00295 38D

Environment Canada / Environnement Canada

Canada Centre For Inland Waters

Centre Canadien Des Eaux Intérieures

COLD ENVIRONMENTAL HYDRAULICS RESEARCH FACILITY AT CCIW.

by

G. Tsang and R. Carson

UNPUBLISHED REPORT
RAPPORT NON PUBLIE

Tsang (28)
Carson (1)

This manuscript has been submitted to
The Canadian Society for Civil Engineering
for presentation at
The Third Canadian Hydrotechnical Conference
Quebec City - May 1977.

COLD ENVIRONMENTAL HYDRAULICS RESEARCH FACILITY AT CCIW.

by
G. Tsang and R. Carson

Hydraulics Research Division
Canada Centre for Inland Waters

January 1977

COLD ENVIRONMENTAL HYDRAULICS RESEARCH FACILITY AT CCIW

Robert Carson and Gee Tsang

ABSTRACT

The recently constructed cold environment hydraulics research facilities, consisting of two cold rooms refrigerated by a new "frost-free" glycol spray system, a recirculating flume with attached wind tunnel, a wave flume and a cold water storage and supply system, are described.

Our experiences relating to the design, construction and operation of the facilities are reported. The capabilities of the research facilities are demonstrated by some ongoing and planned research programs.

RESUME

Les installations de recherche hydraulique en milieu réfrigéré se composent de deux chambres froides réfrigérées par un dispositif de vaporisation au glycol. On décrit la canalisation de récirculation et la soufflerie attenante, la canalisation à vagues et le dispositif d'entreposage et d'approvisionnement d'eau froide. On signale les expériences touchant la conception, la construction et le fonctionnement des installations. Enfin, on indique, par le truchement de certains programmes de recherche en cours ou projetés, la capacité de ces installations.

COLD ENVIRONMENTAL HYDRAULICS RESEARCH FACILITY AT CCIW

Robert Carson* and Gee Tsang**

Introduction

Canada, with her abundant water resources and a northern climate, needs a comprehensive cold environmental hydraulics research program for optimal utilization of her water resources. A cold environmental research program has been established at Canada Centre for Inland Waters and research facilities have been constructed. The facilities consist of cold rooms, a recirculating flume with an attached wind tunnel, a wave flume and a cold water storage and supply system. The potential of these facilities has not yet been fully utilized, both time-wise and from the point of scientific scope. Conduction of coordinated and cooperative research projects with outside organizations is a way to better use the modern facilities at CCIW. The components of the research facilities are described below and some of the capabilities are demonstrated.

The Cold Rooms

The two adjoining cold rooms occupy a floor space of 18.5 m x 6.2 m (60' x 20'). The smaller room, measuring 3.7 m x 6.2 m (12' x 20'), occupies one corner of the floor space and serves mainly for instrument development, cold environment calibration and torture testing of meteo-hydrological instruments. Each room is refrigerated by an independent system. By opening the interconnecting door or by removing the partioned walls, the two rooms then become one and are simultaneously cooled by the two refrigeration systems. When operating independently, one room serves as the anteroom for the other to avoid thermal shock.

The refrigeration systems of the cold rooms employ a newly-patented polypropylene glycol spray process which eliminates the usual defrost cycle and the accompanying temperature fluctuations. For a conventional refrigeration system, the cooling efficiency of the heat exchanger is gradually reduced as the moisture of the air being cooled is condensed and frost is formed on the cooling surface. Therefore, the coefficient of heat exchange is continuously reduced. Eventually, the heat exchanger has to be heated to melt the frost. The existence of a defrost period results in a thermal shock to the cold room as the heat exchanger is stopped and restarted. For the systems employed, a shower of glycol is installed above the heat exchanger. This shower of "antifreeze" washes the frost away from the heat exchanger surface as soon as it is formed. Thus, a constant coefficient of heat exchange is maintained. Glycol has a very low vapour pressure, so there is a negligible evaporation in the air stream. The quantity of glycol therefore may be recirculated almost indefinitely.

---

*Research Engineer, **Research Scientist, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario.

