MODEL STUDY OF THE INTAKE AND DISCHARGE STRUCTURES FOR ZION NUCLEAR STATION

I. INTRODUCTION

The Zion Nuclear Station, being built by the Commonwealth Edison Company on Lake Michigan, was designed by Sargent and Lundy of Chicago, Illinois. The plant requires condenser cooling water flows of 3450 cfs during midsummer. Harza Engineering Company, also of Chicago, acted as consultants on the hydraulic design of the intake and discharge structures and determined that a model study would be desirable for checking some of the hydraulic features of these structures. The model studies were conducted at the St. Anthony Falls Hydraulic Laboratory. This report describes the studies and the results thereof.

The general plan of the structure was shown on Sargent and Lundy Drawing No. B-31. From examination of this plan, it was determined that the models should be at a scale of 1:24. Also, because of certain symmetries in the structures, it was feasible to use half models rather than full models, as will be explained subsequently.

Preparation of drawings for the construction of the model basin began on February 3, 1969 and all of the tests were completed by August 15, 1969. The intake structure was modelled first. Then, while revisions were being made in the intake structure plans, the discharge structure was modelled. Finally, the revised intake structure was modelled. The basin in which the tests were conducted is shown in Photo 1.

The intake and discharge structure models, respectively, are described separately in Sections II and III of this report.

II. INTAKE STRUCTURE

The intake structure is located about 2600 ft from shore where the lake is about 22 ft deep. It is a large circular structure serving 3 intake pipes. The two outside pipes are each served by a separate large well near the center of the structure while the center pipe is served by a peripheral collecting ring. The flow in this center pipe may be reversed to emit warm water from holes in the roof of the ring, called a "thawing box", to prevent ice formation from interfering with flow into the other two pipes in winter.

The intake is designed for an inflow of 1150 cfs per pipe. The roof of the structure is submerged about 10 ft at mean lake level.

The objectives of the intake structure study were:

1. To determine the head loss of the peripheral collecting ring as compared to that in the two central intakes under various operating conditions.
2. To observe the circulation pattern established during winter flow conditions and to modify the openings in the thawing box as necessary to obtain uniform flow distribution from them.
3. To observe the flow characteristics of the structure at various lake levels, paying particular attention to vortex formations that may cause adverse flow conditions.

Beginning with the original design proposed by Sargent and Lundy, tests were conducted and the model changed as required until a finally acceptable configuration was developed.

A. The Model

The 1:24 scale model was constructed based on Sargent and Lundy Drawings Nos. B-32 and B-36. The general layout of the model is shown on Chart 1. As already noted, it was possible to use a half model because the structure is symmetrical about a vertical plane along the centerline of the center intake pipe. Use of a half model reduced construction costs; it also facilitated observation of the internal flow by making it possible to use a lucite viewing window in the wall along the plane of symmetry. (Because the center pipe leading from the peripheral ring was split vertically in the half model, there may have been a slightly greater head loss in the center pipe of the model as compared to the outside pipes than will occur in the prototype.) Photo 2 shows the intake structure under study in the basin.

A major change was made in the transition from the center pipe to the peripheral ring after initial studies on the intake were made. Two views of the final form of the intake model are shown in Photo 3. Photo 4 shows the model without its roof as installed in the basin before it was filled with water. Chart 2 shows the details of the finally selected transition as constructed in the model.

The model incorporated several features to facilitate the test program. These included a roof removable in two sections so that either the entire roof or only the outer 12 ft could be taken off. The cover plate on the thawing box was also removable to facilitate changing hole sizes. A dye injection system was provided in the center pipe to permit observing the flow pattern during winter operation. The model was instrumented so that the flow rate under various operating conditions could be measured by orifice meters and the head loss could be measured between the lake surface and piezometer taps on the intake pipes located 96 ft (prototype) shoreward of the center of the structure, as shown in Chart 1. The surface flow pattern (vortex pattern particularly) could be observed and recorded photographically.

For a structure in which a free water surface exposed to atmospheric pressure exists, dynamic similarity is obtained when the model-prototype relationships are determined by the Froude law of similarity. The following relationships for velocity, discharge, and pressure in terms of the length scale ratio $(L_r = 24)$ are then obtained:

$$\text{Velocity ratio} = L_r^{1/2}$$

$$\text{Flow ratio} = L_r^{5/2}$$

$$\text{Pressure ratio} = L_r$$

By utilizing the above equations, the model discharge can be determined and pressures and velocities as measured in the model can be readily translated to the prototype values.

