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TECHNICAL REPORT H-76-9

# ICE FLUSHING FROM ST. LAWRENCE SEAWAY LOCKS

Hydraulic Model Investigation

by

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July 1976

Final Report

Approved For Public Release; Distribution Unlimited



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Massena, New York 13662

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The St. Lawrence Seaway Development Corporation secured the services of the U. S. Army Engineer Waterways Experiment Station to determine, with the aid of physical model tests, the most effective and economical method of ridding a lock chamber of floating ice. Tests were conducted in an existing 1:25-scale lock model modified to simulate the pertinent features of the St. Lawrence Seaway Lock chambers. A manifold at the upstream end of the chamber proved best for flushing ice from the chamber. Flow through the manifold was pumped <div style="text-align: right;">(Continued)</div>		

## 20. ABSTRACT (Continued).

from various locations in the chamber or piped through the upstream miter gate sill; both of these methods were designed to create a sufficient slope of the water surface in the chamber to flush the ice. These model tests provided the means to determine the size and configuration of the manifold and the amount of flow required for total flushing.

Initially, the concept of pumping water to an upstream manifold from the lower end of the chamber was tested with limited success. Total flushing of the chamber was not accomplished with the pumped high-velocity manifold submerged, and considerable spray from the high-velocity jets would generate additional ice in actual prototype conditions with the jets at the water surface. Therefore, a high discharge with a low head to reduce velocities and increase the water-surface slope was preferred for greater flushing efficiency.

Heads of 38.5 to 42.5 ft at Dwight D. Eisenhower Lock (Robinson Bay) and 46 ft at Bertrand H. Snell Lock (Grass River) are available for gravity flow water-supply systems to the manifold located beneath the upstream ship bumper. These heads proved sufficient to flush 10- by 10-ft blocks of ice 1.5 and 3.0 ft thick from the entire 860-ft-long by 80-ft-wide chamber with the proper size and placement of the manifold.

Optimum flushing of the surface ice was accomplished with four 4-ft-diam pipes spaced 16 ft apart between the lock walls with their center line level with the lower pool. A total discharge of 2000 cfs was required for optimum flushing. Special consideration was given during these development tests to accommodate a 2- to 3-ft variation in water-surface elevation of the lower pool and to minimize spray which would generate additional ice. The average total flushing time for 120 blocks of 10- by 10- by 3-ft ice was 15 min.

## PREFACE

A hydraulic model investigation to determine effective ways and means of flushing ice from the St. Lawrence Seaway Locks was authorized by the Office, Chief of Engineers, in the first indorsement dated 25 July 1974 to a letter dated 16 July 1974 from the Director of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The St. Lawrence Seaway Development Corporation considered it highly desirable that the tests be conducted at WES where research concerning application of multiport diffusers had been conducted for desalinization plants and to induce circulation in stagnant embayments. It was considered that the suggested application and development of a multiport manifold to induce sufficient circulation downstream from the upper miter gate would be of use in removing ice from similar Corps locks with side port or bottom longitudinal filling and emptying systems. The desired tests were technically feasible and were performed with existing facilities and available personnel without interfering with work in progress at WES. The study was accomplished in the Hydraulics Laboratory of the WES during the period 6 September 1974 to 19 February 1975.

The investigation was conducted under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; John L. Grace, Chief of the Structures Division; and G. A. Pickering, Chief of the Locks and Conduits Branch. The engineer in immediate charge of the model was Mr. N. R. Oswalt, assisted by Messrs. H. H. Allen and C. L. Dent. This report was prepared by Mr. Oswalt.

During the course of the investigation, Messrs. John B. Adams III, William S. Spriggs, and Patrick M. Gillon of the St. Lawrence Seaway Development Corporation; Messrs. Walter E. Webb and Martin Liou of the St. Lawrence Seaway Authority, Canada; and Dr. George D. Ashton of the U. S. Army Cold Regions Research and Engineering Laboratory visited WES to observe model operation and discuss test results.

Directors of WES during the conduct of the tests and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)  
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
feet per second	0.3048	metres per second
cubic feet per second	0.02831685	cubic metres per second
degrees (angular)	0.01745329	radians

# ICE FLUSHING FROM SAINT LAWRENCE SEAWAY LOCKS

## Hydraulic Model Investigation

### PART I: INTRODUCTION

#### The Prototype

1. Dwight D. Eisenhower and Bertrand H. Snell Locks are located on the St. Lawrence Seaway between Lake St. Lawrence and the St. Lawrence Seaway International Bridge (Figure 1). Both locks have side port systems for filling and emptying the 80-ft-wide\* by 860-ft-long chambers. Lifts vary from 38.5 to 42.5 ft at Eisenhower and remain near 46 ft at Snell. The existing period of navigation without ice flushing devices is approximately April through November. With the proposed ice flushing system, the navigation period could be extended approximately two months, allowing navigation from March through December.

#### Description of the Prototype Problem

2. In the early spring (and sometimes late fall) when navigation is under way and there are ice formations in the river, considerable problems occur in clearing the lock approaches and chambers of ice to permit vessel transits. Conditions are such that, upon a downbound entrance into the lock, a vessel tends to move the ice ahead of its bow and push the ice into the chamber. The proposed ice flushing system will enable moving ice masses out of a lock chamber quickly, safely, and completely without causing undue strain and stresses to develop in the present lock operating equipment. As a result, the plans for extending the navigation season will be greatly enhanced.

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\* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

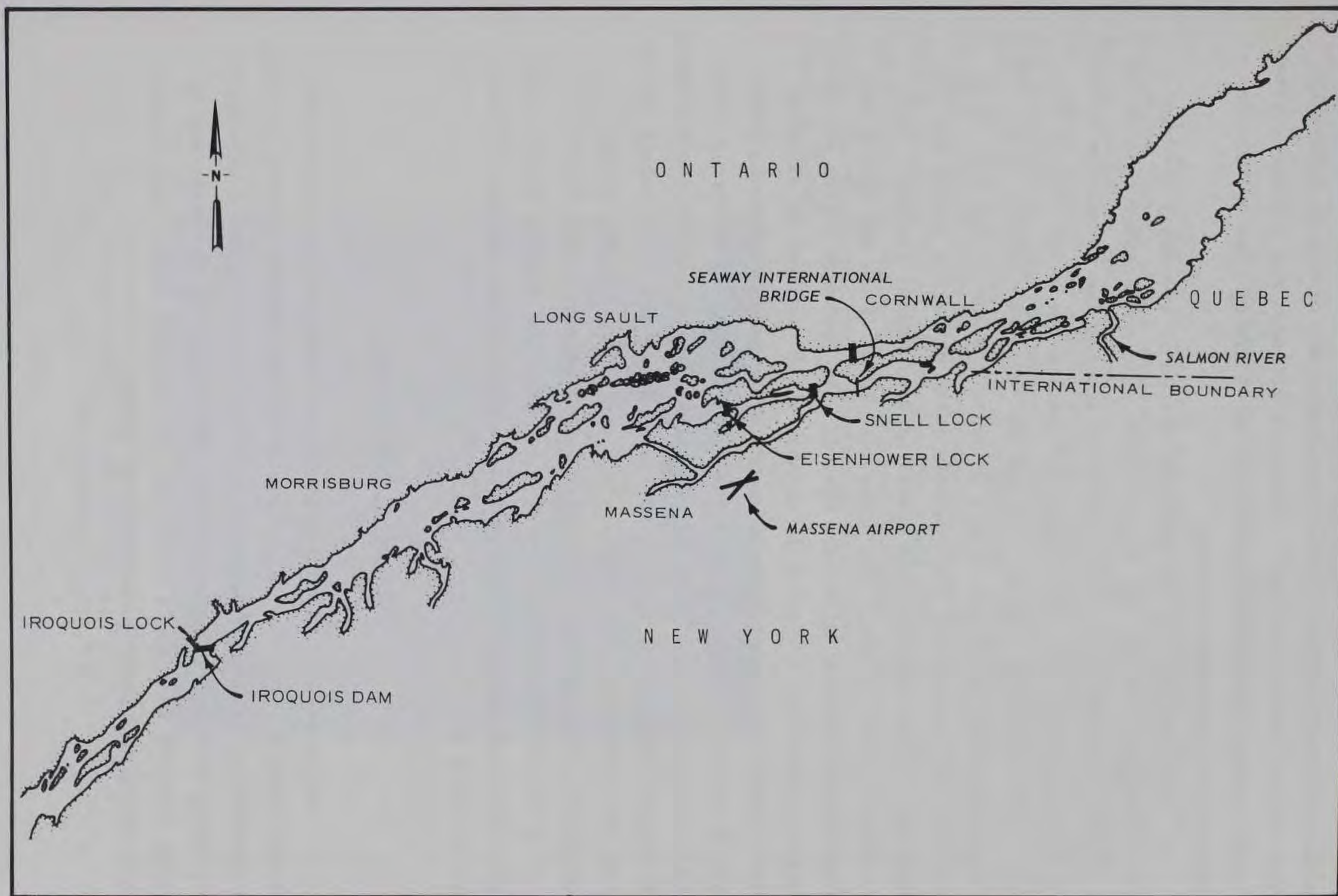


Figure 1. Vicinity map

Sometimes as many as five or six ice lockages are necessary before the vessel can be "locked through." These ice lockages are extremely slow, and each lockage consumes as much as 30 to 45 min of time before the chamber can be partially cleared.

3. The lock filling and emptying system is presently used for the ice lockages. First, the ice is drawn into the chamber by closing the upstream culvert valves and partially opening the downstream valves to create a current into the chamber by drawing the water through the ports. (This would be similar to lowering the lock chamber, except that the upstream miter gates are opened to allow the ice to enter.) Once the ice is in the chamber, the upstream miter gates are closed and the downstream culvert valves fully opened as in a normal lockage. When the chamber is at low pool, the downstream miter gates are opened and the downstream culvert valves are closed. The upstream valves are then partially opened and a current is created in the chamber by allowing water to enter the chamber via the ports. As the current moves downriver, it carries the ice along. The whole process is extremely slow, inasmuch as extreme caution has to be maintained to protect the equipment from surges, ice jamming against the gate, etc., which can happen if the valves are opened too much. This whole operation, besides being extremely slow, only partially clears the lock chamber since there is no way to create a current and clear the ice from the chamber in the area between the upstream miter gate and the most upstream filling port as shown in Plate 1.

#### Purpose of Model Study

4. Model tests were conducted to determine the most effective ways and means to move ice masses out of a lock chamber quickly, safely, and completely, without causing undue strain and stresses to develop in the present lock operating equipment. The object of the tests was to develop a system that would flush the ice from the entire lock chamber without using the filling and emptying system.

## PART II: THE MODEL

### Description of Model and Appurtenances

5. An existing 1:25-scale lock model was used for the study. It reproduced 800 ft of upstream approach, the entire filling and emptying system including intakes, valves, floor culvert system, lock chamber, and outlet basin, and about 600 ft of downstream approach. The model was modified to simulate only the pertinent physical features of Eisenhower and Snell Locks. The most significant revisions were to the lock chamber. The filling system was simulated, although it was not used during flushing tests. Basic geometric and structural features such as the bottom shape and ship bumper were considered significant to the tests and subsequently were accurately reproduced. The model flume is shown in Figure 2.

