ISM.

The Canadian scientists who studied ice entrainment under ice edge related the critical velocity (v_{cr}) with depth (height) (h), characterizing the critical moment with the Froude number $\mathrm{Fr} = \frac{v_{cr}}{\sqrt{gh}}$ (g – acceleration due to gravity). According to *G. Kivisild*, Fr = 0.08, according to *E. Pariset* and *R. Hausser*, Fr = 0.15. Trying to reconcile these values, *B. Michel* introduced a porosity factor of ice aggregates forming an obstacle and suggested the following formula:

$$\mathrm{Fr} = 0.154\sqrt{1-\varepsilon}, \qquad (1)$$

where ε is porosity of ice mass before ice edge. In accordance with formula (1), the Fr values obtained by *G. Kivisild, E. Pariset* and *R. Hausser* may be comparable with $\varepsilon = 0.73$ and 0.05, accordingly [*Kivisild, 1959; Pariset and Hausser, 1959; Michel, 1965*].

A.M. Filippov [*1973*] modeled ice entrainment under an obstacle depending on the planimetric size of ice floes and ice thickness. The obtained range of Fr values was 0.06–0.22.

Z.A. Genkin and V.I. Sinotin conducted modeling of ice entrainment under an obstacle in the automotive area according to Reynolds [*Sinotin and Genkin, 1972*]. The studies showed that, with commensurable ice floe lengths (l) and flow height (h), the critical flow velocity determining ice entrainment under an obstacle depends on l:

$$v_{cr} > \sqrt{0.035gl},$$

or

$$\mathrm{Fr} = \frac{v_{cr}}{\sqrt{gH}} \approx 0.19. \qquad (2)$$

In [*Sinotin and Genkin, 1972*] the effect of obstacle deepening on ice diving is studied. The investigation results are shown for deepening (the ration of the obstacle deepening height to ice thickness) h/δ = 0.37, 0.44, 0.62, 0.67. With Fr = 0.035 for the indicated values of h/δ entrainment of ice under ice edge occurs, which does not affect the critical flow velocity (at which ice entrainment under an obstacle begins).

V.F. Tsilikin [*1967*], when examining the moment of ice impact against an obstacle, obtained the following dynamic equilibrium equation for an ice floe:

$$\frac{1}{2}g\rho_i l^2 + K'_n \rho l \delta \frac{v_{cr}^2}{2} - \frac{1}{2}g\rho l^2 \delta - K_n \delta\rho \frac{v_{cr}^2}{2} = 0, \qquad (3)$$

where δ is ice thickness; K_n is the coefficient of ice floe shape, equal to 0.95–1.0; K'_n is the proportionality factor, equal to 0.95–0.97; ρ, ρ_i are water and ice density, respectively.

Solution of equation (3) in relation to v_{cr} provides a formula for critical velocity as

$$v_{cr}^2 = \sqrt{g\frac{\delta(1-\rho_i/\rho)}{K'_n\,\delta/l - K_n\,\delta^2/l^2}}. \qquad (4)$$

It follows from equation (4) that the critical velocity depends on ice thickness and the length of an ice floe [*Tsilikin, 1967; Chetyrbotsky, 2005*].

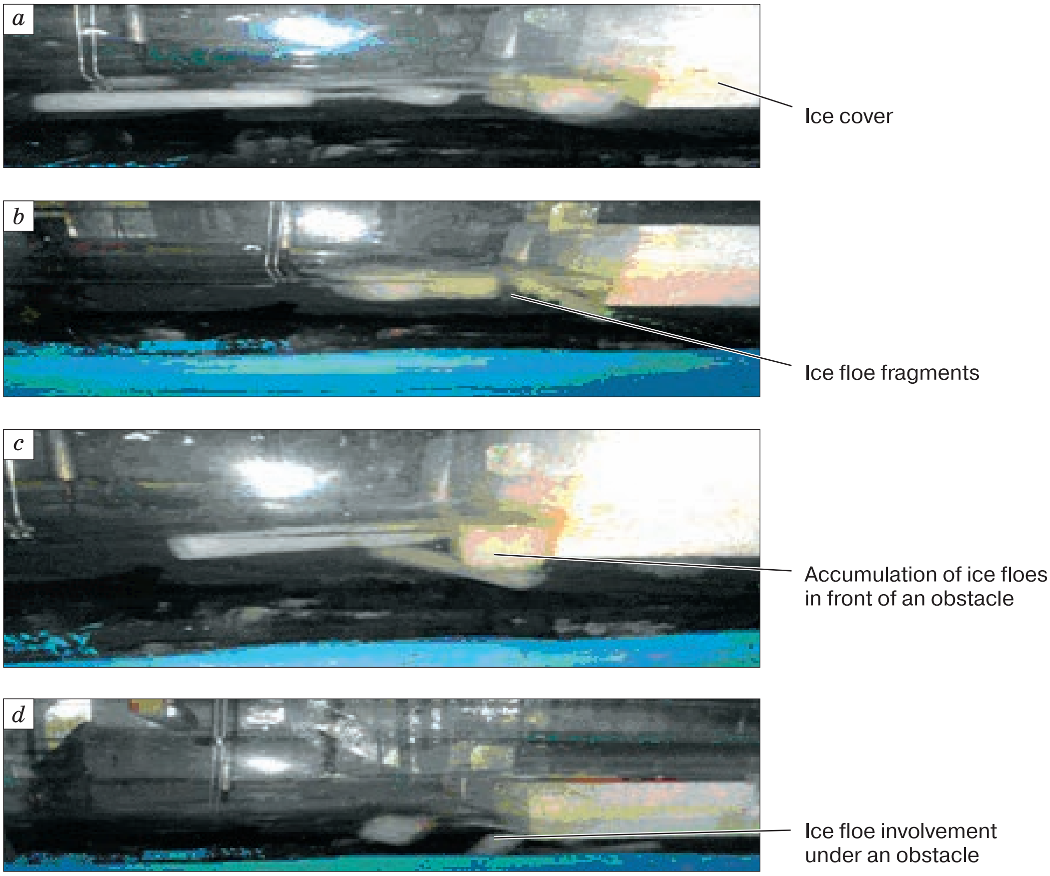

Fig. 1. Entrainment of ice floes under an obstacle edge:

a – the process of ice floe fragments moving towards solid ice cover; *b* – the process of collision of ice floe fragments with an obstacle; *c* – the process of aggregation of ice floe fragments in front of an obstacle (at a flow velocity below the critical value); *d* – the process of entrainment of ice floe fragments under an obstacle at a critical flow velocity.

The goal of this study was experimentally to determine the effect of obstacle deepening on ice entrainment under an obstacle, during which the critical velocity of water flow grows.

MODELING

The experimental part of the study was conducted in a trough 8.0 m long and 0.3 m wide, having glass walls of the height 0.6 m. The variation range of the flow velocities in the model was 0.10–0.35 m/s. The flow velocities were measured with a Pitot tube. Imitating ice floes were paraffin plates (the specific gravity of paraffin is 0.9 g/cm^3). Ice cover was simulated by a polystyrene plate submerged in water and touching the trough walls 0.3 m wide and 1.0 m long. Plates with the length l = 3–12 cm and with thickness δ = 0.4–4 cm were used in the experiment.

In the calculations, the water depth was set depending on the planimetric size of the plates (l = = 3–12 cm). With different flow height, the average flow velocity may be the same, therefore, when conducting the same tests in different ranges of depths, one can obtain certain values of Fr = const, which do not agree with each other.

With the set obstacle depth height (h = 2–7 cm), thickness of the plates varied (δ = 0.4–4 cm) and flow velocities were generated in the trough, at which the critical velocity of ice entrainment under an obstacle was increased (for depth h/δ). In the following series of experiments, a new height of obstacle deepening was set, plate thickness was varied again, and critical flow velocities were generated.

Shown in Fig. 1 is the process of ice stopping in front of ice cover and of ice entrainment under the ice cover with the given critical flow velocity.

As the plates were set going towards the obstacle, they were uniformly distributed across the trough width. With a certain flow velocity, depending on the deepening height, the plates were dragged under the obstacle when the critical flow velocity was achieved. Further movement along the lower surface of the obstacle was initiated by multiple tripping (rotation) of the plates. To a lesser degree, the plates were sliding along the lower surface of the obstacle.

Shown in Fig. 2 are the results of studying ice entrainment under the ice cover edge with the critical flow velocity. It can be seen that with $h/\delta \geq 6.2$ (Fr $\geq$ 0.05, v_{cr} = 0.12 m/s), ice floes stop being dragged under the obstacle, and the Froude number can no longer be used for describing this process.

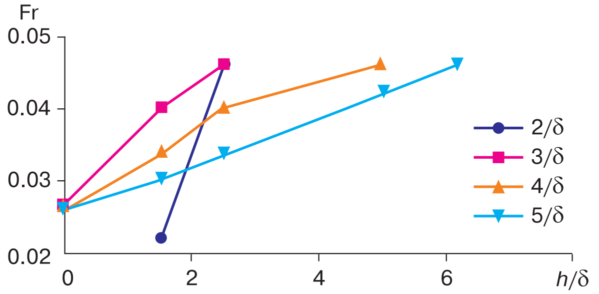

Fig. 2. The effect of obstacle deepening (h/δ) on the critical velocity of ice involvement under an obstacle depending on the Froude number.

CONCLUSION

In the process of modeling ice entrainment under the ice cover edge, the heights of obstacle deepening in relation to the plate thickness were varied (h/δ = 6.2; 3.1; 0.89; 0.6). With the ratio between the obstacle deepening height to the plate thickness h/δ = 6.2, the critical flow velocity v_{cr} = 0.12 m/s and the Froude number Fr = 0.05, ice floes stop being dragged under the ice cover (they get accumulated in front of the obstacle and form solid ice cover). With $h/\delta > 6.2$, v_{cr} = 0.12 m/s and Fr = 0.05, ice flows get involved under the obstacle edge, thus making ice jamming possible due to stoppage of ice floes under the ice cover.

References

Chetyrbotsky, A.N., 2005. Formation and destruction of the ice cover of freezing seas. Kriosfera Zemli IX (3), 45–53.

Filippov, A.M., 1973. Ice jamming in rivers (in Russian). Transactions, State Hydrology Institute, 201, 107–114.

Kivisild, G., 1959. Studies of jamming formation. Proc. 9th Congress of IAHR, Leningrad, pp. 1–47.

Michel, B., 1965. The criterion of hydrodynamic stability of the frontal edge of ice cover. Proc. 11th Congress of IAHR, Leningrad, pp. 17–24.

Pariset, E., Hausser, R. 1959. Formation of ice cover on rivers. Proc. 9th Congress of IAHR, Leningrad, pp. 209–210

Sinotin, V.I., Genkin, Z.A., 1972. Studies of ice diving under an obstacle, Proceedings of the State Hydrology Institute, 192, 37–43.

Tsilikin, V.F., 1967. Issues of entrainment of floating bodies into deepened orifices under conditions of planar and spatial problems: Synopsis of a doctorate thesis, Leningrad, 35 pp.

Umirkhanov, M.G., 2011. Eliminating jamming in the lower reaches of the River Syr-Darya, Bulletin of Vedeneyev Hydrology Research Institute, 264, 137–139.

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