B. Results and Discussion

1. Head Loss Characteristics

a. Head loss-discharge relationship, center intakes: The data reported in this section were obtained using the final hole size configuration in the thawing box and with the entire roof in place. The presence or absence of the roof affects the head loss value less than ten per cent. Figure 1 shows the head loss for the center intake in the half model as a function of flow for various flow conditions in the thawing box. The data indicate that at design flow for both summer and winter operations, the head loss through the center is essentially the same. Also, the head loss in the center intakes is almost independent of the flow in the thawing box.

b. Head-loss-discharge relationship thawing box:

(1) Figure 2 shows the head loss for the thawing box and transition section to the 16 ft diameter pipe as originally designed. The values of head loss reported were for the port sizes which resulted in uniform flow from the thawing box during winter operation. The head loss at design summer flow condition (2.4 ft) was considered excessive and various schemes to reduce the head loss were tested.

(2) Original transition - vanes added. The effects of various turning vanes installed in the transition from the ring to the pipe, as well as the effect of rounding the entrance to the 16 ft diameter pipe on the head loss of the structure are shown in Table A.

TABLE A

	No. Vanes		Top Horizontal Vane		Lower Horizontal Vane		Vertical Vane	
	h_{TB} ft	h_C ft	h_{TB} ft	h_C ft	h_{TB}	h_C	h_{TB}	h_C
Normal winter operation:	0.9	1.3	0.8	1.4	0.8	1.4	0.9	1.4
Normal summer operation:	2.4	1.4	2.4	1.4	2.4	1.4	2.3	1.4

h_{TB} = prototype head loss for thawing box ($\pm$ 0.1 ft)

h_C = prototype head loss for center intake ($\pm$ 0.1 ft)

The addition of one turning vane and the rounding of the entrance to the 16 ft pipe did slightly reduce the head loss through the intake structure. However, when all three vanes were added, the head loss was increased rather than decreased (see Fig. 2).

(3) New Transition

A head loss of 2.3 ft was still considered excessive and a new rounded transition section was designed and modelled as shown on Chart 2. Fig. 3 shows the head loss for the final design (new transition with correct port sizes) as well as the original for comparison. The new transition reduced the head loss to 2 ft during summer operation at design flow, which was considered acceptable. It was thought that tapering the first few openings in the thawing box might further reduce the head loss, but this had no measurable effect. It might be observed that the main reason for the apparent excess head loss when flow is drawn into the thawing box ring is that most of the flow must enter through the first few holes. It is the loss through these holes which produces the excess head loss. The new rounded transition section to the pipe made it possible to obtain uniform outflow with the first two holes considerably enlarged, thus reducing head loss on inflow (and outflow, as well). The head loss could be reduced even further if the outflow could be distorted so that the first two holes would be even larger. Also from the overall test program it was observed that the head loss characteristics of the thawing box are relatively independent of the flow through the center intake (see Fig. 2 for intake flow as an example).

2. Thawing Box Flow Distribution:

Because of the curvature of the peripheral ring and because the center to center spacing of the outlet holes was only slightly greater than the hole size, it was not possible to determine analytically either the flow distribution from a given set of openings or the correct hole sizes for uniform flow distribtuion. Thus it was necessary to use an experimental trial-and-error method to obtain the hole sizes needed for relatively uniform flow distribution. The results of the test program are as follows:

a. Hole sizes: Fig. 4 shows the recommended hole sizes for uniform outflow as determined from the tests. The hole locations were specified on Sargent and Lundy Drawing B-32. Photo 4 shows these holes in the final version of the model.

b. Flow distribution: The relative flow from each opening was measured with a propeller meter. The propeller meter readings were converted into relative flow values. The resulting flow values are shown in Fig. 5.