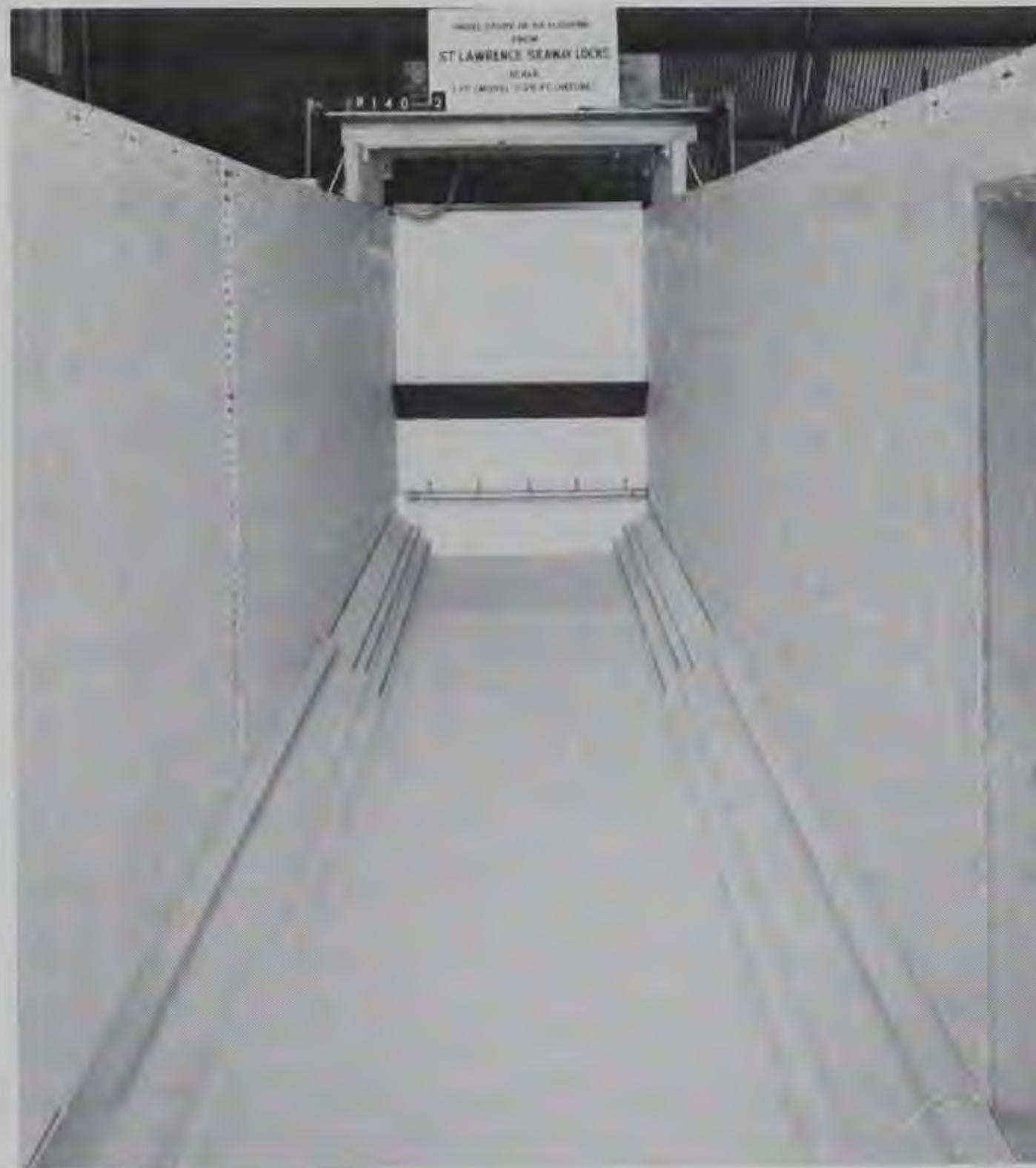


Figure 2. Inside test flume; looking upstream to ship bumper (in black) and type 1 ice flushing manifold

6. Discharges through the ice flushing diffuser were measured with a rotameter and/or V-notch weirs, and water-surface levels were set with piezometers and staff gages. Flushing times were taken with hand stopwatches and electronic timers.

7. A low-density polyethylene material which has the same density as ice was used to simulate 10- by 10-ft blocks of ice both 1.5 and 3.0 ft thick.

### Scale Relations

8. The accepted equations of hydraulic similitude, based on Frouddian relations, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for transference of model data to prototype equivalents are as follows:

<u>Characteristic</u>	<u>Dimension</u>	<u>Model:Prototype Scale Relation</u>
Length	$L$	$L_R = 1:25$
Area	$L_R^2$	$A_R = 1:625$
Velocity	$L_R^{1/2}$	$V_R = L_R^{1/2} = 1:5$
Time	$L_R^{1/2}$	$T_R = L_R^{1/2} = 1:5$
Discharge	$L_R^{5/2}$	$Q_R = L_R^{5/2} = 1:3125$

All characteristics in this report are given in prototype dimensions.

## PART III: TESTS AND RESULTS

### Test Procedure

9. The lock chamber water surface was covered with 10- by 10- by 3-ft blocks of ice to determine the efficiency of various types of manifolds and manifold positions required to flush the blocks from the chamber. Efficiency was measured by the manifold discharge and velocity versus the time required to move the ice mass various distances in the chamber. Various ice loads and relative spacing between ice blocks were tested to establish realistic flushing times. Special consideration was given to developing a system that would eliminate the use of the filling and emptying valves for ice flushing operations or otherwise develop undue stresses on the present lock operating equipment.

### Low Discharge-High Head Manifold

10. During the initial tests, discharges of 100, 150, 200, and 300 cfs were pumped at heads of 60 ft from various locations within the lock chamber to the ice flushing manifold beneath the ship bumper. The initial diffuser consisted of a 2-ft-diam manifold (type 1) with five 0.92-ft-diam, 4-ft-long nozzles. The manifold was submerged 34 ft below lower pool as shown in Figure 3. The 4-ft-long nozzles did not allow the jets to spread over the width of the lock chamber, and tests were conducted with various lengths of nozzles to determine their optimum length, which was found to be 2 ft (type 3 manifold). Shorter lengths, unsymmetrical jets, or improper jet angles created eddies that reduced flushing efficiency. Photo 1 shows flow conditions with the type 3 design with the upper third of the chamber initially covered with ice. This design moved the blocks 200 ft downstream in 350 sec (prototype) with a total discharge of 200 cfs (60-ft head); however, it was not effective in removing the ice from the entire lock chamber.

11. The manifold was raised to the elevation of the lower pool and tests were conducted with the nozzles discharging horizontally along



Figure 3. Close-up of ship bumper and type 1 ice flushing manifold

the water surface. This greatly improved the efficiency of the system and was designated type 4 manifold (Plate 2). Flow conditions with this design are shown in Photo 2. The blocks were moved from the upper 220 ft of the lock chamber in 180 sec with a discharge of 200 cfs; however, this design was not successful in removing the blocks from the entire lock chamber.

12. Tests were conducted with one, two, and three jets discharging horizontally from the manifold. The efficiency of any of these designs was about the same as with design 4 with only the upper 250 ft of the lock cleared of ice. Flow conditions with only one jet in the center of the chamber (manifold 6) are shown in Photo 3.

13. Various angles of discharge were tested with the manifold submerged 1 to 6 ft below the water surface; however, none of these designs was as effective as the horizontal discharge along the water surface of the lower pool.

14. During all of the above tests, the water was pumped from the lock chamber, 50 ft below the lower pool. Four different intake locations along the lock center line were tested (sta 0+50, 2+20, 4+30, and 6+00); and sta 0+50 (Plate 2) was found to be the most effective location. Flow was also withdrawn from the side culvert in an effort to create a circulation pattern capable of moving the floating ice the full length of the 860-ft chamber without success.

15. Several tests were conducted in an existing 3- by 3- by 40-ft-long glass flume to observe the current patterns produced by various heads and discharges from multiport manifolds in an effort to capitalize on any helpful ice flushing currents in a homogeneous chamber. No obvious helpful current patterns were generated during these tests, indicating that only high discharges would effectively move large ice masses from the lock chamber.

#### High Discharge-Low Head Manifold

16. During tests with low discharges pumped at high heads, it became obvious that larger discharges would be necessary to completely flush the ice from the lock chamber. It is desirable to obtain these discharges in the prototype with gravity flow from the upper pool rather than by pumping. Heads of 38.5 to 42.5 ft at Eisenhower Lock and 46 ft at Snell Lock are available for gravity flow water-supply systems to the flushing manifold. Previous tests had also indicated that the best flushing was produced with the manifold jet or jets discharging horizontally at the water surface; however, consideration had to be given to accommodating a 2- or 3-ft variation in the chamber water surface and preventing spray which would generate additional ice. Supply pipes 4 ft in diameter were used to provide the large discharges and accommodate the variation in tailwater, thereby eliminating the need for an adjustable manifold. Also, ice generation should be minimized with this size jet since there was no spray at the manifold. A 40-ft head was used for comparison of the various manifold designs; however, higher heads were tested with the recommended design.

17. Tests were conducted to determine the effect of varying lock chamber water levels on the time required to rid the chamber of ice. Results of tests with three different water levels are plotted in Plate 3, indicating that the half-submerged jet is best for total flushing. Therefore, the center line of the flushing jets should be positioned at the normal lower pool (Plate 4) to provide the best flushing and remain effective within the expected range of varying tailwater. As shown in Plate 3, prototype times of 67, 50, and 43 min were required to flush 220 lin ft of 10- by 10- by 3-ft-thick ice blocks from the 860-ft-long chamber with the two 4-ft-diam jets discharging a total of 580 cfs while fully submerged, nonsubmerged, and half submerged. Movement of the ice during the tests with the jets half and fully submerged is shown in Photos 4 and 5, respectively. Since less time was required to remove the ice from the chamber with the manifold center line even with the water surface, all remaining tests were conducted with the discharge jets half submerged.

18. The effects of increased discharge on the time required to rid the lock chamber of 220 lin ft of ice were determined with two, three, and four 4-ft-diam pipes located beneath the ship bumper. The two pipes were spaced 13 ft from the lock center line; the third pipe was placed on the center line; and with the design using four pipes, the pipes were spaced on 16-ft centers across the lock width. Each of the pipes had separate intakes in the approach area. Total flushing times for respective discharges of 580, 830, and 1080 cfs were 42, 39, and 29 prototype minutes as shown in Plate 5.

19. A multiported manifold (Figure 4) which had twenty 1-ft-diam ports on 3-ft centers was sensitive to jet alignment and produced eddies that kept the ice in the lock chamber when flow was directed other than parallel to the lock walls. Even with properly directed flow, the multiports tested were less effective than 2, 3, or 4 larger jets with equal discharge.

20. In an effort to reduce the time required to completely flush the lock chamber, tests were conducted with two 4-ft-diam pipes beneath the ship bumper and two entering the lock chamber at sta 2+75 at a