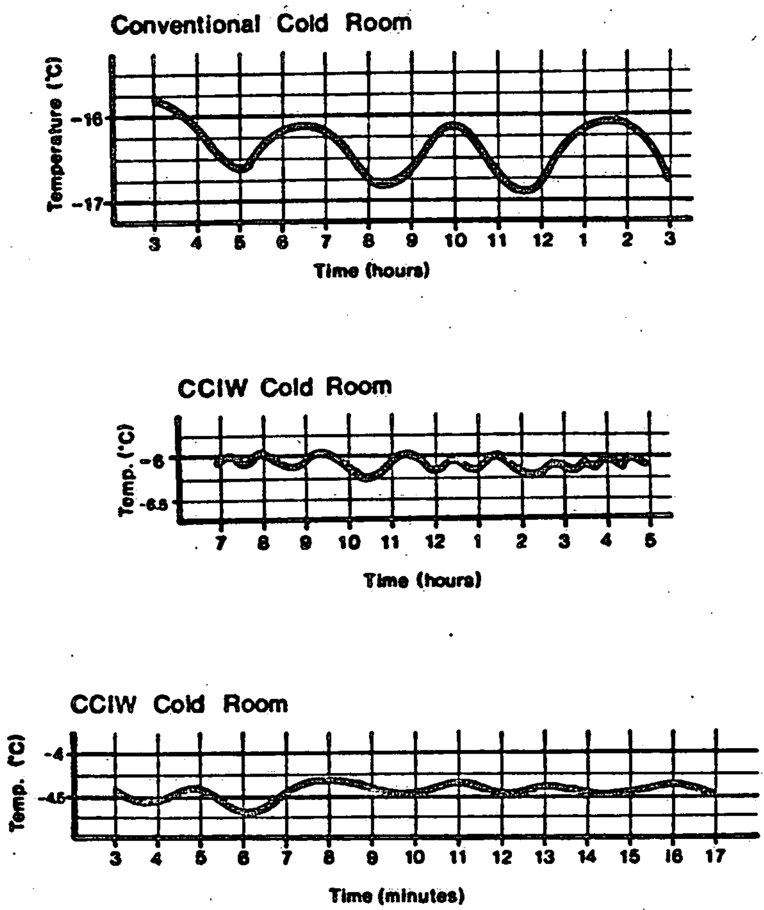


Fig. 1. Temperature Recordings for the CCIW Cold Room and a Conventional Cold Room.

The advantage of the glycol spray system can be seen by comparing the temperature recording of our cold rooms with the temperature recording of a conventional cold room (Fig. 1). Because of the steady state operation and the maintenance of a high heat exchange coefficient, the compressor capacity can be reduced. In our case, a 10 HP compressor is needed for the larger room (Room A), which otherwise would require a 25 HP compressor.

Fig. 2 illustrates schematically the air, coolant and glycol circulations of the systems that are used in the cold rooms. Air is delivered from the heat exchanger at a temperature approximately -34.4^{0}C (-30^{0}F) and is heated electrically to the desired temperature. Temperature control is achieved by a feedback system using a thermistor at the air return. The sensed temperature is continuously logged by a recorder. Design specifications are listed in Table 1.

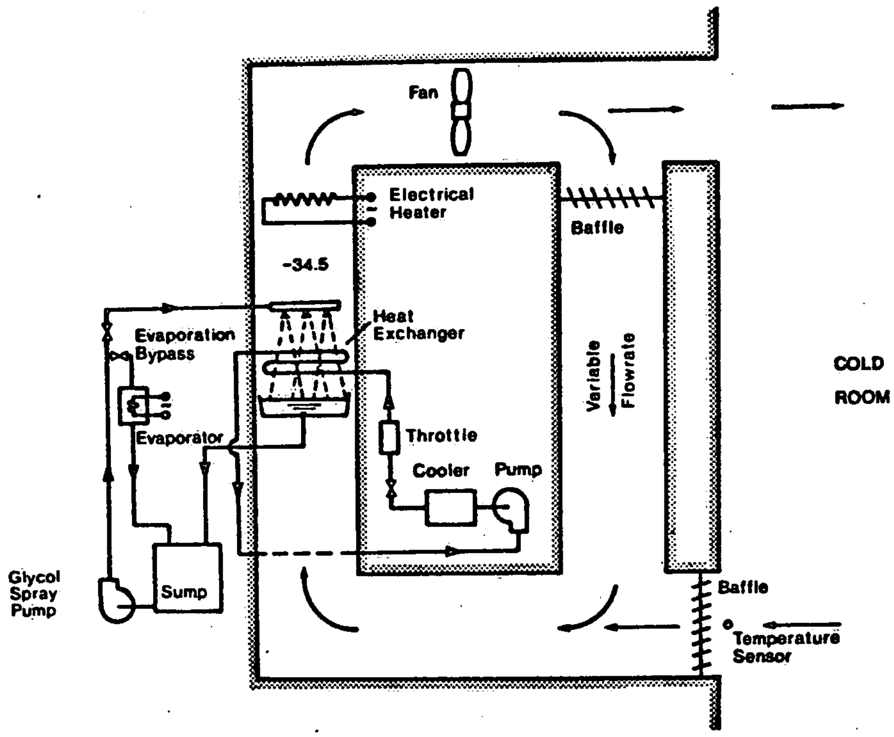


Fig. 2 - Schematic Diagram of CCIW Cold Room Systems

Table 1. Cold Room Cooling System Design Specifications

Room	A	B
Air flow (maximum)	4.72 m^3/s (10,000 cfm)	1.37 m^3/s (2,900 cfm)
Cooling	13,620 kg (15 tons) 9,625 cal/s (137,500 BTU/hr)	3,630 kg (4 tons) 2,744 cal/s (39,200 BTU/hr)
Reheating coil	40 kw	15 kw
Minimum space temperature	-30°C (-22°F)	-30°C (-22°F)
Maximum space temperature	+15°C (+59°F)	+15°C (+59°F)

Operations showed that the rooms can be cooled down from a temperature of +15°C (59°F) to the minimum temperature of -30°C (-22°F) in about an hour and a half, which is less than the design time of two hours. The spatial temperature variation is within ±1°C. The timewise fluctuation of temperature is within ±0.5°C from the mean temperature.

