SNOW AND ICE CONTROL AROUND STRUCTURES

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Summary

Two main topics are treated here: control of ice jams including mitigation measures, and control of snow accumulations around structures. The nature of ice jams is described and the difference between jams formed of frazil ice and jams formed of broken ice is

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discussed. Also discussed are various ice control techniques used for specific problems.

1. Introduction

Ice jams result in millions of dollars of damage each year so there have often been attempts to control them and prevent or alleviate the damages. Lake ice also causes damage to structures, particularly docks and marinas and, again, there have been many attempts to avoid these damages. Ice buildup also often interferes with the operation of hydraulic structures such as gates and navigation locks. Blowing snow causes drifting around buildings and may impede access, and in some cases may result in extreme roof loads. Blowing snow also may accumulate on highways and snow fences have often been used to alleviate those conditions. All these effects are discussed with the overall objective of providing an understanding of the processes that may lead to the problems and an appreciation of the effectiveness of various measures that have been used to prevent or alleviate the problems.

2. Nature of Ice Jams

There are two main types of ice jams and they are quite different in usual time of occurrence and cause. The first type are jams resulting from accumulations of frazil ice in the form of thick deposits downstream of an open water reach of river subjected to cooling by the cold air above that surface. Frazil ice may also clog intakes used to withdraw water for water supply or for hydropower production. The second type of jam is the breakup jam that results when a river ice cover “breaks up” under the influence of high river discharges. These tend to occur in the spring of the year but may also occur when mid-winter thaws result in rising discharge. The broken ice is transported down the river and accumulates when there are conditions that interrupt that transport and result in large accumulations. These accumulations increase the water depth and may result in flooding, often at levels much higher than would be experienced from open water floods. It is not uncommon for flooding associated with ice jams to occur frequently and exceed the water levels associated with the return period of so-called “100 year” open water floods (those that have a probability of occurrence of 1% in any single year).

While the ice associated with jams may cause some damage due to impact of floes on structures such as bridges (especially when the water levels attain heights to impact the superstructure), the majority of the damages associated with ice jams are associated with the resulting flooding. The large depths of flow associated with jams are due both to the rise associated with passing water beneath the floating accumulation but also, and importantly, by the thickness of the ice accumulation. It is not uncommon for the flow depth beneath the ice to be exceeded many times by the thickness of the accumulation. Occasionally the ice jam may become “grounded” with the broken ice extending to the bottom of the river, although usually with some flow channels through the ice mass. Figure 1 shows an idealized longitudinal cross section of an ice jam with the vertical scale very much exaggerated relative to the horizontal scale.

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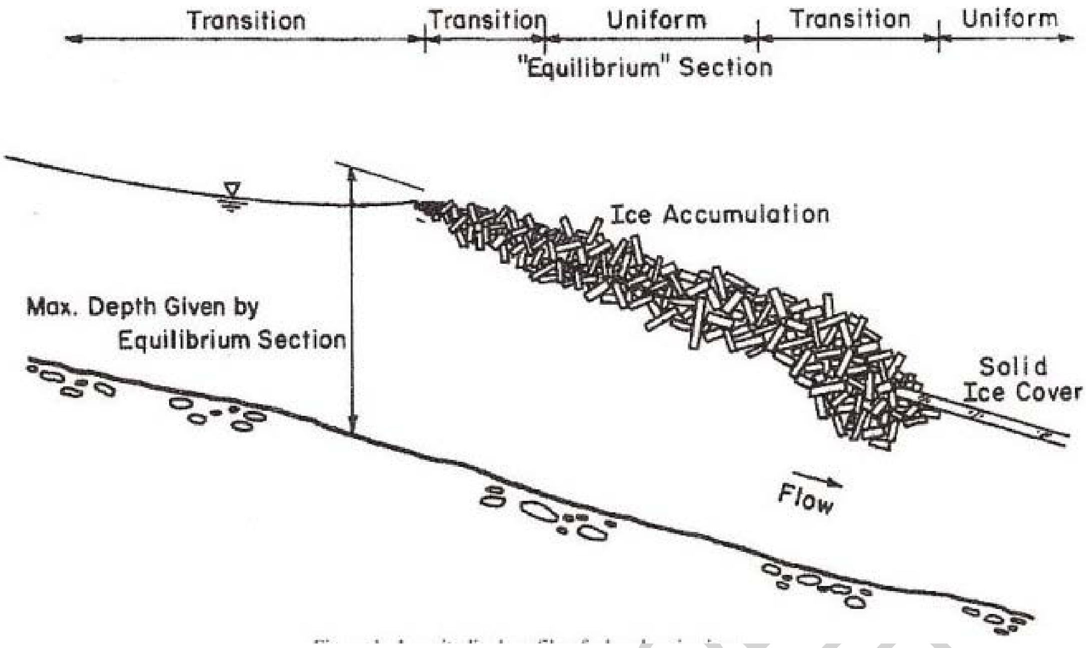

Figure 1. Longitudinal profile of a breakup ice jam (Note: Vertical scale greatly exaggerated).