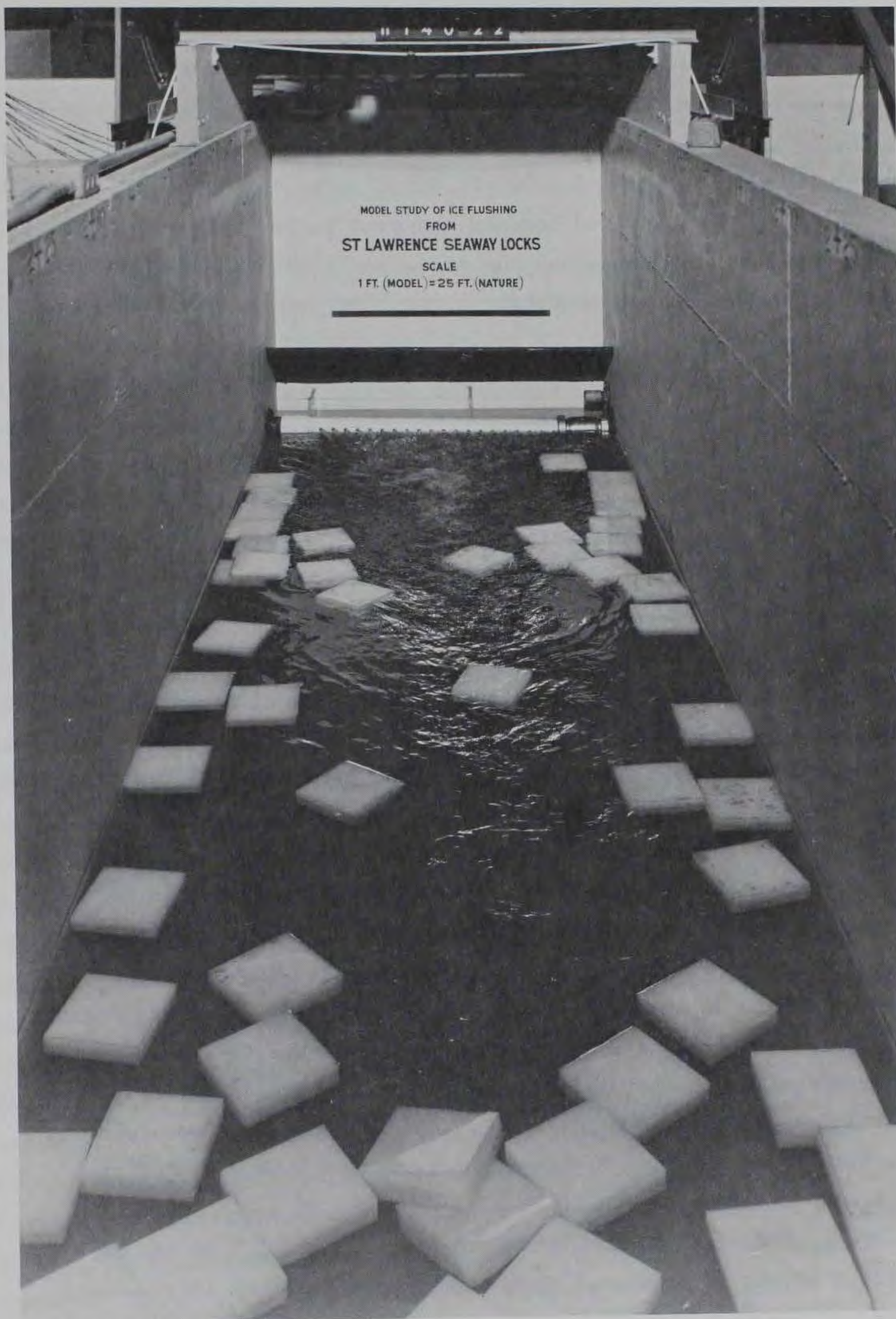


Figure 4. Multiported manifold (half submerged) discharging 580 cfs, 150 sec (prototype) after starting

45-deg angle. A discharge of 580 cfs from the two upstream pipes moved 120 blocks of ice to sta 2+75 in 450 sec, at which time the two side pipes were opened to discharge an additional 500 cfs. Movement of the ice during these tests is shown in Photo 6. The best flushing time obtained with this design and 1080 cfs was 28 min, compared with 29.5 min with all four pipes located beneath the ship bumper and the same discharge. Since the pipes along the sides would be considerably more costly to install in the prototype locks, they were considered unworthy of further testing.

21. While the model study was being conducted it was determined that the intakes for the discharge pipes could possibly be located in the upper gate sill. This would eliminate considerable energy losses that were present with the original model piping and valves and increase the discharge from the 4-ft-diam pipes. The model piping was rearranged as shown in Plate 4. This increased the discharge for each pipe to approximately 480 cfs with the 40-ft head.

22. Optimum flushing of the surface ice with a 40-ft head was accomplished with four 4-ft-diam pipes spaced 16 ft apart between the lock walls and a total discharge of approximately 2000 cfs released parallel to the lock walls as shown in Plate 4. The average total flushing time for 120 blocks of 10- by 10- by 3-ft ice was 15 min. Additional total flushing times and relations between length of ice movement versus time throughout tests with discharges up to 1920 cfs are shown in Plate 6.

23. A plot of the total flushing time versus discharge is provided in Plate 7 for three different ice loads to show the effect of these loads and discharges upon flushing times. As expected, lighter ice loads move faster and have less tendency to create jams. Another factor affecting the total flushing time is the concentration of ice (relative spacing between ice blocks) which becomes more obvious with large ice loads as noted by the scatter of data obtained with the 245 blocks of ice in Plate 7.

24. Reducing the ice thickness from 3 ft to 1.5 ft had no significant effect on the total flushing times with fifty 10-ft-square blocks of ice.

25. An increase in head from 40 ft (Eisenhower Lock) to 46 ft (Snell Lock) reduced the total flushing times required with 120 blocks of ice with discharges up to about 2000 cfs as shown in Plate 8. Increasing the total discharge from 1800 cfs (3 pipes) to 2400 cfs (4 pipes) with the 46-ft head resulted in only a 2-min reduction of the total flushing time.

26. Movement of the ice during several flushing operations with 120 blocks of ice, 40- and 46-ft heads, and two and four 4-ft-diam pipes discharging from 960 to 1920 cfs is depicted in Photos 7-10; flow conditions are shown on each photograph. During each flushing operation, a photograph was taken at intervals representing 0, 50, 150, and 300 prototype seconds.

#### Special Considerations for Prototype Installation and Operation

27. Several observations were made during these tests that could be pertinent to the installation and operation of the prototype flushing system. Although opening all ports simultaneously is effective, it is better to open the valves that discharge flow through the two pipes near the lock walls first and then open the valves that will control the two inside jets about 5 min later. This helps to avoid ice jams, boosts the ice movement, shortens the flushing time, and conserves water for power generation. For large ice loads, jams can be created by mooring bit or miter gate recesses, and discharges of 1500 to 2000 cfs are needed to assure complete flushing. The optimum flushing operation should be determined in the prototype by using several sequences of valve openings that might permit reduced discharges with lighter ice loads. Regardless of the number or size of pipes chosen to discharge the recommended flow rate of 2000 cfs, the pipes should be equally spaced across the lock width and flow should be distributed uniformly across the lock to prevent eddy action. It is believed that a four-port manifold system capable of discharging 2000 cfs will provide an effective means of flushing ice from the lock chambers.

## Prototype System Designed for Eisenhower Lock

28. Engineers for the St. Lawrence Seaway Development Corporation, using the test results herein, designed the ice flushing system shown in Plate 9 for Eisenhower Lock. In attempts to be both practical and economical, several modifications were made to the recommended (model) design. The most significant modification was the use of five 4-ft-diam manifold pipes which will be supplied from one-directional flow into a 10-ft-diam feeder pipe as shown in Plate 9. Five pipes were essential to keep equal spacing between the ship bumper supports. The single 10-ft-diam feeder pipe from only one 12- by 14-ft culvert was basically an economic factor.

29. Engineers at the U. S. Army Engineer Waterways Experiment Station reviewed the design with the above modifications and computed the expected head losses through the entire ice flushing system. For the 42-ft head at Eisenhower Lock, a total head loss of 24 ft was computed leaving an 18-ft effective head at the outlet portals. The maximum flow release was computed to be 2050 cfs with velocities of 30 to 34 fps. This was in close agreement with the total discharge recommended from the model study.

#### PART IV: DISCUSSION OF RESULTS

30. Model tests were conducted to assist engineers in selecting the best ice flushing system for the St. Lawrence Seaway Locks. All tests were concerned with quickly ridding the entire 860-ft-long by 80-ft-wide chamber of ice without using the filling valves, creating undue stresses on the structure and operating machinery, or passing excessive volumes of water through the lock.

31. Efforts to establish helpful ice flushing currents or sufficient water-surface differential with low discharge-high head manifolds to rid the chamber of ice were unsuccessful. Only partial flushing was possible with discharges below 1000 cfs for heads up to 60 ft.

32. A manifold with a relatively large discharge and a low head is preferred in lieu of a low discharge with high head. The best flushing was produced with the manifold jets discharging horizontally along the water surface. Consideration was given to accommodating a 2- to 3-ft variation in the water-surface elevation of the lower pool and to preventing spray which would generate additional ice.

33. Optimum flushing of the surface ice with a 40-ft head supplied from the upper pool was accomplished with four 4-ft-diam pipes spaced 16 ft apart between the lock walls and a total discharge of approximately 2000 cfs released parallel to the lock walls. The average total flushing time for 120 blocks of 10- by 10- by 3-ft ice was 15 min. The discharge from a 4-ft-diam pipe could be slightly different in the prototype and model, since the bends, valves, etc., will be different. Thus, the flushing times may be altered somewhat. However, this should have only a minor effect on the flushing operation.



a. Before test



b. 30 sec (prototype) after starting test

Photo 1. Type 3 manifold, discharge 200 cfs (sheet 1 of 2)



c. 150 sec (prototype) after starting test



d. 350 sec (prototype) after starting test



a. Before test



b. 50 sec (prototype) after starting test

Photo 2. Type 4 manifold, discharge 200 cfs (sheet 1 of 2)



c. 150 sec (prototype) after starting test  
Photo 2 (sheet 2 of 2)



a. 50 sec (prototype) after starting test,  
discharge 200 cfs



b. 50 sec (prototype) after starting test,  
discharge 300 cfs

Photo 3. Type 6 manifold, discharge 200 and 300 cfs

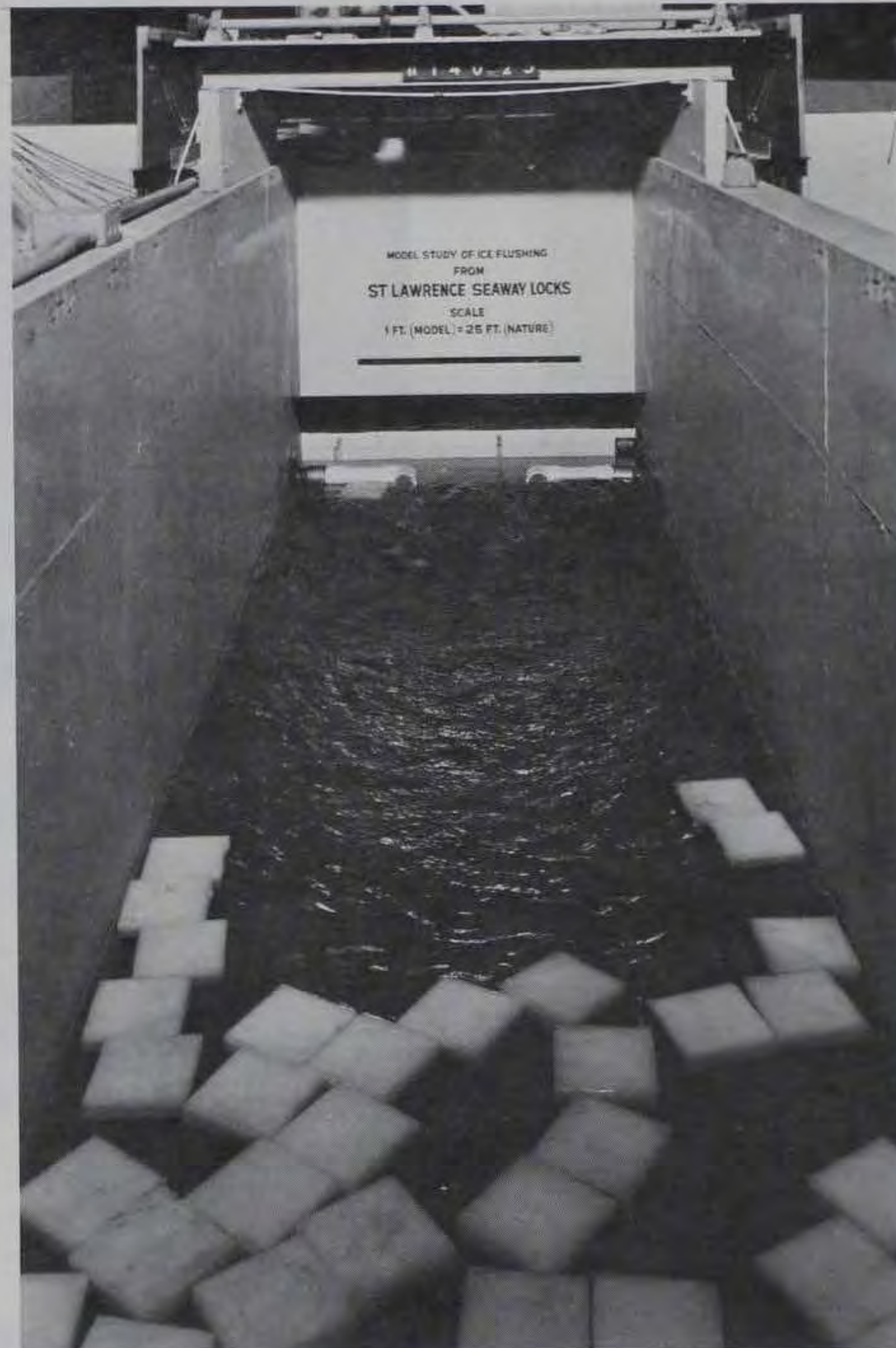


a. Before test



b. 50 sec (prototype) after starting test

Photo 4. Type 8 manifold (half submerged), discharge 580 cfs (sheet 1 of 2)



