FIELD INVESTIGATIONS OF SOME ICE COVER PROBLEMS IN AN EXPERIMENTAL CANAL

by

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Nota Bene: Opinions expressed in this paper do not in any way engage the responsibility or acquiescence of the Quebec Hydro-Electric Commission.

INTRODUCTION

Ice problems as encountered in the planning and operation of hydro-electric power developments have received since a long time much attention in some parts of this country and in Canada. In his paper Mr. Cousineau outlined some aspects of these questions in reference to the conditions prevailing in the province of Quebec and particularly in the area covered by the Quebec Hydro-Electric Commission's developments. No doubt other power companies could contribute much to this by an esposè of their experience in this domain.

Since its inception the Quebec Hydro-Electric Commission has devoted efforts to evaluate these problems, in relation to its programme of development in different areas of the province. In connection with engineering studies considering power development of the Lachine Rapids section of the St. Lawrence River in the Montreal area (Figure 1), where ice problems appear significant in regard to economics of the project and security requirements, the Commission has given since 1957 further impetus to these ice studies, in order to supplement previous experience and knowledge by theoretical and laboratory investigations, in the expectation this new approach would contribute to the solution of these problems and establish new fundamental knowledge of ice phenomena which could have more general application in hydro-electric practice.

Messrs. Pariset and Hausser have reviewed briefly in their paper the extent of the recent theoretical and experimental investigations conducted in the LaSalle Hydraulic Laboratory on the principal subjects of ice phenomena which are of importance in hydro-electric practice, namely ice cover formation, flow and ice entrainment under an ice cover, ice jams and hanging dams, rates and quantities of ice formation in rapid flowing open sections of rivers, ice evacuation by special devices, etc.

In relation to the above studies and, as part of an intensive program of ice investigations, to obtain further direct information in the field on some other points of importance, it was decided by the Commission in 1957 to conduct experimentation in an outside canal, utilizing ice as naturally occurring in nature and in a location where prevailing winter weather conditions would be representative of conditions expected for the development under study.

The present paper covers briefly the installation of this canal, the objectives and the nature of the experiments and some results so far obtained.

THE EXPERIMENTAL CANAL

Next to the Rapids, on the north side of the St. Lawrence River, the remaining power-house substructure and intake canal dyke of the old Lachine Rapids power development built in 1896 offered conditions suitable enough for installation of this experimental canal, with availability of drifting ice for experimentation and under water and weather conditions corresponding fairly well to those expected (Figure 2).

The old power-house extends from the north shore of the river into the main current for approximately 1000 feet, at the end of which a rock and earth dyke extends upstream for some 900 feet, constituting in this way the intake canal which has an average depth of 8 to 10 feet. This dyke is also produced downstream of the power-house to form the tailwater canal. There is a drop of 11 feet between headwater and tailwater under open water conditions.

The experimental canal was built in this forebay canal and along the upstream dyke, making use of this dyke (with plank revetment) as one wall of the canal, the other wall being constructed of timber cribwork loaded with rock and covered by a plank revetment inside. The width of this canal corresponds to the width of two adjacent turbine intake flumes which have been provided with regulating gates at their entrance.

The canal has an overall length of 300 feet in order to obtain reasonably good flow and velocity distribution over a reasonable reach. In cross-section the water area is rectangular, 9 feet in average depth by 46 feet in width. The regulating gates, heated electrically, are operated by electric hoisting equipment and permit variation of flow velocity in the canal between 0 and 5 feet per second, a range in velocities sufficient for the proposed experiments.

A movable foot-bridge spanning the canal and equipped with a small crane allows observations and measurements to be made over the whole length and width of the canal (Figures 3 and 4). Two floating booms, of the rigid one-piece and articulated three-piece types respectively, are used as starting line for ice cover formation and for control of ice movements in the canal.

Point velocities across the section are measured with a Dumas type current meter. Special thermometers are provided for measurement of water temperature, while the weather elements are measured by a recording thermometer and hygrometer, a wind velocity and direction indicator, and an ordinary aneroid barometer. Additional weather data are available from the Montreal Forecast Center at Dorval Airport.

