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HYDRAULIC MODEL STUDIES OF ICE BOOMS TO CONTROL RIVER ICE

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Ice jams frequently occur on rivers in the western United States. Many of the jams are small and may even go unnoticed in sparsely populated areas. Some occur infrequently and are caused by unusual meteorological conditions or temporary unsteady river hydraulics. However, others reoccur on a somewhat frequent basis and at the same locality. Although there are many factors involved, there are several which play a major role in creating an ice jam. These major factors include control sections in a river such as a channel constriction or a lake or reservoir, ice covered river systems where the ice in the headwaters melts before the downstream river ice melts, and river reaches where large quantities of frazil ice are produced (figure 1).

The North Platte River flowing through Casper, Wyoming, experiences ice cover formation every winter and at times ice jams are formed. Storage reservoirs upstream and downstream have permitted increased river discharges during winter months. The frequency of ice jam formation has reportedly increased due to the increase in winter river discharges above the native flow. In the fall of 1966, the Casper Project Office of the U.S. Bureau of Reclamation initiated an experimental ice boom study on the North Platte River. The major objective of the study was to develop a structure capable of containing the slush ice upstream from a small residential area west of Casper, Wyoming, affected by ice jams. The operation of the ice boom was expected to trigger an artificial ice cover by capturing slush ice thus creating an ice cover which would progress upstream from the boom in an area where a flood easement was established. The prototype log boom was installed 11 kilometers upstream from Casper, Wyoming, as shown in figure 2. The ice boom consisted of two 25-millimeter cables with 3.66-meter timbers attached to the cables by 1-meter lengths of chain. The timbers had spikes extending 305 millimeters above and below on 225-millimeter centers. Several prototype ice boom configurations were tested on the river; however, due to time and cost limitations, the Project requested a model investigation of the ice boom to optimize the design of the existing structure.

Modeling Hydrodynamic River Ice Phenomenon

Groat 1/, as early as 1918, used a hydraulic model to study ice diversion using paraffin to simulate float ice. Several investigators 2/ 3/ 4/ have since used hydraulic models as a tool to better understand ice processes on rivers. Materials such as wax, paraffin, wood, and polyethylene have been used to simulate river ice. There are two areas of similitude considered in modeling ice processes. One involves the modeling of individual ice floes in a river system where the internal properties of the ice are neglected and the similitude is based on hydrodynamic considerations. The other area involves modeling of the ice properties per se. This investigation considered only the hydrodynamic forces and therefore the Froude model laws were used to scale the model.

North Platte River Model

A 1/2-kilometer reach of the North Platte River was modeled in the laboratory study at a 1:24 undistorted scale (figure 3). The model riverbed was constructed of concrete using river cross sections taken at 30-meter intervals along the river reach. River ice was simulated in the model using 3.2-millimeter hemispherical particles of low density polyethylene plastic with a specific gravity of 0.92 (figure 4). A 2.7-meter-long hopper with a 0.25 m^3 capacity was used to drop the plastic ice onto the water surface at the upstream end of the model. Since the laboratory has a recirculating water supply, a wire screen basket was installed at the downstream end of the model to collect the plastic used in the study.

A uniform test procedure was followed throughout the test program. Each test was operated with a discharge representing 26.6 m^3/s in the prototype river. To keep the absorptive properties of the plastic stable, the plastic model ice was stored in large drums containing water which kept the plastic wet at all times. The plastic model ice was applied to the water surface across the width of the model river. Discharge and water surface elevations were recorded during each test. The tests were normally terminated when the ice cover ceased progressing upstream. This was usually accompanied by a significant amount of model ice passing under the ice cover and boom. The quantity of model ice that had accumulated in the screen basket at the downstream end of the ice model during each test was removed from the basket and measured as "ice lost" by the boom.

Model Test Results

Initial ice boom. - The model test results indicated that the initial field location for the ice boom did not provide ideal flow conditions for proper operation of the ice boom. Due to a bend in the river, the flow concentrated on the right side resulting in a considerable amount of ice flowing under the ice boom as shown in figure 5. Establishment of a uniform approach flow was further aggravated by a rock protrusion on the left side of the riverbed. The average flow velocity at the ice boom section was 0.5 m/s with an average depth of 1 meter. Several investigators 5/ 6/ recommend slower velocities for proper ice retention at this flow depth.

Modifications to the ice boom. - Several modifications to the initial ice boom structure were tested in the model including ice boom cable sag (4.3 and 14 meters), spacing between booms (24, 47, and 88 meters), timber spikes, and cable configurations.

In general, the least amount of cable sag resulted in the best ice retention by the boom. The spacing between ice boom cables was not critical. The use of one ice boom should be all that is required when properly located.