c. 150 sec (prototype) after starting test  
Photo 4 (sheet 2 of 2)



a. Before test



b. 50 sec (prototype) after starting test

Photo 5. Type 8 manifold (fully submerged), discharge 580 cfs (sheet 1 of 2)



c. 150 sec (prototype) after starting test

Photo 5 (sheet 2 of 2)



a. Before test



b. 50 sec (prototype) after starting test

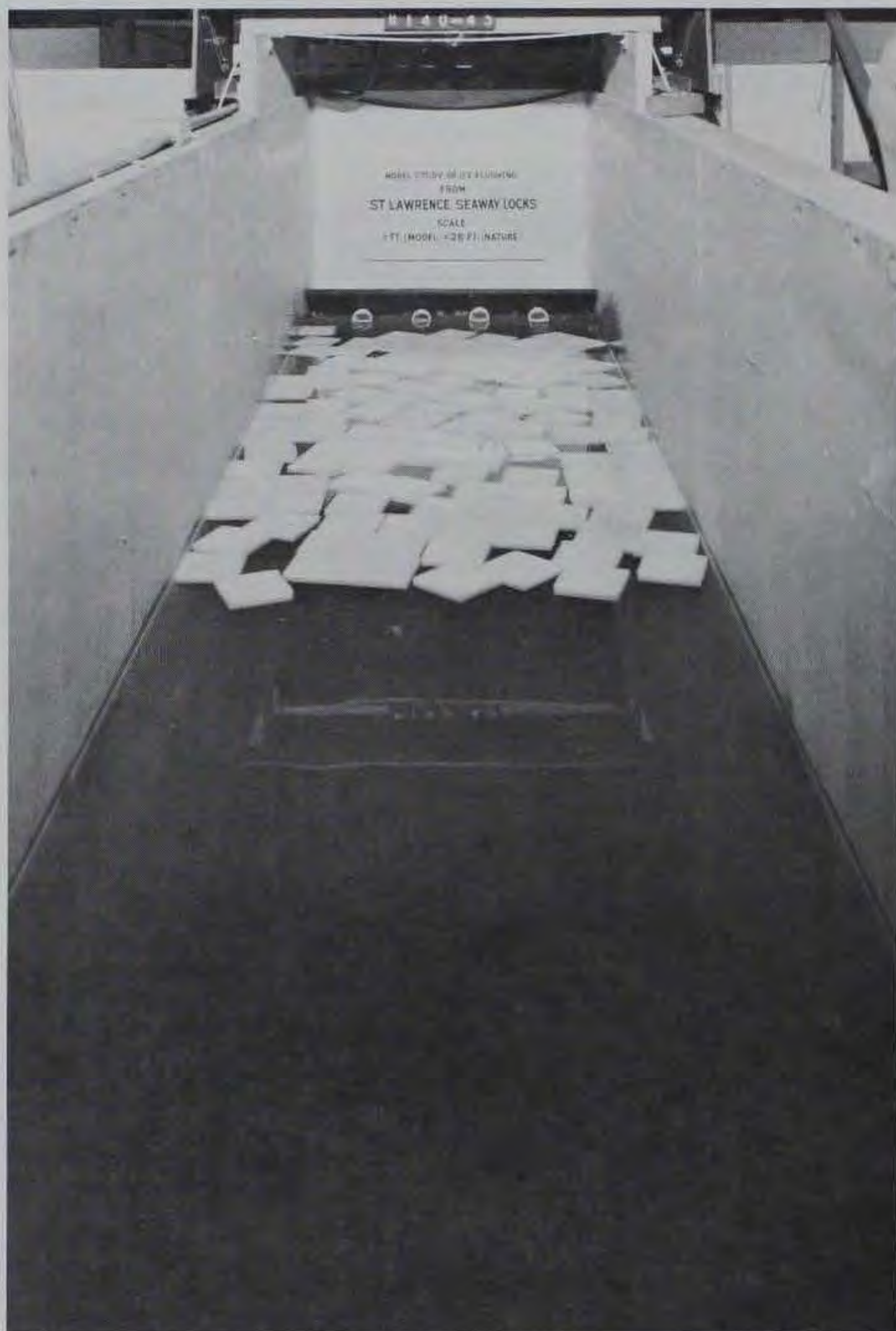
Photo 6. Two 4-ft jets at sta 0+20, two 4-ft jets at sta 2+75 with 40-ft head, discharge 1080 cfs (the two 4-ft jets at sta 2+75 were turned on at 450 sec after starting test)  
(sheet 1 of 2)



c. 150 sec (prototype) after starting test



d. 600 sec (prototype) after starting test

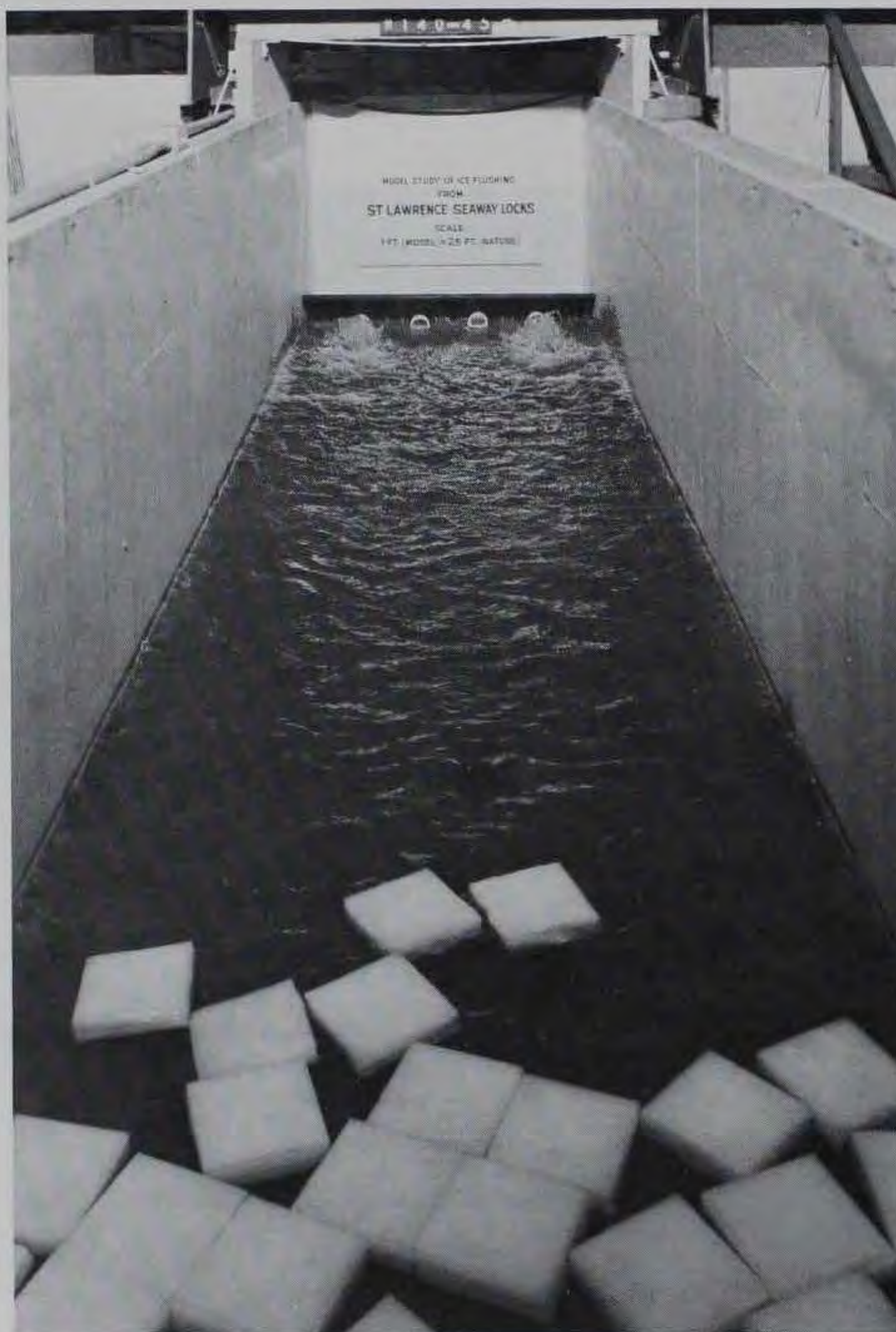


a. Before test



b. 50 sec (prototype) after starting test

Photo 7. Two 4-ft-diam jets at sta 0+17 with 40-ft head, discharge 960 cfs;  
120 blocks of ice (10 by 10 by 3 ft) (sheet 1 of 2)