Construction of this canal was completed by mid-December 1957. Installation of equipment and other facilities were completed by mid-January 1958. Figure 5 is an aerial view of the canal and the surrounding area taken during the winter 1957-1958.

EXPERIMENTS

On account of restrictions and delays imposed by unfavourable weather conditions mainly and by other difficulties such as necessary adjustment to the equipment and machinery or blocking of ice inlet at the upstream end of the canal, the period of operations during the winter of 1957-1958 was of short effective duration one month only, in February. It is hoped the winter of 1958-1959 will prove more advantageous in this respect.

The main objectives of these experiments may be summarized as follows:

a) to study the formation and progression upstream of ice covers formed by inflow of drifting ice and particularly;

b) to determine safe upper limits of flow velocity insuring formation and upstream advancement and stabilization of an ice cover;

c) to determine flow velocity causing the breaking of an established ice cover by progressive increase of flow, and to study the mechanism of this breaking of the ice cover;

d) to determine surface velocity of flow causing over-turning of variously shaped blocks of ice, in order to substantiate on a larger scale and with natural ice the data obtained from the research done in the laboratory;

e) the program for the 1958-1959 winter, in addition to supplementary tests on cover formation and breaking, includes special tests on a model of a vortex-type ice spillway or sluice that has been tested recently in the laboratory. No results are available yet on the field tests which have just begun.

During the short period available in the winter 1957-1958, the experiments conducted include formation and breaking of 23 ice covers as well as 73 tests on the overturning of ice blocks against a floating boom. Observations were made also on frazil ice, its appearance and behaviour, but will not be dealt with in this paper.

The tests on ice covers were made in three consecutive steps with increasing velocities, to allow determination of low velocities corresponding to: first the total or partial accumulation of incoming ice against the cover being formed; second the condition of equilibrium of the upstream edge of the cover when all incoming ice is carried underneath; third the breaking of the cover under slowly or rapidly increased flow velocity.

Of the 23 covers studied, 13 were formed by inflow of surface ice, the dimensions of the blocks varying between 1 foot by 1 foot by 1/8 inch to 2 inches in thickness and in a few cases with large blocks of border ice of up to 12 feet by 12 feet by 12 inches in thickness (Figure 6). Some more covers were studied which were formed mainly of incoming slush ice. No measurements could be made in all those tests of the quantity of ice carried under the cover.

As regards the tests on the overturning of ice blocks, these blocks were sawed off in the ice field adjacent to the canal in rectangular, square or triangular shapes with dimensions varying generally from 3 by 6 feet to 12 by 12 feet and thicknesses between 1 and 1.8 feet. The blocks were placed against the boom and the velocity of flow was slowly increased until overturning and entrainment under the boom, this final surface velocity being measured (Figure 7).

RESULTS

The experiments of this first season on these aspects of ice cover formation, progression and breaking lead to the following preliminary results and conclusions.

1) Formation of an ice cover.

a) For given ice inflows the rate of upstream progression of the cover is maximum for flow velocities under 1.5 feet per second. For higher flow velocities, up to 2 feet per second, part of the incoming ice is carried underneath and consequently the rate of upstream advancement diminishes.

b) For flow velocities between 2.0 and 2.2 feet per second, the cover still advances upstream but with much difficulty, most of the incoming ice being entrained under the progressing cover and it appears that only under special circumstances will an ice cover pack upstream for higher flow velocities. Tests on overturning of ice blocks confirm the upper limit by the mean value of 2.30 feet per second obtained for the velocity causing overturning.

c) Tests results also indicate that an already established ice cover will be dislocated at its upstream edge when the surface velocity of the water reaches approximately 3 feet per second, the range in values obtained from the tests being from 2.5 to 3.8 feet per second. The covers had thicknesses of some 6 inches and it is to be recalled that the number of degree-days since formation of the cover has a bearing on the thickness of the cover and on the allowable velocity of flow under the cover.