We are satisfied with the performance of the refrigeration system and have experienced no difficulties as yet. Maintenance of the system is minimal because of the steady state process which rids the parts of thermal stresses. One half-day is required for general cleaning each month and one or two days are required annually to clean the heat exchanger and spray pans.

The cold room shell is 10 cm (4") thick urethane insulation with aluminum sheet siding on both sides. Difficulties were experienced in gluing the aluminum sheeting to urethane. We recommend that, in future cold room construction, sheet plywood should be glued to the urethane slab first and then glue the sheet metal to the plywood. The cold room is raised off the laboratory floor on 15 cm x 15 cm (6" x 6") timber joists to provide adequate air circulation to prevent condensation. Major loading is transferred directly to the laboratory floor through cutouts in the cold room floor. Vapourproof instrument portholes are provided on the walls to permit the passage of tubing and wiring from the cold rooms. Fluorescent lights are used in the cold rooms and they dim as temperature goes down, especially below -20°C. We recommend the use of incandescent lights for future cold rooms. The cold rooms are 3 m (10') high, but 0.6 m (2') is used to accommodate the ductwork and wiring, reducing the working height to 2.4 m (8'). We find such a working height too low for most research projects involving material handling and the use of flumes and recommend at least 0.6 m (2') more head room for future cold rooms. We further recommend that more strength should be built into the walls and the ceiling for general supporting purposes.

The Recirculating Flume

The Flume - The self-contained recirculating flume (see Fig. 3) is located in the larger cold room with the insulated return pipeline located outside the cold room to save valuable cold room space. The working section of the flume is 11.0 m (36'6") long with a rectangular cross-section 0.6 m wide x 0.5 m deep (2' x 1'6"). The flume is made of plywood on a steel frame and the surfaces are fibreglass coated. Heated glass windows are installed in the front side-wall of the flume to permit viewing. Hinged insulation panels are installed in front of the glass windows to reduce heat loss where viewing is not needed. Fine alignment adjustments of the flume are obtained by adjusting the leveling bolts which support the frame of the flume at 0.5 m (1'8") intervals. Throughout the whole flume, no metal part comes into direct contact with water to avoid localized freezing and local thermal stress. Leakage had been experienced, but the problem was solved by increasing the width of the sealing strip to allow for greater flexible expansion as the water pressure pushes the windows away from the seal. Eight sets of three flush-mounted pressure tappings, each connected to a common manifold, are provided at the bottom of the flume at 1.5 m (4'11") intervals to give the water levels along the flume. An adjustable, sharp-crested weir is installed at the end of the flume to control the flow depth. Some icing of the weir guides and the sprocket-chain lifting mechanism has been experienced, but it does not pose major operational problems. After flowing over the weir, the water free-falls