c. 150 sec (prototype) after starting test



d. 300 sec (prototype) after starting test

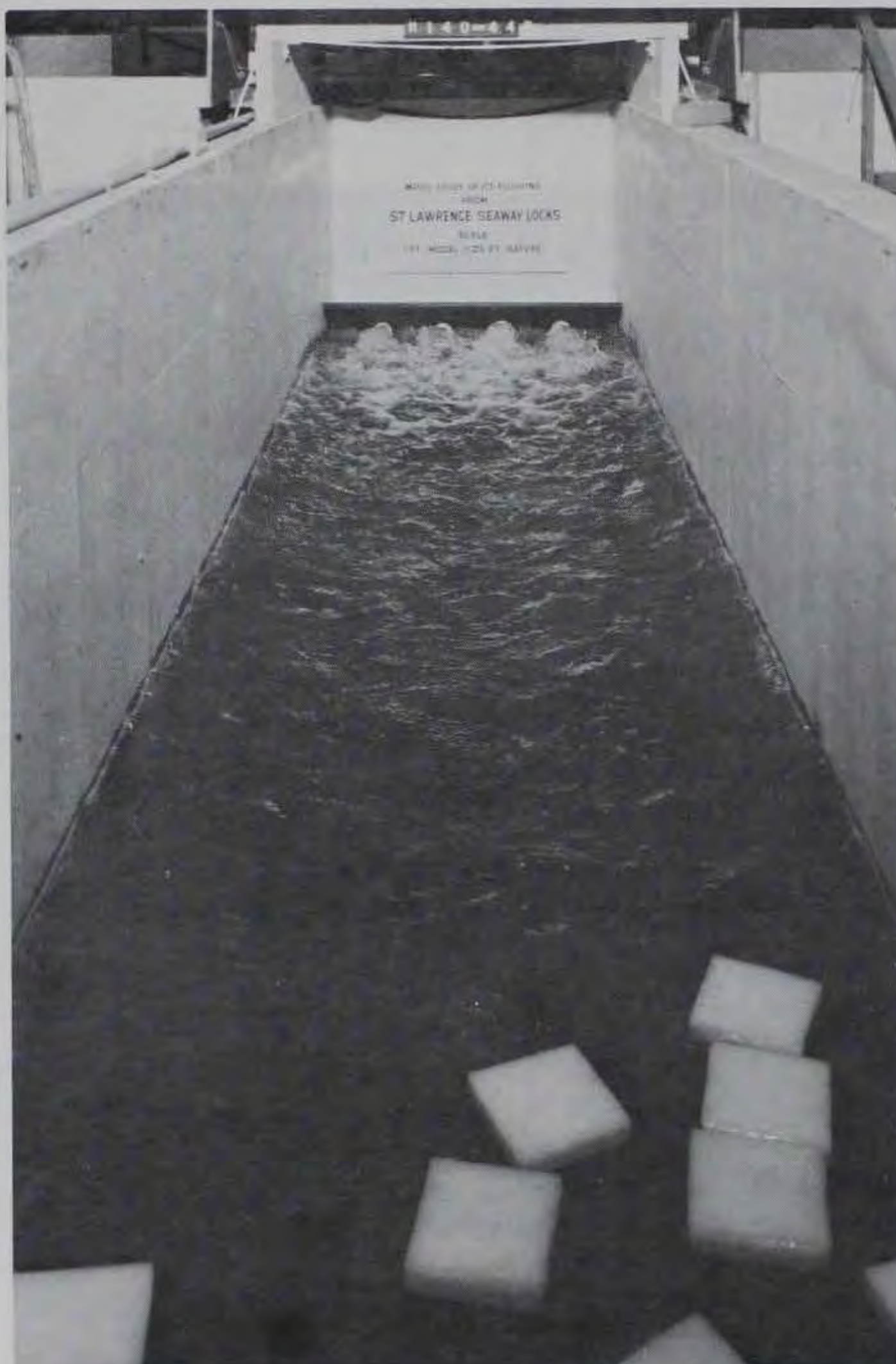


a. Before test



b. 50 sec (prototype) after starting test

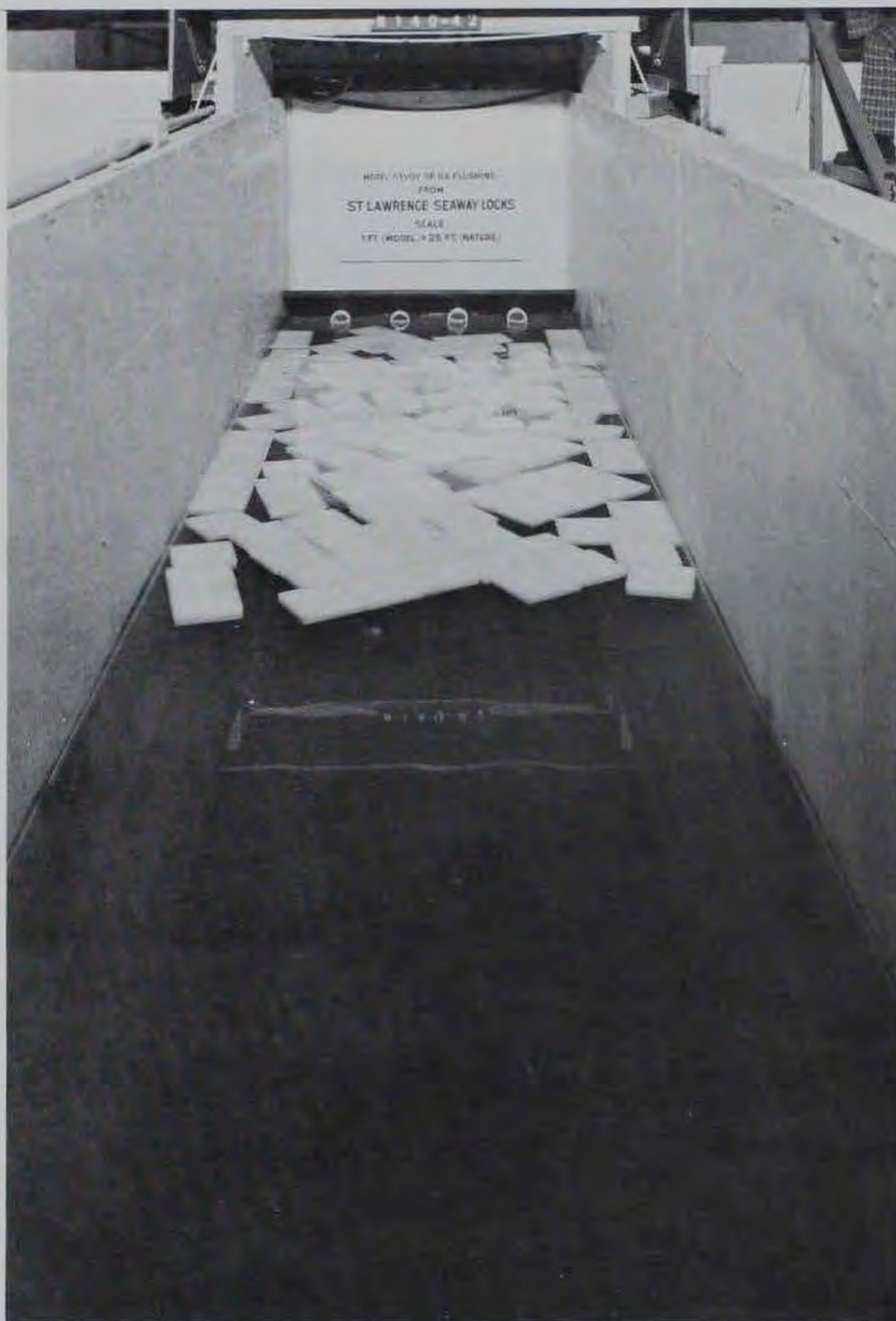
Photo 8. Four 4-ft-diam jets at sta 0+17 with 40-ft head, discharge 1920 cfs;  
120 blocks of ice (10 by 10 by 3 ft) (sheet 1 of 2)



c. 150 sec (prototype) after starting test



d. 300 sec (prototype) after starting test

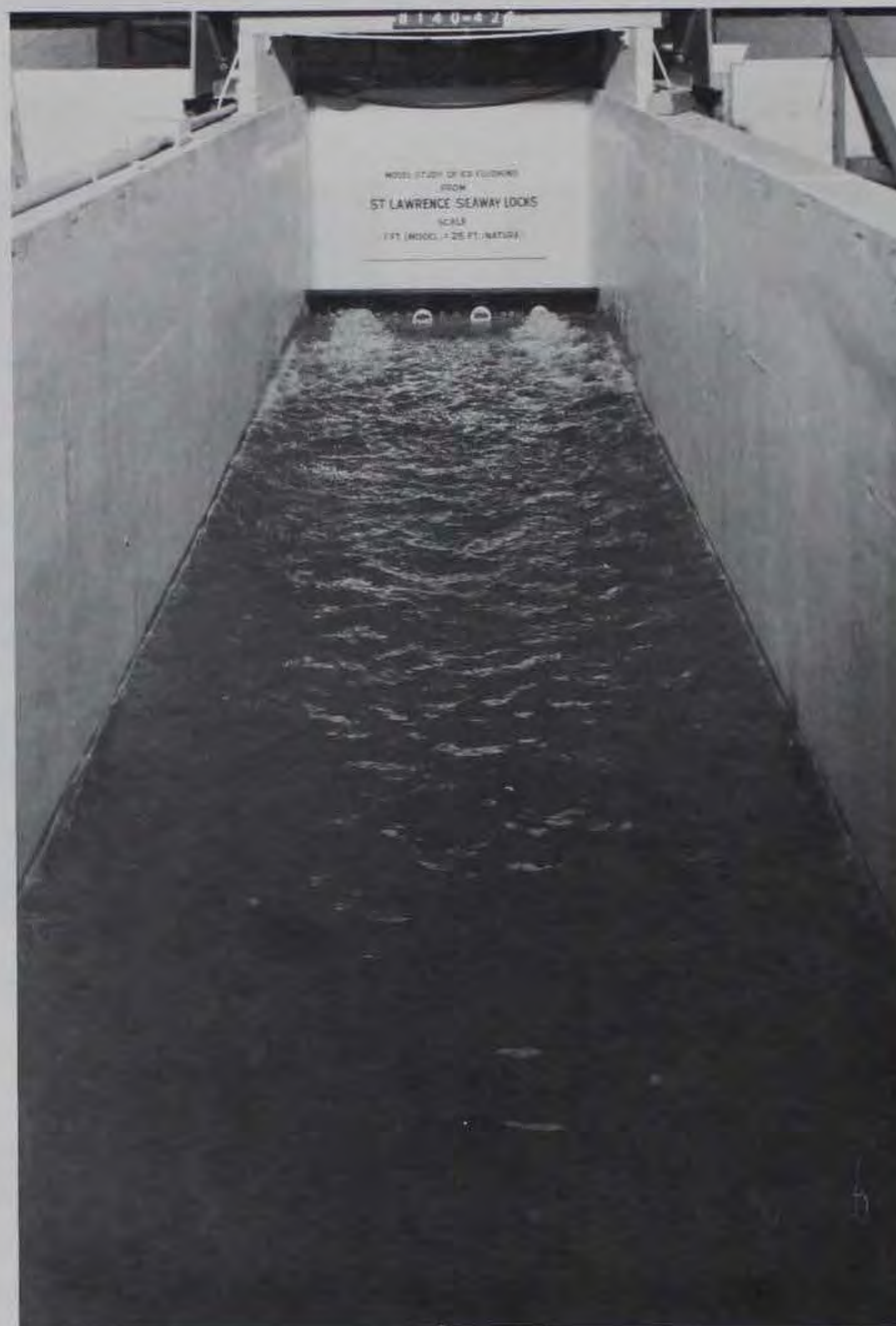


a. Before test



b. 150 sec (prototype) after starting test

Photo 9. Two 4-ft-diam jets at sta 0+17 with 46-ft head, discharge 1200 cfs;  
120 blocks of ice (10 by 10 by 3 ft) (sheet 1 of 2)



c. 300 sec (prototype) after starting test  
Photo 9 (sheet 2 of 2)