2) Overturning of ice blocks

Velocities obtained ranged between 1.6 and 3.2 feet per second, according to shapes and dimensions, and these values substantiate in the range observed the results obtained in the laboratory, correlating closely with theoretical analysis and laboratory experimentation.

GENERAL CONCLUSION

It is our belief that these first experiments in the field have proven of value by giving better understanding of the phenomena of ice cover formation and maintenance in rivers and by fixing certain numerical values which, combined with results of other investigations, will aid to define practical rules for insuring the security of operation and economy of development of hydro projects under winter conditions.

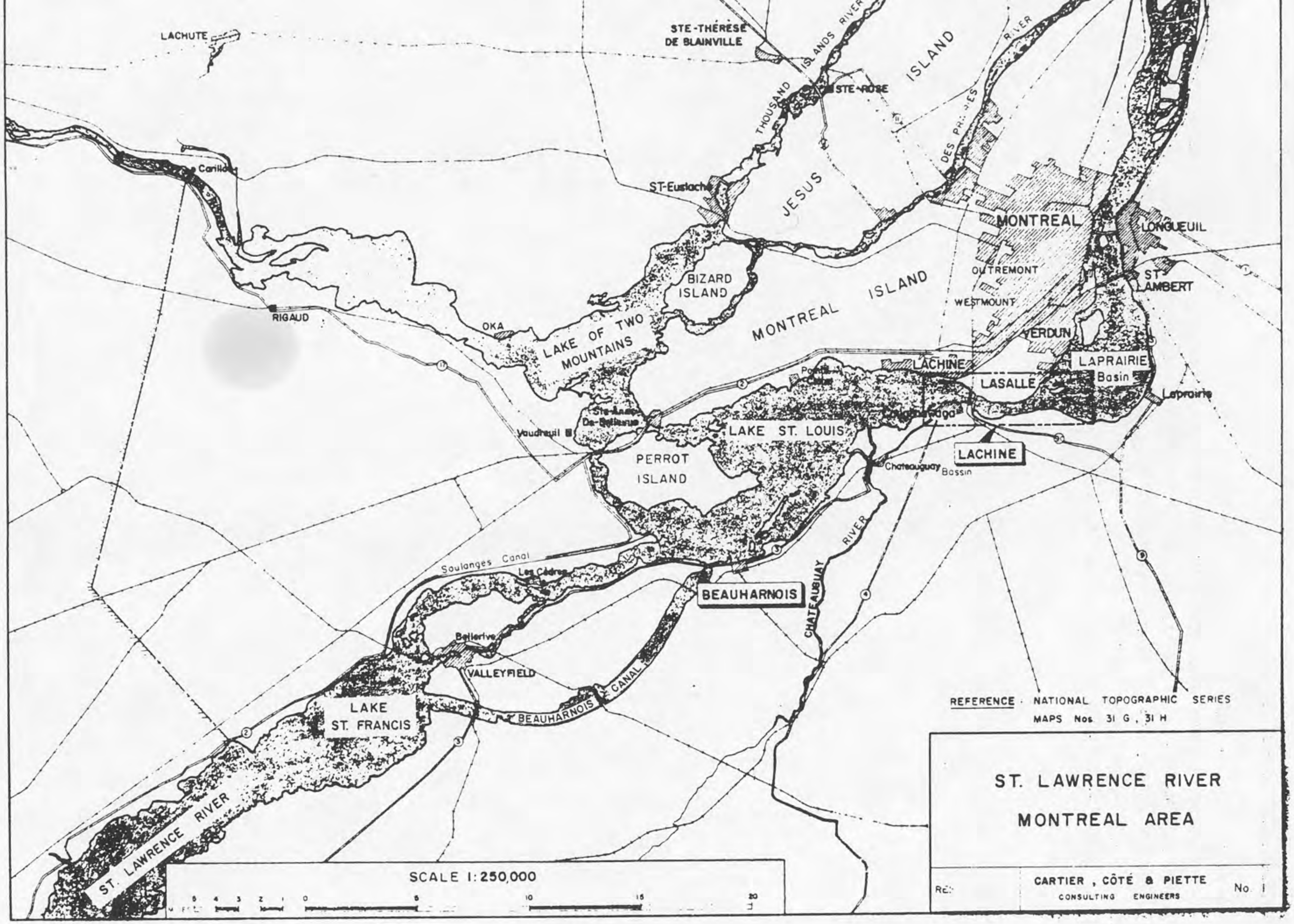

LACHUTE
STE-THÉRÈSE DE BLAINVILLE
THOUSAND ISLANDS RIVER
STE-ROSE
JESUS ISLAND
DES PRAIRIES RIVER
ST-Eustache
Carillon
BIZARD ISLAND
MONTREAL ISLAND
MONTREAL
OUTREMONT
WESTMOUNT
VERDUN
LONGUEUIL
ST LAMBERT
RIGAUD
OKA
LAKE OF TWO MOUNTAINS
LACHINE
LASALLE
LAPRAIRIE Basin
Laprairie
Vaudreuil
LAKE ST. LOUIS
PERROT ISLAND
LACHINE
Chateauguay Bassin
CHATEAUGUAY RIVER
Soulanges Canal
Les Cèdres
BEAUHARNOIS
Bellerive
VALLEYFIELD
BEAUHARNOIS CANAL
LAKE ST. FRANCIS
ST. LAWRENCE RIVER
SCALE 1:250,000
REFERENCE · NATIONAL TOPOGRAPHIC SERIES
MAPS Nos 31 G , 31 H
ST. LAWRENCE RIVER
MONTREAL AREA
CARTIER , CÔTÉ & PIETTE
CONSULTING ENGINEERS
No. 1