The thickness of the ice accumulation is determined by that required to carry the forces on the accumulation to the bank areas with thicker jams occurring in wider and or steeper rivers since those result in the greatest forces. The process involved in the thickening is often termed “shoving and thickening”. The forces are due largely to the shear stresses of the flow beneath the ice on the undersurface and to the component of gravity acting in the longitudinal direction due to the slope of the river. The region at the “toe” of the jam tends to be thicker than the upstream portions of the jam. This behavior is different from frazil ice jams where the ice jam forms by deposit of the frazil particles beneath a downstream ice cover and may be conceived of quite well as an “upside down” delta deposit. In this case the deposit continues to thicken by deposition (upwards) of the frazil particles when the flow velocity is below the transport velocity of the frazil particles. Frazil is also often responsible for the formation of an initial ice cover with collection of the frazil at the surface and the frazil freezes together to form the initial ice cover. Sometimes, and particularly for wide rivers, the initially formed frazil ice cover cannot withstand the forces on the cover and may suddenly compress to form a cover that can withstand the forces; this process is sometimes called “telescoping.” Usually this process does not result in a significant jam but may raise the water surface due to both the undersurface roughness contribution to the flow resistance and the blockage effect.

2.1. Frazil Ice

When a water surface has cooled to 0°C and undergoes further heat loss to the atmosphere, the water first supercools (temperature below the freezing point) and then begins to form ice. In natural rivers and streams this supercooling rarely exceeds a few hundredths of a degree C. If the flow velocity is low the ice formation will be in the form of a sheet of ice on the surface, and this sheet ice effectively blocks heat loss from

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the water below the sheet ice to the atmosphere above (The ice sheet then continues to lose heat and the sheet thickens.). If the velocity is higher, the ice formation will be in the form of tiny crystals of ice that nucleate in the water and are carried with the flow. At relatively low flow velocities, these crystals rapidly rise to the surface and may form an initial cover that looks much like slush ice (actually "slush" ice is similar in appearance but derived from snow falling on the water surface). The appearance of floating frazil ice is shown in Figure 2. At intermediate velocities the ice crystals tend to flocculate together and may form clumps of frazil carried on the surface, often in the form of "frazil pans" that appear from above as circular discs but are usually more like half-bowl-shaped masses of frazil. As the flow velocities further increase, the turbulence of the water prevents such pans from forming and the frazil may be distributed throughout the depth of the flow and this behavior has often been described as a "snow storm in the water." Two main results are typical. The first is attachment of the frazil particles to the bottom which may build up to a substantial thickness and is called "anchor ice." Anchor ice is of some concern in that it raises the water levels about the same amount as the thickness of the anchor ice deposit. The more serious problem associated with frazil ice, however, is the transport downstream where it deposits beneath the downstream ice cover in reaches of the river where the velocity is slow enough to allow formation of a solid ice cover and the frazil then deposits beneath this solid ice cover. The amount of frazil ice that is produced in the open water reach upstream of this solid ice cover is proportional to the rate and duration of heat loss to the atmosphere and the area of open water exposed to the cold air temperatures. Unlike the growth of a solid ice cover which is limited by the insulating effect of the solid ice cover, the amount of frazil produced in an open water reach may be of the order of several meters of equivalent solid ice per unit area over a winter period.

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Figure 2. Frazil ice on the surface of a river

2.1.1. Hanging Dams

Such a production of frazil may result in extremely thick deposits downstream and the thick deposits are termed “hanging dams” since they act to dam the water flow by an accumulation “hanging” beneath the downstream ice cover. The result, of course, of these hanging dams is to block the flow cross section, thus raising the water level in the reach where the frazil is deposited. In extreme cases such frazil production has been known to nearly completely fill a downstream reservoir with frazil deposits and, in some cases, have made the purpose of the reservoirs to produce hydropower during the winter to be compromised. There is little that can be done to control such frazil ice production, short of imposing dams that reduce the flow velocity in the rapids or fast flowing reaches where the frazil is produced. The general principle of controlling such frazil ice production is to induce a solid ice cover to form over the frazil-producing reaches, by either raising the water level (thus slowing the velocity so that a solid ice cover has formed), or by reducing the flow by upstream retention in reservoirs to reduce the flow velocity until a solid ice cover may form. Inflatable dams imposed on the top of concrete dams are sometimes used to raise the water level upstream so as to either slow the velocity to allow the upstream cover to form more easily or to drown out rapids areas just upstream where frazil is produced. Upstream retention of water requires storage and involves construction of dams to delay the flow discharge downstream.