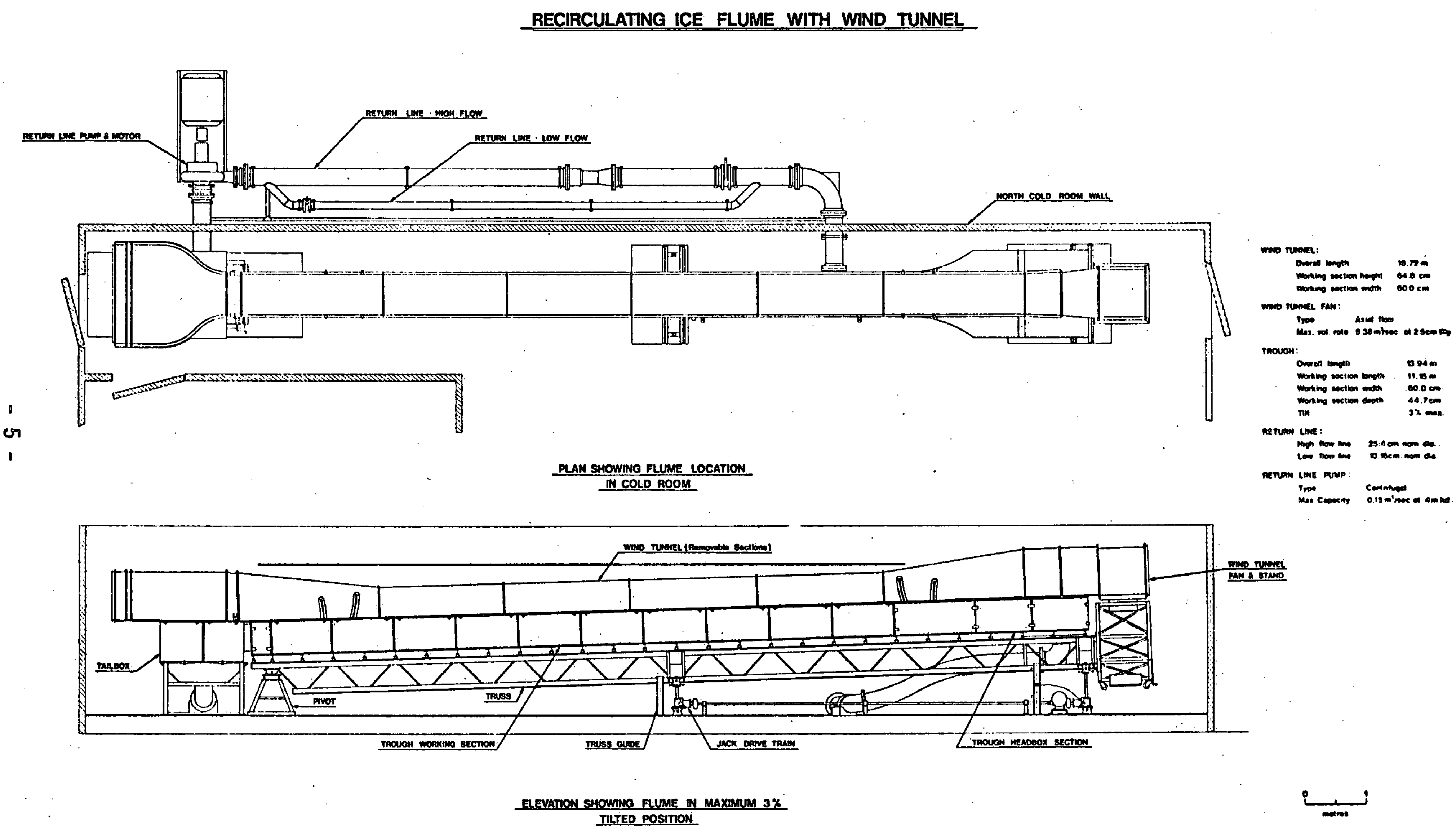


Fig. 3 - The CCIW Cold Room Recirculating Flume with Wind Tunnel

into the conical tailbox. It is then pumped back to the headbox to be recirculated.

Although an axial-flow pump is more efficient and produces less heat for a given discharge against a low head, a centrifugal pump is used because it is capable of operating stably over a larger discharge range and has a smaller bearing loading. The 15 HP variable-speed pump provides a flow range of 0 to 0.15 m^3/s (5.3 ft^3/s) against a design head of 4.0 m (13').

For better flow metering, the return flow is permitted to pass through either of two branches of the return line, a 25.5 cm (10") line for high flow rates from 0.015 to 0.15 m^3/s (0.53 to 5.30 ft^3/s) and a 10.2 cm (4") line for low flow rates from 0.00625 to 0.028 m^3/s (0.22 to 0.99 ft^3/s). Flow is measured in the larger branch by a Venturi meter and measurement in the small line is obtained by an Annubar. The flow re-enters the cold room and enters the headbox by way of a 2.9 m (9'6") long, 25.5 cm (10") diameter flexible hose which permits the slope changes of the flume. The flow enters the headbox at a right angle to the bottom. The entry of the water is characterized by surging and upward jetting which affect the downstream flow. Because of space limitations, a stilling head tank cannot be built in the cold room. Various conventional methods to stabilize the flow had been tried and failed due to the freezing up of the openings or the accumulation of frazil ice in front of the flow eveners. Eventually, a simple float stabilizer complimented by a flow divider (see Fig. 4) was used. The PVC float effectively absorbs the turbulent energy associated with level fluctuations and its smooth surface inhibits ice accumulation. The flow beyond the stabilizer is divided evenly by trial and error by adjusting the angles of the dividing vanes which are also made of PVC plates and experience no icing problems. Our stabilizing system reduces temporal velocity fluctuations from ±50 percent to under 5 percent and reduces the unevenness of the velocity profile from in excess of 20 percent from the mean velocity to a fairly uniform profile within 5 percent for average flows and 10 percent for the lowest flow rates. Our experiences showed that, after a prolonged run of 2 to 3 hours, the frazil ice would eventually bridge the gap between the dividing vanes and cover the headbox area in front of the divider with a thin layer of ice. However, the flow is not noticeably affected by this minor ice accumulation and it can be easily removed manually or by momentarily increasing the flow. In general, the float stabilizer works well for our research purposes and we would recommend it for other researchers.

The flume pivots about the downstream end and its slope can be varied from -1 to +3 percent by the use of two pairs of synchronized jack screws. A digital counter is attached to the gear box of one jack and is calibrated to give the slope. The jacks and pivot rest on oak beams which transfer the load of the flume directly to the concrete floor.

An ice feeding-retrieving system is being constructed to introduce a continuous supply of ice floes of varying sizes and at different rates at the upstream end of the flume and to retrieve them at the downstream end for reuse.