Figure 1

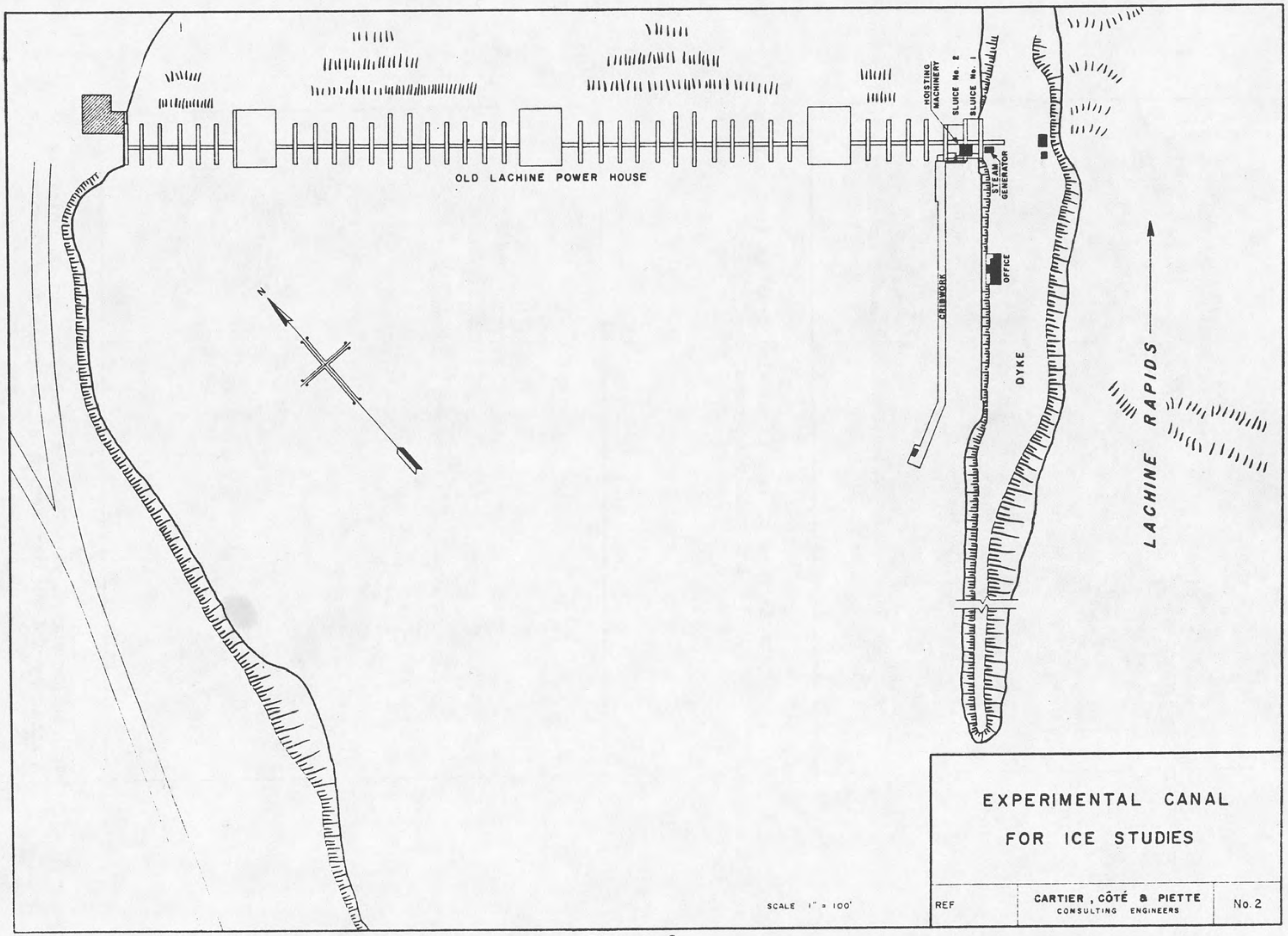
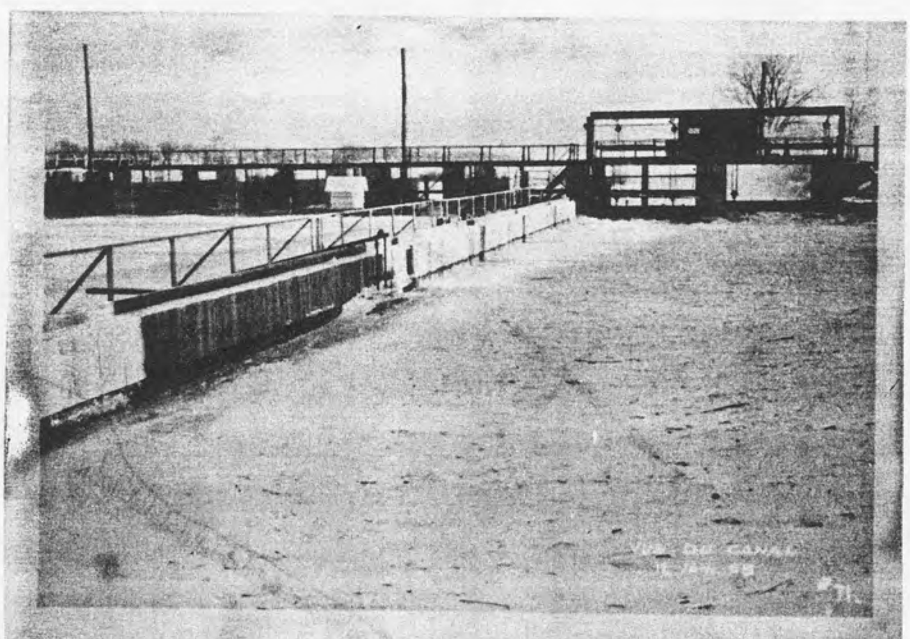

OLD LACHINE POWER HOUSE
HOISTING MACHINERY
SLUICE No. 2
SLUICE No. 1
STEAM GENERATOR
OFFICE
CRIBWORK
DYKE
LACHINE RAPIDS
N
SCALE 1" = 100'
EXPERIMENTAL CANAL
FOR ICE STUDIES
REF
CARTIER , CÔTÉ & PIETTE
CONSULTING ENGINEERS
No. 2