3. General Flow Pattern: Summer Operation

a. Without roof: A large vortex forms over the center intake, as can be seen in Photo 5, and an occasional small vortex forms over the first few holes in the thawing box. This occurs at all lake levels since the three views in Photo 5 correspond to lake levels of 574, 578, and 582 ft. The formation of these vortexes--particularly the large center vortex, which is sufficiently strong to draw air into the intake pipe--would cause intolerable flow conditions. Thus, to eliminate the undesirable flow pattern and at the same time provide a measure of protection and safety, the alternative of providing a roof seems highly desirable.

b. Partial roof: Again a vortex pattern forms at all lake levels of sufficient strength to draw air into the intake pipe, as shown in Photo 6. However, due to the partial roof, the vortexes form over the first few openings in the thawing box, and thus the air is drawn into the thawing box instead of into the center intake.

c. Full roof: Perhaps most significant is the fact that vortex flow occurs at all anticipated lake levels from 574 through 582, as can be seen in the views of Photo 7. However, the following points should be noted:

(1) Both the frequency and the strength of the vortex are relatively unchanged as the lake level is raised from 574 to 582. At lake levels below approximately 572, provided the top of the structure is just covered, no vortex formation occurs.

(2) The vortexes will not draw air into the prototype structure at any lake level provided the roof is submerged. The maximum anticipated depression of the lake surface, due to vortex formation at lake levels from 574 to 582, will be less than one foot.

(3) It is not anticipated that vortexes of the size and strength which do occur would constitute any danger to

small fishing craft or to the intake structure. The diameter over which rotative velocities up to a few feet per second may occur is only a few feet.

4. General Flow Pattern: Winter Operation, Full Roof On

The views in Photo 8 show that during normal winter operation the flow issuing from the thawing box does not disturb the lake surface; in fact the vortex formation that occurred during summer operation is absent.

As may be seen from Photo 9, taken with water marked by dye issuing from the thawing box, some of the heated water will disperse into the lake toward the center of the lake and some will be drawn into the central intakes as return flow. This flow pattern is a result of various factors. Perhaps the two most significant are, first, the fact that the flow issues from the ports with a radial velocity component that tends to carry the flow outside the structure, and second, that the momentum of the flow issuing from the ports on the lake side of the structure is greater than that near the entrance to the thawing box. These two factors combine to produce the general flow of warm water toward the lake. If it is desired to draw a larger proportion of warm water into the central intakes this could be accomplished by allowing a greater percentage of the flow to issue from the ports near the transition section by increasing their size. Increasing the size of these ports would also reduce the intake head loss as mentioned earlier.

C. Recommendation:

The intake design and hole size and spacing shown in Chart 2 and Fig. 4 is recommended as it produces nearly uniform outflow distribution from the thawing box and the least intake head loss of the various designs tested.

III. DISCHARGE STRUCTURE

There are two identical discharge structures symmetrically placed with center lines 154 ft each side of the intake pipe lines. The structures terminate about 760 ft from shore. Prototype drawings were provided by the Harza Engineering Company. (Sargent and Lundy drawings B-31, showing the general plan of the intake and discharge structures, and B-35, showing details of the discharge structures, are pertinent.) Each discharge structure is in itself symmetrical with respect to a central vertical plane through the continuation of its discharge line.

The objectives of the discharge structure study were:

(1) To obtain relatively uniform flow with minimum surface disturbance from each structure. This involved, primarily, the determination of the simplest guide vane configuration which, when placed in the basic structure, would accomplish the objective.

(2) To determine the discharge-head loss characteristics of the structures.

A. The Model

The symmetry of each discharge structure was used to advantage to build a half model of one structure for the experimental work. The model was placed in the same basin as was used for the intake model study. Chart 3 and Photos 1 and 10 show the general layout of the model.

It may be noted that the wall opposite the half model may be considered a minor interference when the outside half of a discharge structure is being considered and a plane of symmetry when the inside half is under consideration; in the latter case, it may be imagined that there is another half model an equal distance beyond the wall. (To be truly representative of the area between the two discharge structures, the wall would have to be about 6 1/2 ft from the center line of the model rather than 9 ft as it was during the model study. It may also be noted that the shore to structure end distance of 760 ft would require about 32 ft in the model compared to the approximately 24 ft actually used; this is an unimportant difference.)

Details of the half model are shown in Charts 4 and 5 and in Photo 11. Provision was made in the model to test several vane designs. The roof was removable to facilitate exchange of the vanes. A dye injection system in the discharge pipe line made it possible to observe the flow out of the ports in the discharge structure as illustrated by the two views in Photo 12.