Several timber spike designs were tested as shown in figure 6. The boom timbers with 152-millimeter bottom spikes on 225-millimeter centers retained more ice than timbers without bottom spikes. Larger, 305-millimeter bottom spikes showed little improvement over the 152-millimeter bottom spikes and collected large amounts of debris when initially installed in the field.

Test with an "upstream V" configuration resulted in a more stable ice cover and better ice retention than the simple parabolic design. The ice boom was anchored to the model riverbed to form a 45° upstream angle with the river shoreline. This boom configuration wedges the slush ice between the boom and the river shoreline thus increasing the ice cover stability at the boom (figure 7).

To determine the effect of field shore ice on ice cover stability at the ice boom, large sheets of polyethylene were cut to simulate shore ice in the model (figure 8). The model shore ice produced a more stable ice cover which progressed upstream further than the tests without shore ice. The absence of any cohesive property in the polyethylene plastic resulted in a less stable model ice cover than what would occur in the field.

Artificial channel modifications. - To decrease the flow velocity and thus improve the ice retention capability of the ice boom, two artificial constrictions were tested in the model. The constrictions were located some 15 meters downstream from the ice boom and caused an increase in the water surface of approximately 0.3 meter reducing the flow velocity to 0.4 m/s. The first constriction was created by an opposing jetty which reduced the river width from 64 meters to 15 meters for the winter discharge of 26.6 m^3/s (figure 9). The model jetties were designed to overtop at a discharge of approximately 42 m^3/s. The second constriction consisted of a submerged overflow sill. The sill had a crest width of 0.3 meter and 2:1 side slopes. For the ice boom to function properly, the water surface at the ice boom site should be increased by 0.49 meter and the rocky protrusion on the riverbed as shown in figure 10, should be removed. This will reduce the river flow velocity to 0.30 m/s.

Although this investigation was limited to a specific reach of the North Platte River, the results can be applied to other rivers flowing through alluvial valleys. The results are encouraging; however, more investigations related to river ice jam formation are needed to better control their occurrence.

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a. Ice jam on the Payette River upstream from Black Canyon Reservoir