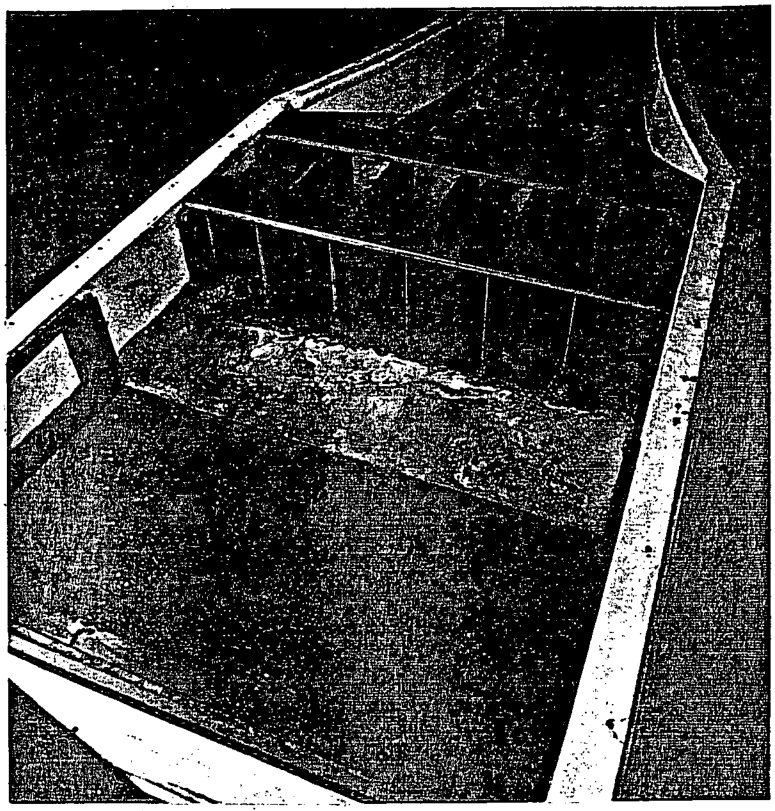


Fig. 4 - Dampening Paddle and Flow Dividers in the Headbox.

The Heating Systems and Insulation - To prevent ice deposition and accumulation on the flume walls, bottom, windows and return pipe lines, they are heated. The heating rate is minimized by reducing the heat loss to the ambient air by insulation. Such an arrangement also simulates the natural situation of river flows where heat is only lost from the free surface and is gained from the warmer river bed.

A total of ten independent heating circuits are used to heat the different parts of the recirculating flume. Heating cables rated at 44.3 watts/m (13.5 watts/ft) are used as heaters. For the PVC return pipelines, heating cable is wound around the pipes giving a maximum heating rate of about 780 watts/m^2 (72 watts/ft^2). The heating rate can be varied by varying the voltage to the heaters. Thermistor control is incorporated in the pipeline heating system. The power cut-off temperature can be set from 10°C to 120°C with a setability of about 10°C. We found that such a thermal control is too coarse and the heaters give too much heat to the flow and reduce the cooling rate of the water in the cold room. A finer thermal control from 0°C to 20°C with a setability of 0.5°C and a cut-in and cut-out band width of 2°C would be more suitable. Modification of the pipeline heating control is being planned.

The pipeline is insulated by 5 cm (2") fibreglass with exterior sheet metal protection.

The glass windows are constructed of two 0.6 cm (¼") glass panes with a 1.3 cm (½") gap in between. The outer surface of the inside pane is coated with a transparent, conductive metal compound. By passing a current through the metal compound, a maximum heating capacity of 200 watts/m^2 (19 watts/ft^2) can be obtained. This heating rate also can be varied by varying the input voltage. Each glass window measures 1.0 m x 0.5 m (40" x 20") and they are covered by a 5 cm (2") thick polyurethane insulating panel when not in use, as mentioned earlier.

The flume trough, headbox and tailbox are heated similarily. Heating cables are fastened to the exterior surface in a criss-cross manner over an aluminum sheet for even heat distribution. Removeable 5 cm (2") polyurethane panels cover the heating coils. A maximum heating capacity of 540 watts/m^2 (50 watts/ft^2) is provided by the heaters and a smaller heating rate can be obtained by voltage control.

We found the heating arrangement to be adequate. No ice is formed anywhere below the water line. At the very upstream section of the flume, the high turbulence of the wind and the fluctuation of the water surface create some splashing, and consequently some local icing at the water line. This localized icing does not affect the total flow characteristics in the flume and we believe that it can be eliminated by increasing the local heating rate by about 20 percent.

The Wind Tunnel - The wind tunnel mounted on the recirculating flume consists of 2 m (6'10") long removable sections, 0.6 m wide and 0.4 m high (2' x 2'1"). The entrance and the fan sections are interchangeable for alternate wind directions. A plastic fan capable of delivering 5.4 m^3/s (190 ft^3/s) against a head of 2.5 cm (1") w.g. and driven by a variable speed 5 HP AC motor is used. The wind tunnel walls are 0.6 cm (¼") fibreglass stiffened to withstand 8 cm (3") w.g. pressure with no deflection and are insulated with 2.5 cm (1") polyurethane and protected with a further fibreglass coating. Such a design, although strong, makes the sections too heavy and awkward to handle. Similar inconvenience is encountered in handling the fan and the entrance sections. We would recommend a lighter construction to other researchers. An increase in the cold room height will enable the installation of some lifting devices and that would naturally make the handling of the wind tunnel much easier.