The model was instrumented so that flow rate could be measured by an orifice meter and head loss could be measured as a function of flow rate. The model permitted discharges up to 3000 cfs prototype although most tests were made at the design discharge of 1725 cfs (865 cfs in the half structure). Three lake levels were used in the model study, a high level of 582.15, a normal level of 578.15 and a low level of 574.15 ft above sea level. At the low level, the water surface is 4.65 ft (0.194 ft model) above the top of the structure. The head loss is measured between the lake water surface and a pressure tap in the discharge pipe line 140 ft shoreward of the center of the structure as shown in Chart 3. A propeller-type current meter was provided to measure velocity out of the discharge ports; it could be oriented in the flow direction as indicated by yarns held on a rod at the points of measurement.

The model-prototype scale relations are the same as in the intake model. That is, with the length scale ratio of 1:24, the pressure head scale ratio is also 1:24, the velocity ratio is $1:24^{1/2}$ and the discharge ratio is $1:24^{5/2}$.

B. Results and Discussion

1. Velocity Distribution from the Ports and Surface Disturbance

Beginning with the original design proposed by Sargent and Lundy, tests were conducted and the model was changed as required until a final result that appeared satisfactory was achieved. The original design consisted of two horizontally placed, curved vanes in the body of the structure. The velocity distribution using this system was not very good and the water surface was very rough so these vanes were abandoned.

A design with no vanes in the body of the structure (the structure is shown with vanes in Chart 4) and no vanes in a similar body with a raised floor were tried. The flow distribution from these designs is shown in Fig. 6. The average distribution of flow from the various ports without the raised floor is shown in Table 1, Column (2). Neither design was considered satisfactory, of course, and since there was little to choose between them, the original body structure without the raised floor was retained for further study. Fig. 6 is reproduced herein to be used for reference in determining what could be done with later improvements. Actually, the velocities from the ports were directed upward and toward the offshore end of the structure rather than normal to its sides as indicated in Fig. 6. This was especially true at ports 1 through 4 or 5, but the exact angles were not recorded. Photo 12 gives an idea of the horizontal angle which was similar in all tests.

Subsequent trials consisted of various vertical vane combinations placed in the body of the structure. Flat vanes only were tested as it was not believed that enough advantage could be gained from curved vanes to pay for their additional cost. The best of these consisted of four vertical vanes (two in the half model) and may be seen in Photo 11. (There was also a horizontal vane at the end of the structure, which had practically no effect.) The average distribution for this system, known as Trial F, is shown in column (3) of Tabel I and in Fig. 7. Considerable improvement in flow distribution was obtained but, as may be seen from the comments in Table I, this system, as well as the structure with no vanes, created considerable surface disturbance at low lake level. (The same comment with regard to flow direction from the ports applies to Fig. 7 as did to Fig. 6.)

It was noticed from the experiments to this point that there was considerable separation of the flow at the top of the transition from the circular pipe to the box-like discharge structure. This apparently produced excessive vertical velocity components in the structure and was thought to be responsible for the surface roughness. Therefore, a horizontal vane was placed in the rectangular transition region just downstream from the end of the transition from circular pipe to rectangular section. The location is shown in Chart . 4 The average distribution from a trial using only this horizontal vane, designated Trial H, is shown in column (4) of Table I and in Fig. 7.

The success of the horizontal vane in the transition in reducing roughness led to placement of a vertical vane at the same logitudinal position at the third point across the transition in the plan view. This vane made the flow distribution worse, if anything, and was abandoned. Another unsuccessful attempt to improve the surface disturbance involved installing venetian-blind-like horizontal vanes in ports 2, 3, and 4. There were 3 horizontal vanes about 1 ft wide uniformly spaced over the height in each of these ports. These vanes made no improvement and were also abandoned.

Next, a single vertical vane (two in the full structure) was added to the body of the structure to accompany the horizontal vane in the transition; after some experiments it was placed as shown in Chart 4. The results of this trial, known as Trial G, are shown in column (5) of Table I and in Fig. 8. (Again, the velocity directions make an angle with the normal to the wall, especially at ports 1 through 5, but the actual directions are not plotted.) The velocity distribution was excellent as may be seen, but there was still considerable surface disturbance opposite ports 2, 11 and 12.

At this stage another horizontal vane was added at the end of the structure higher than the ineffectual vane used in some earlier tests. Velocity distributions are shown in column (6) of Table I and in Fig. 8. All the vanes are shown in Chart 4. The velocity distribution is not quite as good as without the end horizontal vane, but the surface disturbance is much improved opposite the end ports 11 and 12.