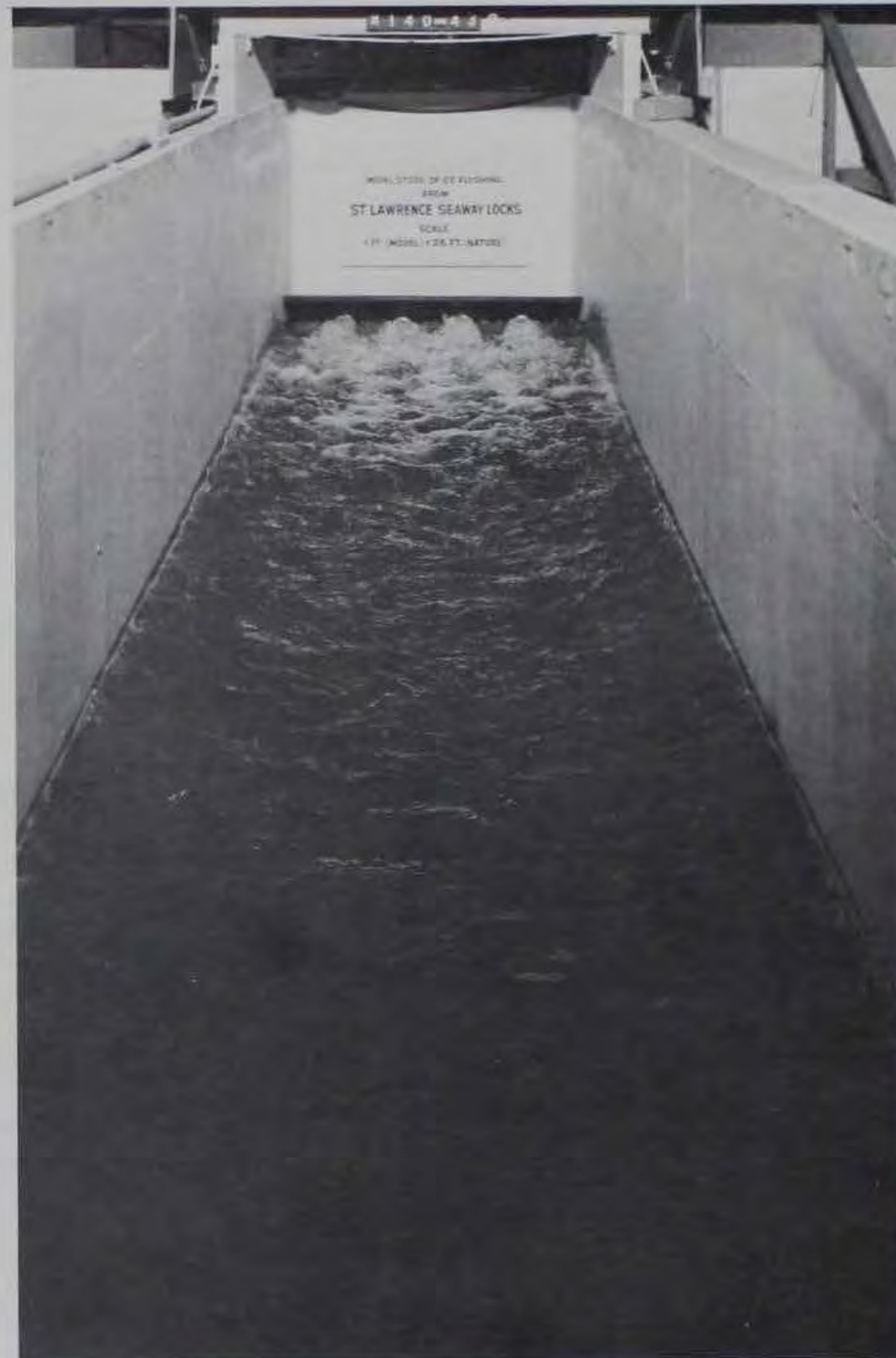


a. Before test

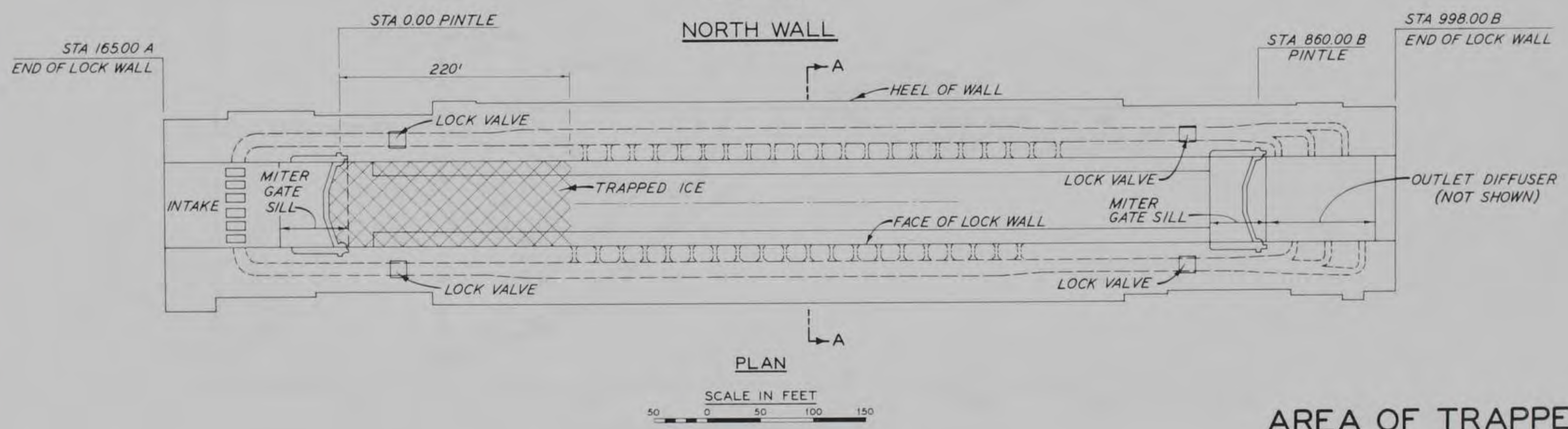
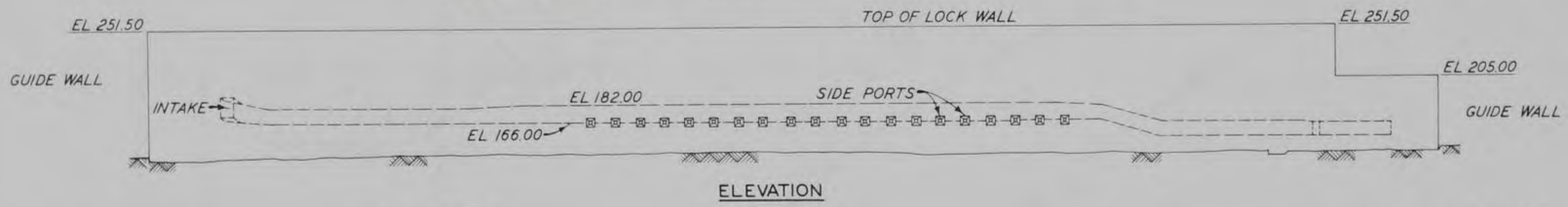
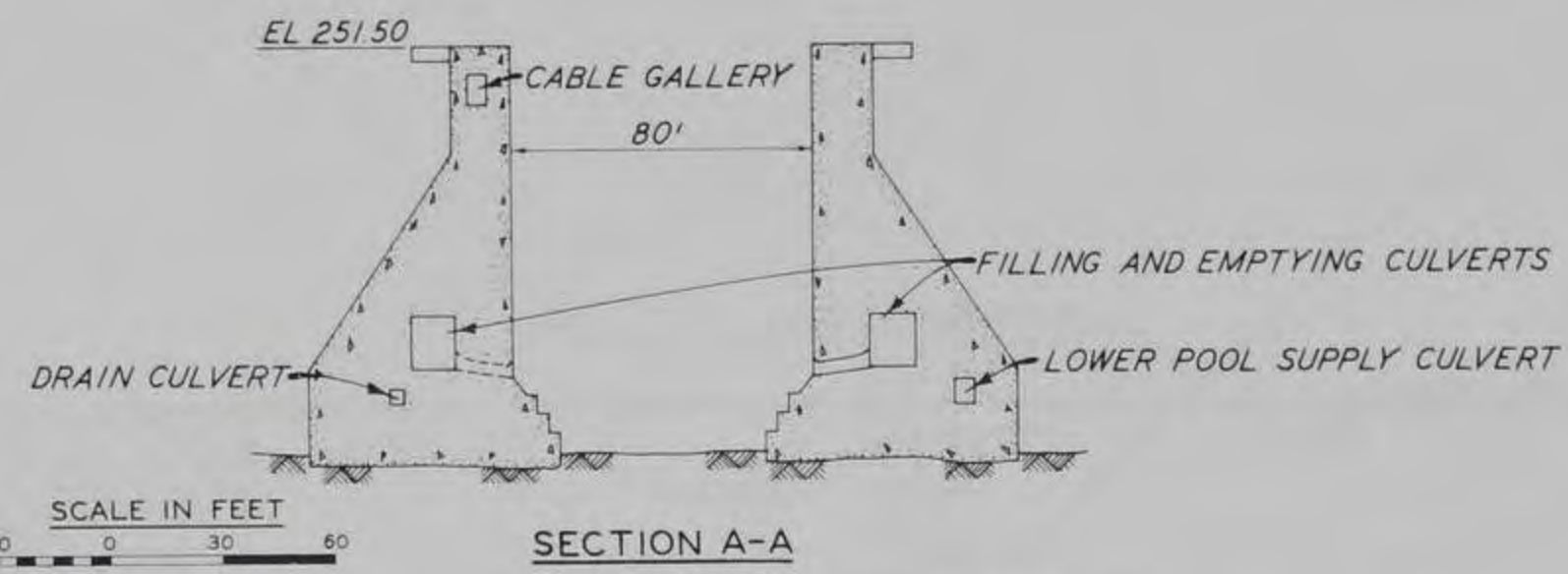


b. 50 sec (prototype) after starting test

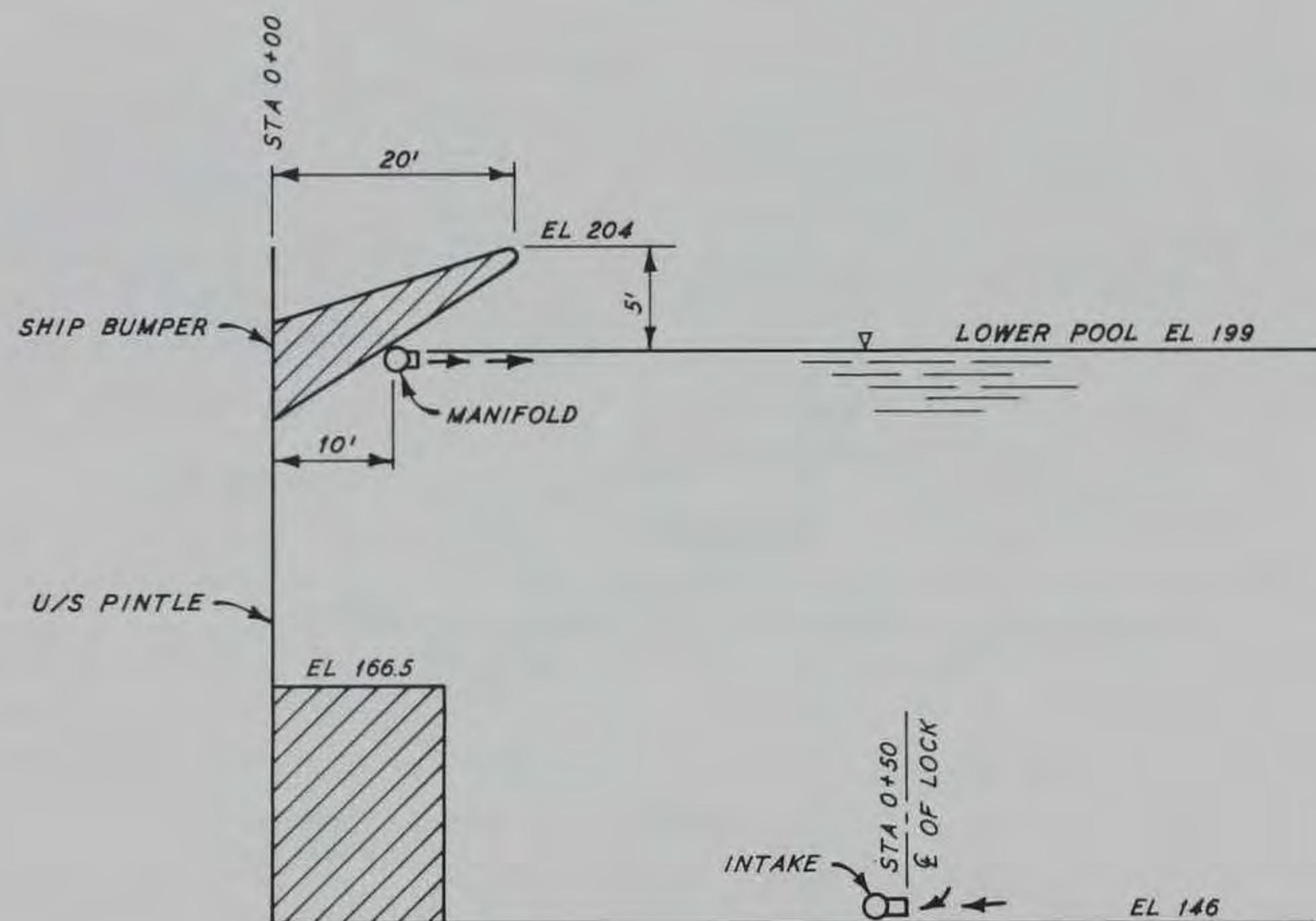
Photo 10. Four 4-ft-diam jets at sta 0+17 with 46-ft head, discharge 2400 cfs;  
120 blocks of ice (10 by 10 by 3 ft) (sheet 1 of 2)