We found that a wind tunnel is invaluable for conducting cold environmental hydraulic research. When the wind tunnel is not running, we found that we are incapable of producing dynamic ice in the flume, even at a minimum cold room temperature of -25^{0}C obtainable under the loaded condition. The heat generated by the pump and produced by the heaters reaches an equilibrium point with the heat loss when the temperature of the water is still slightly above freezing. The cooling of the water by the wind tunnel, even at a low speed, greatly accelerates the cooling rate and we are generally able to produce frazil ice in the cold room in less than one day from 4^{0}C water.

The Wave Flume

The wave flume (Fig. 5) is also located in the large cold room. To save space, the flume is in the form of a modified U-shape. The working section of the flume is 3.7 m (12") long, 0.6 m (2') deep and 0.25 m (10") wide. The flume is made of plywood with fibreglass and resin coating and a plexiglass front wall for the working section. The plexiglass wall is constructed of two panes 0.6 cm (¼") thick with a 1.3 cm (½") gap between them. Heating wires run lengthwise and criss-cross in the gap providing a heating rate of 390 watts/m^2. The flume itself is not heated but is insulated by 1.9 cm (3/4") fibreglass with a 1 cm (3/8") plywood outer shell.

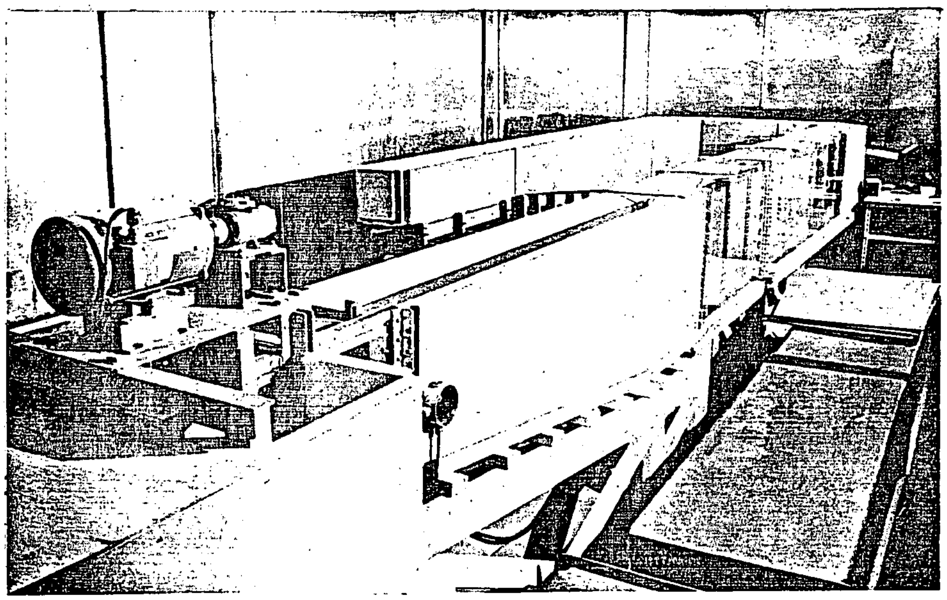


Fig. 5 - The Wave Flume.

Mono-frequencied sinusoidal waves are generated by a paddle-type wave generator driven by a variable-speed 3/4 HP DC motor. Different wave heights are obtained by changing the stroke of the paddle. The maximum paddle stroke is 19.6 cm (7-3/4") and the highest frequency is 5 Hz. The waves are generated in the paddle section which is 0.4 m (14") deep. After passing through the transition section which gradually deepens from 0.4 m to 0.6 m and the working section, the waves are deflected in turn by two 90^0 deflectors into the end section where the wave energy is absorbed by a series of baffles and a wave absorbing beach.

The wave flume can be used as a frazil ice generator and reservoir to supply frazil ice to the recirculating flume if the need arises.

In general, the wave flume does not work as well as the recirculating flume. Minor leaks usually result after a solid ice sheet has been formed in the flume and constant maintenance is required.

The Cold Water Storage and Supply System

The cold water storage and supply system is used for temporary storage of the cooled water after an experiment and for simulation of a hydrograph in the recirculating flume. The system consists of a storage tank, a pump and the necessary pipeline. The storage tank has a capacity of 4.5 m^3 (1000 gal) and can hold all the water from the recirculating flume and the wave flume combined. The fibreglass tank is insulated with polyester and designed to keep the temperature decrease rate to 1^{0}C/day. Water is pumped from the flumes to the elevated tank, but the reverse flow is produced by gravity. The recirculating flume can be filled or emptied in about an hour and the wave flume in about twenty minutes.

We found the storage tank very desirable because it enables us to reuse the cooled water, which may have taken us one or two days to cool down to the experimental temperature. Thus, the existence of the water storage and supply system greatly increases the efficiency of utilization of the research facilities.

Research Capabilities as Demonstrated by the Ongoing and Planned Research Programs

The research capabilities of the available facilities are demonstrated by some of the ongoing and planned research programs, as shown below. Needless to say, these research programs have in no way reached the maximum potential of the facilities. "Planned programs" refer to programs that we are unable to handle at this time due to manpower shortage and have to be postponed until some ongoing programs are terminated.