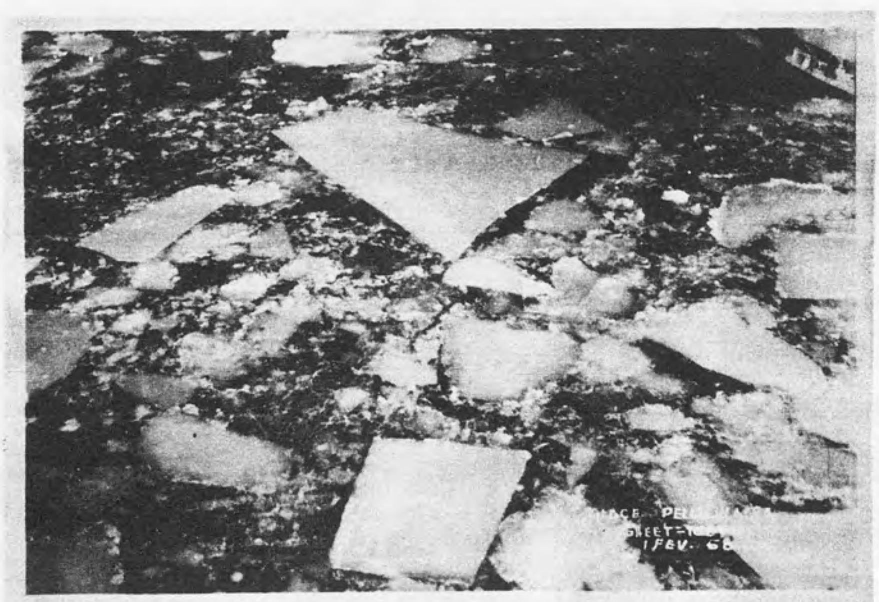
Figure 2

No. 3 - Upstream view of canal, showing movable foot-bridge and retaining boom.

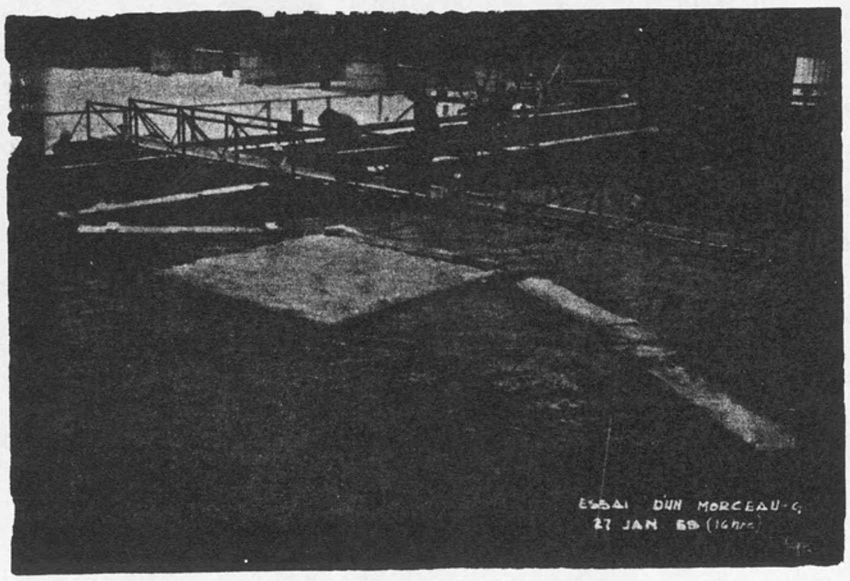


No. 4 - Downstream view of canal, showing gates, hoisting machinery and shelter for meteorological instruments.

No. 5 - Aerial view of canal and surrounding area Winter 1957 - 1958



No. 6 - Typical surface ice for cover formation experiments.



No. 7 - Test on overturning of ice block.