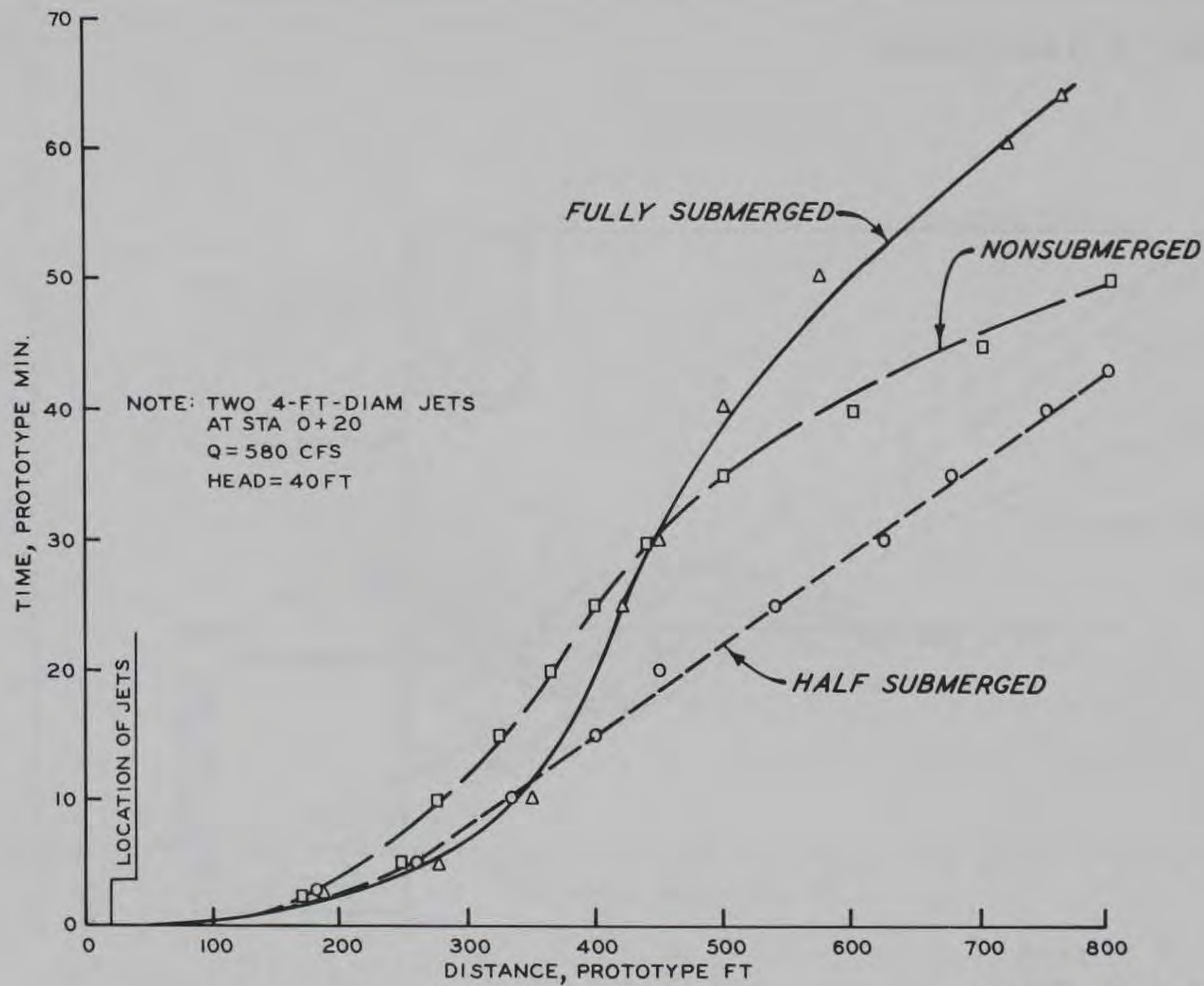
c. 150 sec (prototype) after starting test  
Photo 10 (sheet 2 of 2)



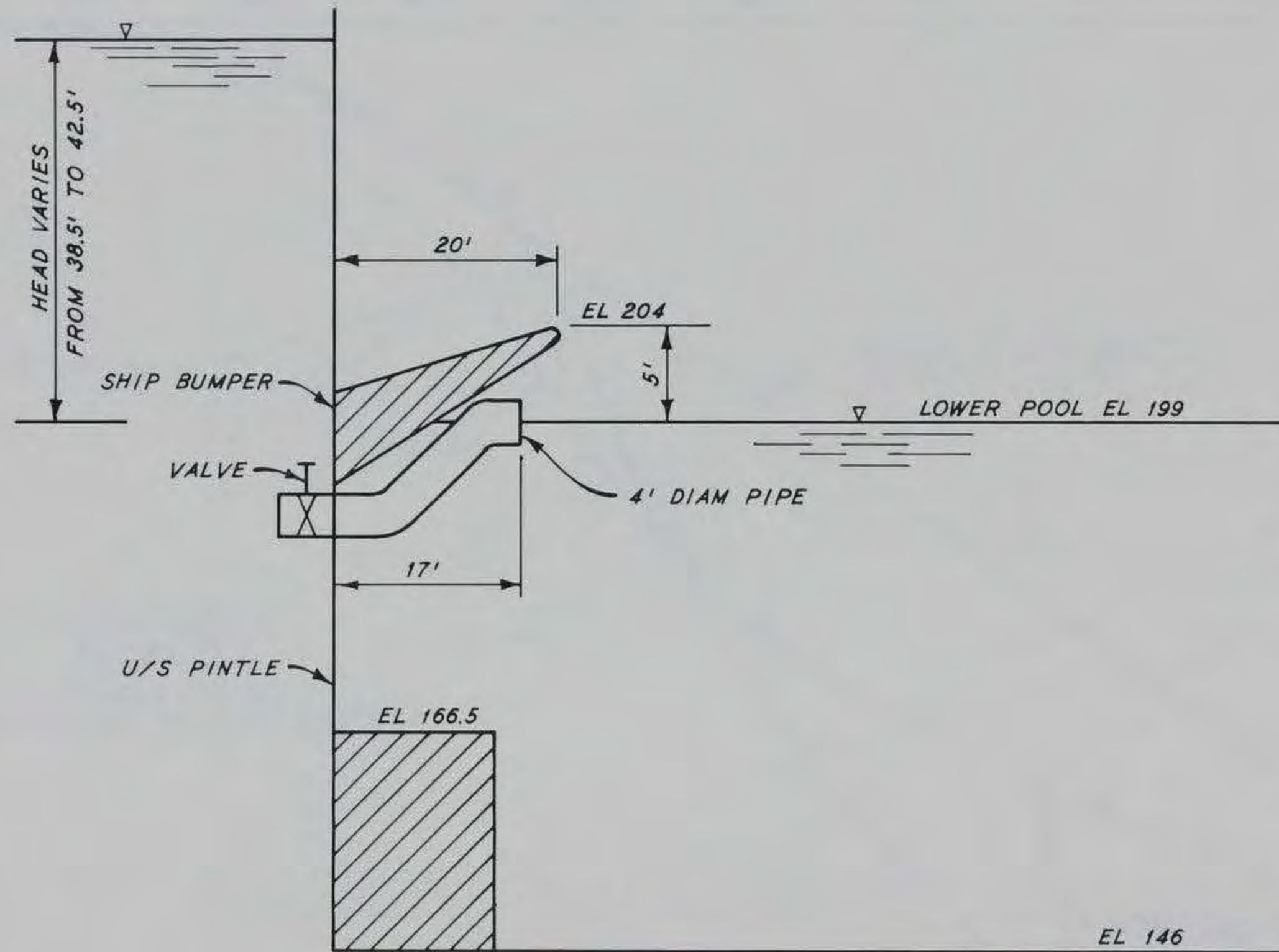
AREA OF TRAPPED  
ICE IN  
EISENHOWER LOCK