b. Ice jam on Yellowstone River due to ice melt in the headwaters

c. Ice jam on Gunnison River due to upstream frazil ice production

Figure 1

Figure 2

View of initial ice boom on the
North Platte River

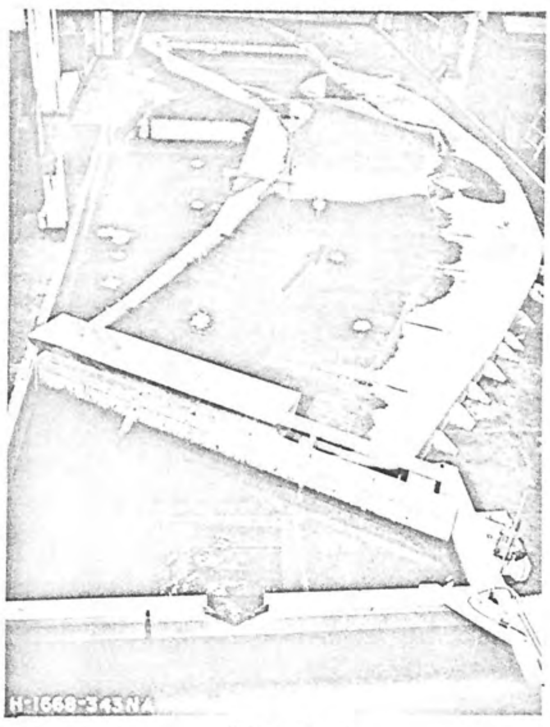


Figure 3
1:24 scale model of
North Platte River

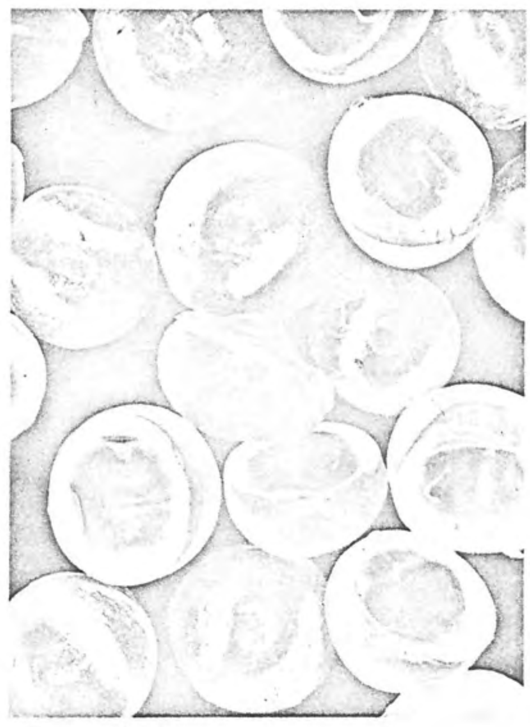


Figure 4
3.2 millimeter polyethylene
plastic - model river ice

Figure 5

View of North Platte River
with ice passing by ice boom

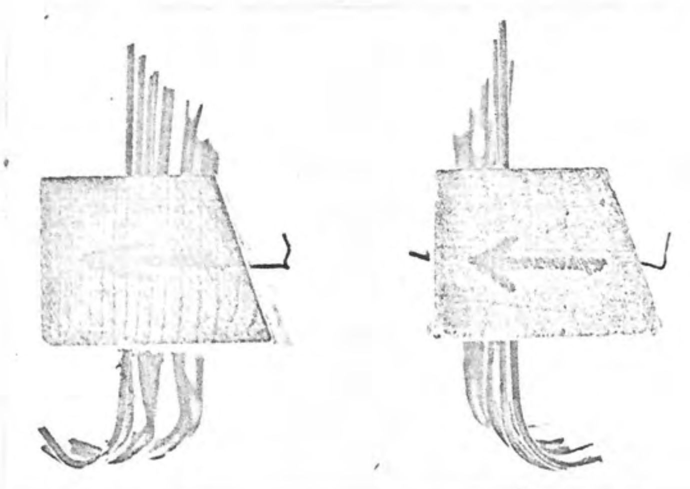
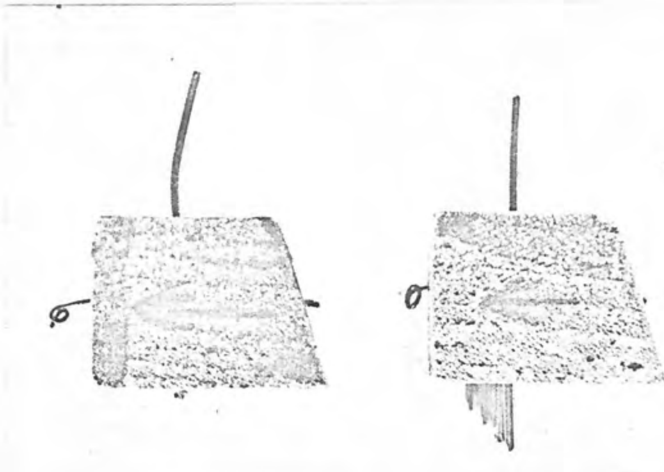