2.1.2. Blockage of Intakes

One of the problems associated with frazil intakes is the accumulation of the particles on “trash racks.” Trash racks consist of grates placed at intakes for the purpose of excluding “trash” from the intake flow. The supercooled water that results in frazil production also cools the elements of the grates to the water temperature (below the freezing point of 0 °C). The frazil particles coming into contact with these elements or bars adheres and results in frazil buildup on the bar elements. The accumulations on the bars may rapidly build up and restrict the passage until the flow is completely, or nearly completely blocked. Initially the buildup starts relatively slowly but accelerates with time and may very suddenly substantially or completely block the flow with little associated warning time. There are three general principles for reducing this hazard. The first is to somehow reduce the contributing area of frazil production (by reducing the velocity upstream such that a solid ice cover forms thus blocking the heat loss to the atmosphere). The second is to make the spaces between the grating bars large so that the accumulation takes longer before the gaps are overly restricted. Among the conflicts in doing this is a desire to reduce the bar spacing on the grates so as to exclude the intake from withdrawing small fish. The third is to heat the intake elements so that the frazil particles do not adhere to the bars. The other constraint has to do with the purpose of the grating to exclude materials (such as rocks) from being ingested into the turbines of hydropower installations. Rocks have been known to be enclosed by upstream anchor ice deposits, raised into the flow by the buoyancy of the anchor ice, and carried downstream. If the grates of the trash racks are too large such rocks may be passed to the hydropower turbines causing considerable damage. Fist-sized rocks in the ice cover downstream of locations of anchor ice deposits are not uncommon. In recent years

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limitations on the spacing of the intake elements associated with exclusion of fish has resulted in rather narrow spacing between the bars. It is sometimes possible to mix warm water into the flow to raise the water temperature slightly above freezing thus changing the frazil from the “active” state in supercooled water to the “passive” state in above freezing water.

The frazil that is produced when there is an open water surface subjected to very cold air temperatures occurs not only in rivers, but also in lakes where mixing of the water by wind action prevents a solid ice cover from forming. Wind induced and other lake currents can carry the frazil to considerable depths and blockage of intakes at least as deep as 30 feet or more have been reported. The nature of the blockage is such that the head loss across the intake grates or the resulting discharge constriction (which is the usual measure of blockage) starts slowly and then accelerates so that there is often little warning that the blockage is about to occur. Necessary conditions for frazil blockage of grates are supercooled water and, of course, a supply of frazil and these occur simultaneously. The supercooled water is necessary since if the water is not supercooled, the frazil is in a relatively passive state and easily passes through the grate elements with no accretion. Prevention of the supercooling or the frazil presence is difficult to control; essentially since it requires blocking of the heat loss to the atmosphere in the regions where the frazil is produced. The other methods that are possible, but often not practical, are to heat the trash rack grate elements, thus preventing accretion, or mixing enough warm water with the flow to raise the below freezing temperatures to slightly above 0 °C.

Once frazil has accreted on a trash rack there are sometimes attempts to flush it off the bars by sudden discharges of air or water; this has generally been shown to be effective in only a few cases. The use of “traveling” screens is sometimes used but even these have sometimes been blocked by frazil since the frazil buildup may occur quite rapidly.

There have also been attempts to divert the frazil away from the intakes. Generally such attempts involve use of surface flow diversions that direct the top water away from the intakes. These diversions have had mixed results. If the frazil is suspended in the flow they are of little use. However, if the frazil has accumulated at the top surface, it may be possible to divert the top surface portion of the flow away from the intake areas.

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Biographical Sketch

George D. Ashton was born in Davenport, Iowa in 1939, received BSCE in civil engineering from the University of Iowa, Iowa City, Iowa in 1961; a MSCE in civil engineering from the University of Arizona, Tucson, Arizona in 1963; and a PhD in mechanics and hydraulics from the University of Iowa, Iowa City, Iowa in 1971.

From 1962 to 1964 he was a Lieutenant in the U.S. Army. From 1964 to 1967 he worked as a Structural Engineer for Bechtel Co. in San Francisco. After his PhD he joined the U.S. Army Cold regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire and held various research and management positions with his research concentrating on river ice processes and problems. From 1990 to 1998 he was Chief Research and Engineering Directorate. He retired in 1998 and now works as a private consultant in Lebanon, New Hampshire dealing primarily with river ice problems.

Dr. Ashton has received the Straub Medal from the University of Minnesota, the Hilgard prize from ASCE, the Stevens Award from ASCE and most recently the 2002 Ice Research and Engineering Award by the International Association for Hydraulic Research. He is the author of numerous papers and book chapters dealing with ice problems. He was Editor of the Journal of Cold Regions Science and Technology from 1995 to 2006.