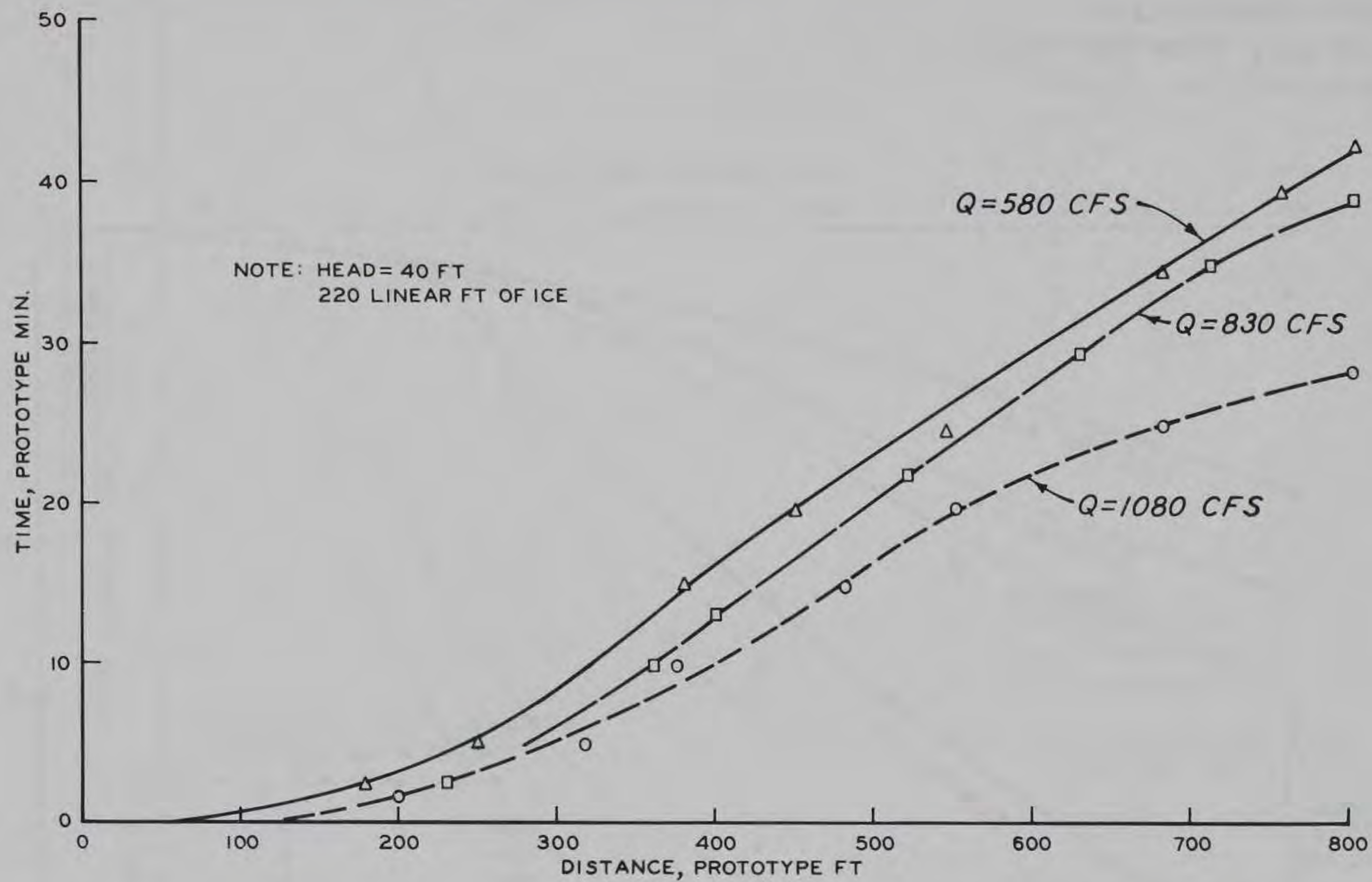
TYPE 4 MANIFOLD



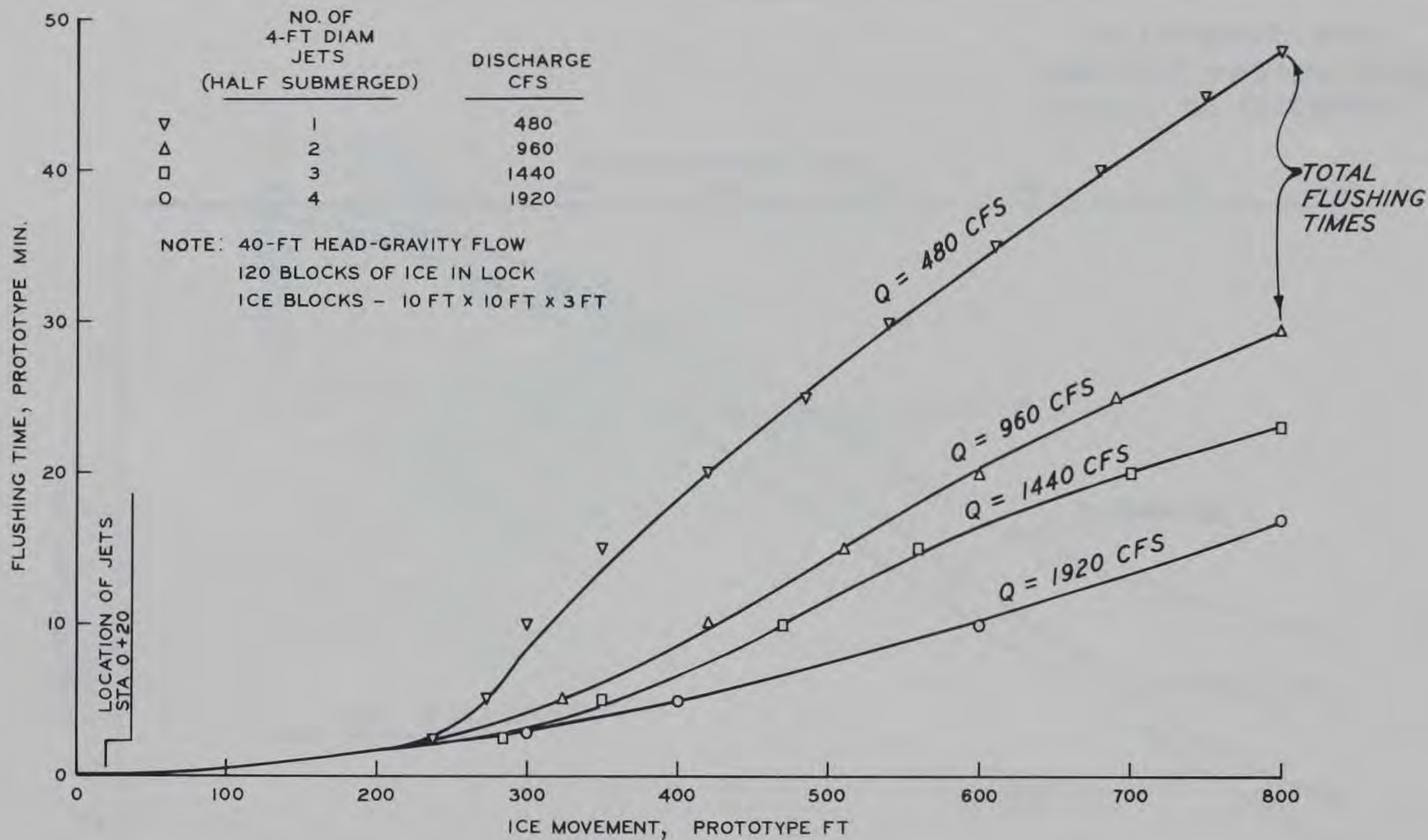
EFFECT OF CHAMBER WATER  
LEVEL ON ICE FLUSHING TIME



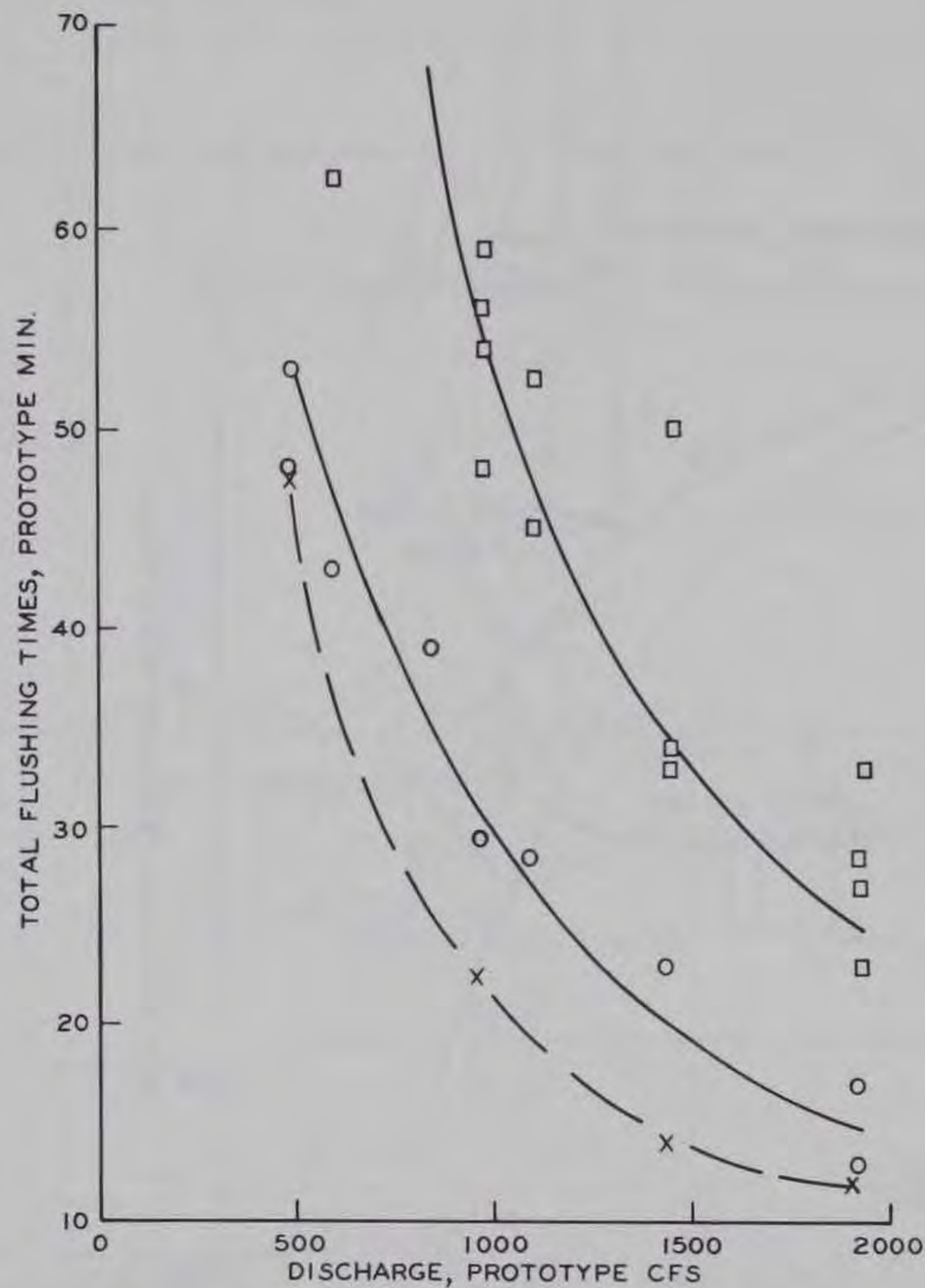
PREFERRED FLUSHING DESIGN



EFFECT OF DISCHARGE  
(580, 830, AND 1080 CFS)  
ON FLUSHING TIME



EFFECT OF DISCHARGE  
(480, 960, 1440, AND 1920 CFS)  
ON FLUSHING TIME



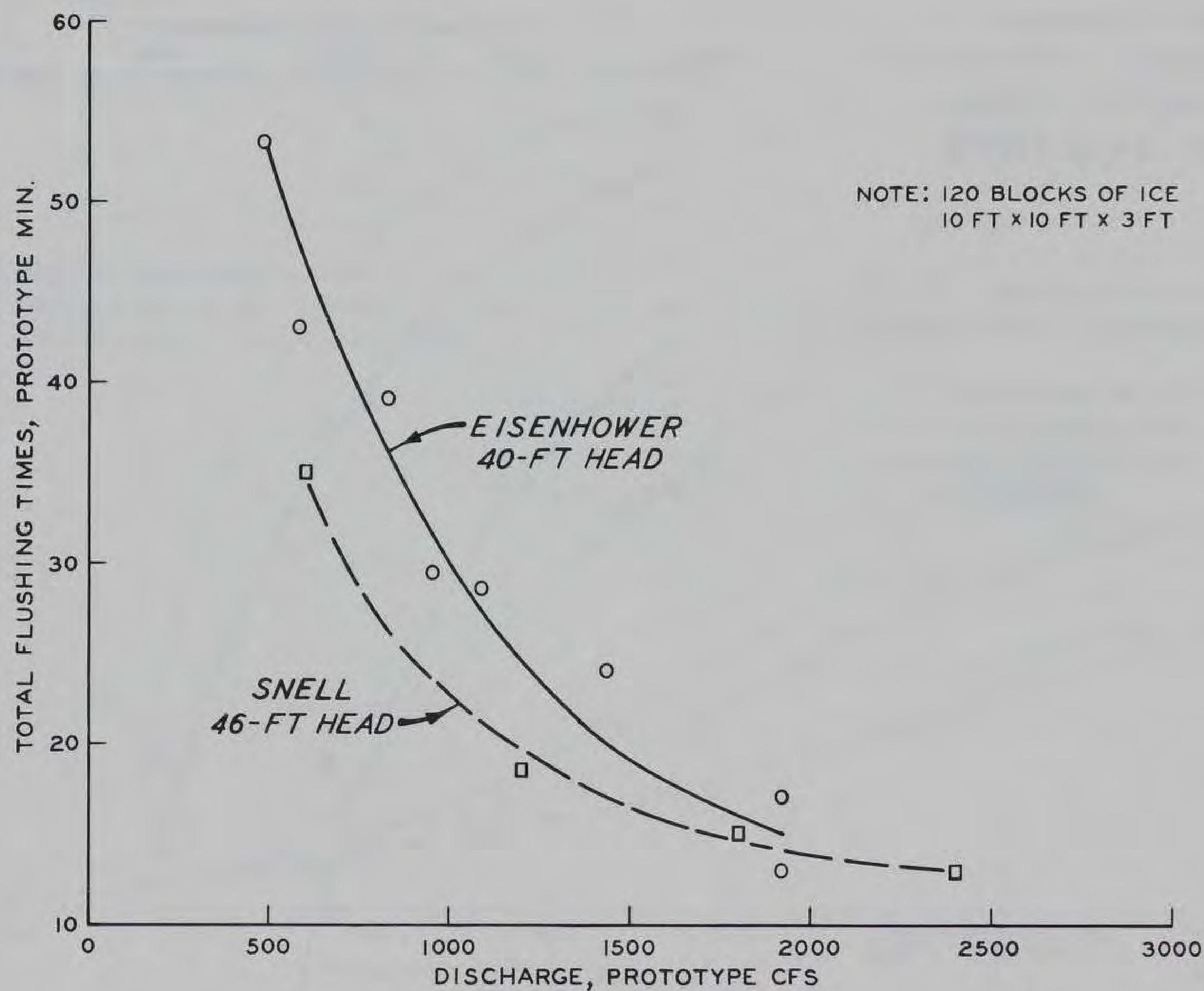
NO. OF 4-FT DIAM JETS (HALF SUBMERGED)	DISCHARGE CFS
1	480
2	960
3	1440
4	1920

#### LEGEND

- 245 BLOCKS OF ICE
- 120 BLOCKS OF ICE
- x 50 BLOCKS OF ICE

NOTE: 40-FT HEAD-GRAVITY FLOW  
ICE BLOCKS- 10FT x 10FT x 3FT

EFFECT OF ICE LOAD ON  
TOTAL FLUSHING TIMES  
1, 2, 3, AND 4 FOUR-FT-DIAMETER  
JET HALF SUBMERGED



EFFECT OF HEAD ON  
TOTAL FLUSHING TIMES  
1, 2, 3, AND 4 FOUR-FT-DIAMETER  
JET HALF SUBMERGED