Figure 6
Spike configurations
tested in the model



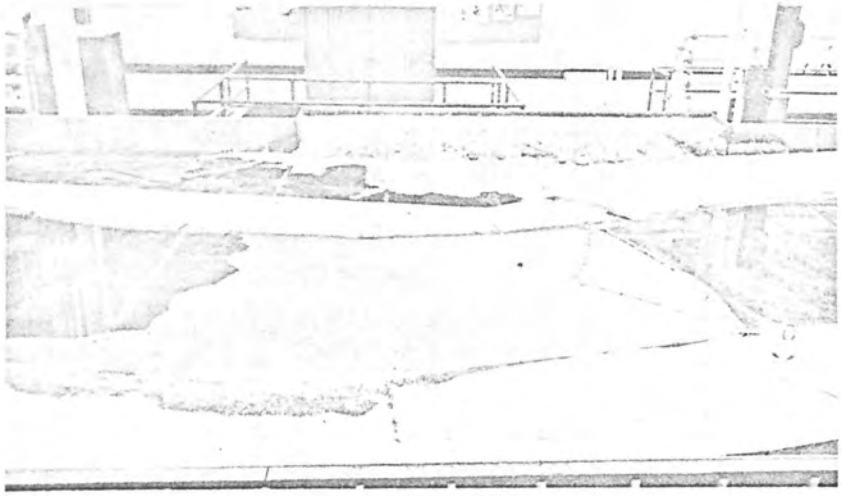


Figure 7
"Upstream V"
configuration
tested in model

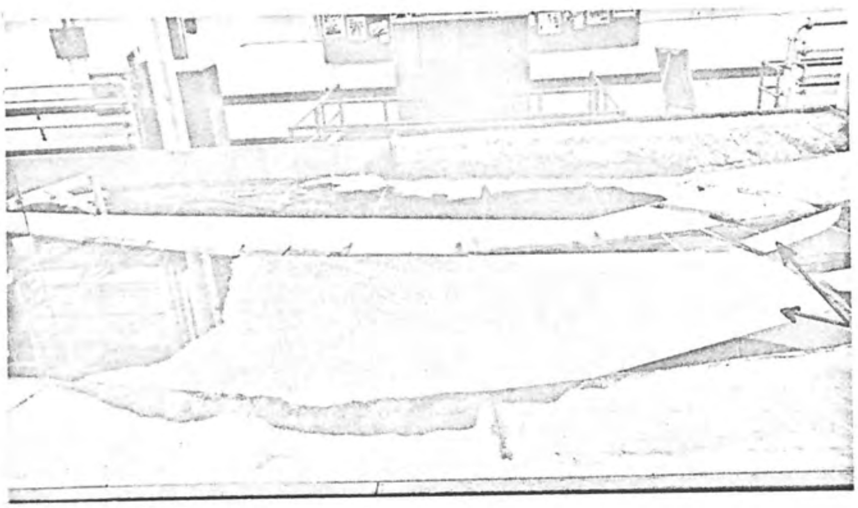


Figure 8
Simulated model
shore ice

shore ice

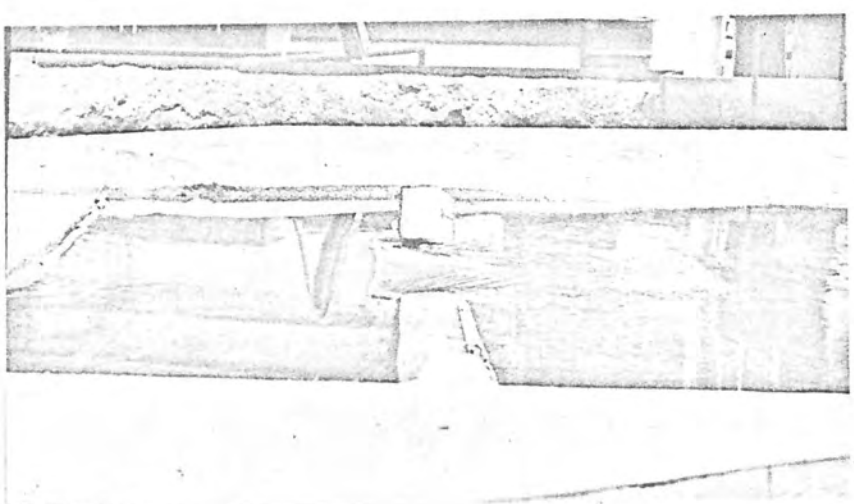
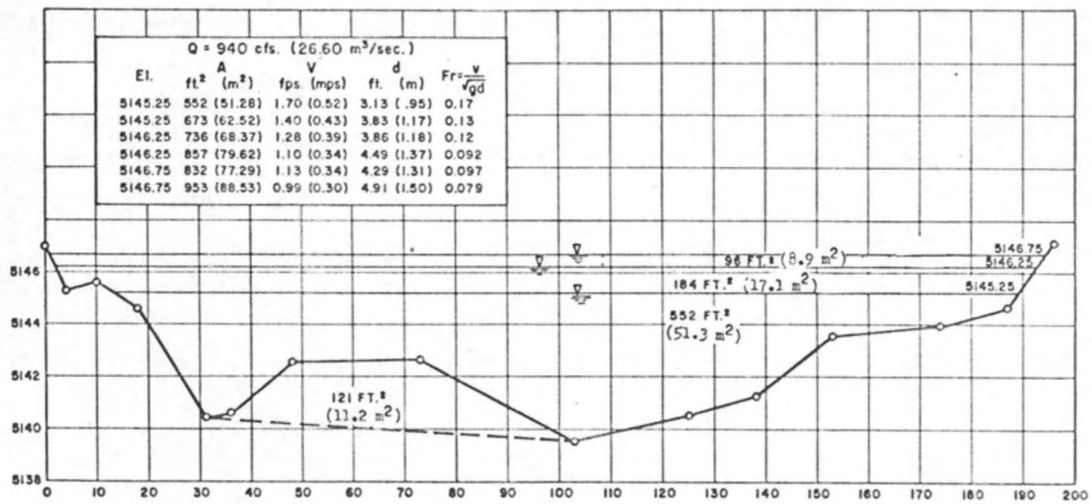


Figure 9
Opposing jetty
constriction in
model river



Q = 940 cfs. (26.60 m³/sec.)

El.	A ft²	A (m²)	V fps.	V (mps)	d ft.	d (m)	$Fr = \frac{v}{\sqrt{gd}}$
5145.25	552	(51.28)	1.70	(0.52)	3.13	(.95)	0.17
5145.25	673	(62.52)	1.40	(0.43)	3.83	(1.17)	0.13
5146.25	736	(68.37)	1.28	(0.39)	3.86	(1.18)	0.12
5146.25	857	(79.62)	1.10	(0.34)	4.49	(1.37)	0.092
5146.75	832	(77.29)	1.13	(0.34)	4.29	(1.31)	0.097
5146.75	953	(88.53)	0.99	(0.30)	4.91	(1.50)	0.079

Figure 10
River cross section at ice boom