A. Ongoing Programs

(i) The Stability of an Ice Cover - The stability of an ice cover and the initiation of ice jamming have been investigated by a number of researchers. From these studies, the stability criteria, mostly in the form of a critical Froude number, have been proposed. In most of the studies, simulation materials were used instead of ice and all the studies treated the problem as a steady state problem. In our study, real ice, including ice floes of different sizes and frazil slushes, will be used. An increasing hydrograph will also be incorporated in the simulated flow. We intend to compare our experimental findings with different formulae proposed by different researchers. We also intend to include the boundary roughness and wind shear of the flow as additional parameters. These parameters have been disregarded by all the previous researchers. Fig. 6 shows a preliminary experiment in which an ice jam is created at critical flow.

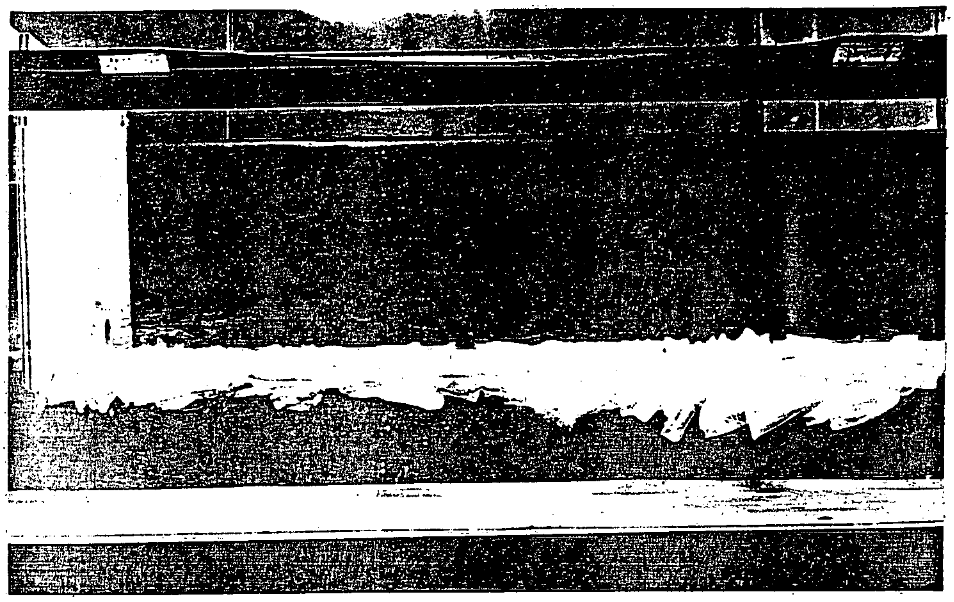


Fig. 6 - A Stable Underhanging Dam created in the Recirculating Flume

(ii) Movement of an Oil Slick Under an Ice Cover - The movement, spread and emulsion of an oil slick under an ice cover will be studied. We plan to study the behaviour of an oil slick under different flow and boundary conditions and also to derive a formula which can predict the movement of the spilled oil after an under-ice oil spill has taken place. At the request of the oil industry, we shall also look into the possibility of oil recovery through cut slots in the ice cover.

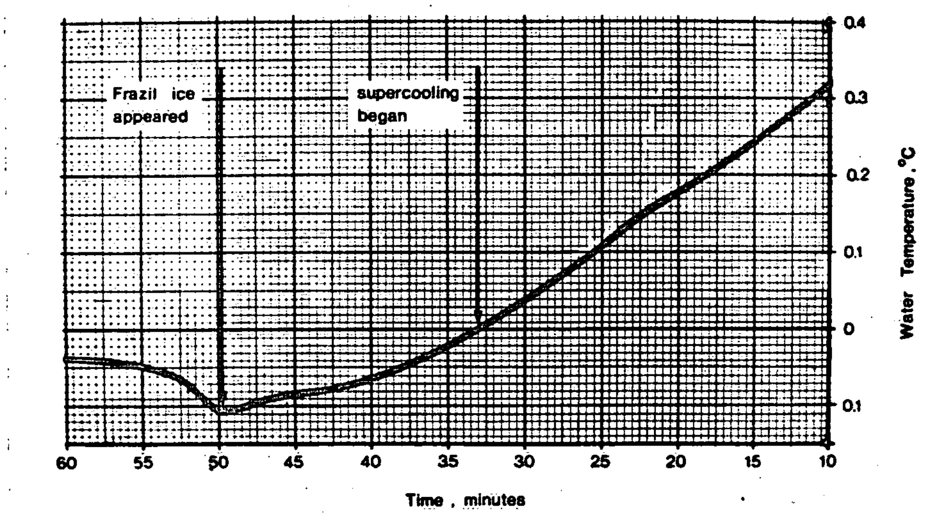
(iii) Resistance of Ice Covered Flow - The resistance of ice covered rivers has been looked into by many researchers. However, no generally applicable formulae have been derived for engineering practice. We intend to use the recirculating flume to study the friction coefficient of ice covered flows. We want to see whether the bottom roughness will affect the undersurface roughness of the ice cover and consequently the overall composite friction coefficient of the flow. The friction coefficient of fragmented ic covers will also be looked into.

For all the above three projects, the recirculating flume is used.

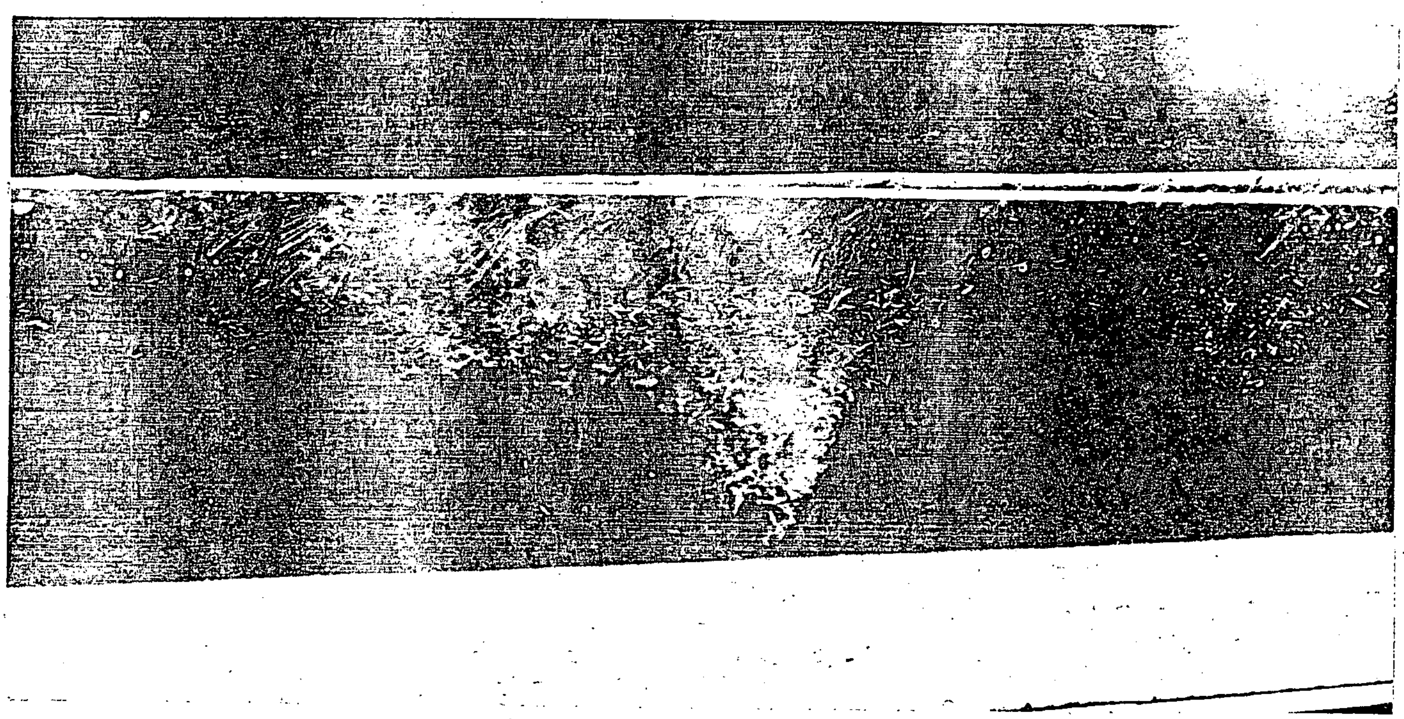
B. Planned Programs

(i) The Formation and Vertical Distribution of Frazil Ice in Water with Surface Waves - In this project, we plan to study the rate of heat loss and the formation of frazil ice as a function of depth and time in a water body with surface waves. The vertical distribution of frazil ice and the variation of the distribution profile will also be studied. The conduction of this program depends on the availability of a frazil ice measuring instrument which is being successfully developed (see another paper by Tsang presented at this conference). The program will help us to understand the formation of ice in lakes and reservoirs.

(ii) <u>The Formation and Distribution of Frazil Ice in Flowing Water</u> - This is a parallel project to the above program, but with flowing water in mind. In addition to studying the formation and distribution of frazil ice, the effect of frazil ice on the flow characteristics will also be studied. Fig. 7 shows frazil ice in the flume and the temperature depression curve for frazil ice production for one of the preliminary tests.



Water Temperature Depression Curve



Frazil Ice in the Flume

Fig. 7 - Frazil Ice Production in the Recirculating Flume

Our planned programs remain flexible, depending on social and other factors. We found that our research activity is constrained by the limitation of scientific manpower rather than by a lack of research facilities or scientific topics.

Summary

This paper describes the available research facilities at CCIW for cold environmental hydraulics research. Some design and operation experiences which we think are beneficial to other researchers are shown. The research capability is not yet fully utilized and we welcome cooperative research endeavours with outside institutions for common good.

DATE DUE
DATE DE RETOUR

APR AVR 12 1982			

LOWE-MARTIN No. 1137