No measurement of velocity distribution for conditions similar to Trial H, column (4) of Table I, with the high end vane added were made. However, the surface disturbance was observed and there was marked improvement opposite ports 11 and 12 compared to Trial H.

Another trial involved using two narrow vertical vanes in the half model along with the horizontal vane in the transition. The results were not as good as with a single vertical vane and are not reported herein.

All of the tests described to this point were conducted at the low lake level of 574.15 ft. This was done to observe the worst possible surface disturbance. However, velocity distribution tests and observations of surface disturbances were also made at other lake levels. As an example, column (7) of Table I shows the velocity distribution for the high lake level corresponding to column (5) for the low lake level. There was no noticeable surface disturbance for this configuration or any of the other configurations in Table I at the high lake level. The variations in velocity between columns (5) and (7) is typical of the variations measured for other configurations between low and high lake levels.

Some other aspects of the surface disturbances were investigated. First, observations were made to determine at what minimum lake level surface disturbances disappeared. For the Trial G configuration, column (5) of Table I, this occurred at 579.3 ft. For Trial H, column (4), with the high end vane in place, it occurred a little closer to 580. Next, the effect of discharge on surface roughness was examined for the configuration of Trial H with the high end vane in place. When the discharge was dropped to half the design discharge, (865 cfs), the roughness decreased noticeably but was still present. Even when the discharge was decreased to 680 cfs, though there was noticeable further improvement, there was still visible surface roughness.

The last observations concerned the effects of surface waves on the roughness at the low lake level. Small waves were generated using a plank placed on edge across the basin at the water surface. This was moved to and fro by hand periodically for a few periods. The waves were of the order of 6 to 8 in high prototype. For both configurations H and G, columns (4) and (5) of Table I, the waves broke up the disturbances so that the surface roughness was hardly noticeable.

2. General Circulation of the Flow

Observation of dye emitted from the ports and confetti floating on the surface tended to circulate in the model basin. The discharge structure acted as a kind of ejector pump, sending water out into the lake and drawing water toward it from the shore. In the model, which had a wall opposite the discharge structure, this caused water to flow back toward shore along the wall and to trap some of the discharge water in a central circulation pattern.

This result is probably typical of what will happen between the two discharge structures since the model is qualitatively correct for this situation as pointed out earlier. It is believed that in this case warm water will be trapped at the surface in two large counter-rotating eddies. As it cools, it will probably sink and flow outward beneath the surface circulation pattern. This last statement is merely a conjecture since the model operated with water of constant temperature.

On the sides of the discharge structures away from the center, there will probably be less tendency to trap the warm water in a circulation pattern than was seen in the model.

3. Head Loss

Fig. 9 shows data for head loss in the flow out of the discharge structure. The lowest head loss is obtained with vertical vanes as originally measured for Trial F, column (3) of Table I. Strangely, it makes no difference what pattern of vertical vanes is used, or whether or not a horizontal vane is used in the transition and at the end; data for Trial G, column (5) of Table I, falls on this curve for vertical vanes. Data for Trial H, column (4) of Table I, falls on the curve without vanes. The intermediate curve for horizontal vanes refers to the curved vanes originally called for in Sargent and Lundy drawings.

D. Recommendations

In view of the preceding discussion, it is recommended that the structure represented by Chart 4 be used in the prototype. This involves using one horizontal vane in the transition and another at the end of the structure and a vertical vane on each side of the center plane in the body.

As an alternative, the vertical vanes may be omitted. The penalty will be a slightly rougher flow opposite ports 5 through 10 (less roughness opposite port 2) and a slightly larger head loss. The flow distribution from the ports would be similar to Trial H, column (4), Table I.

TABLE I

Summary of Flow from Discharge Ports
Percent of Average Outflow

(1) Port No.*	(2) No Vanes	(3) Trial F	(4) Trial H	(5) Trial G	(6) Trial G'	(7) Trial G_1##
Horiz Vanes	0	1 at end (low)	1 intransition	1 in transition	1 in trans. 1 end (high)	1 in trans
Vertical Vanes	0	2	0	1	1	1
1	50	97½	67½	93½	92½	88
2	68	81	83½	102	104½	99
3	87½	97½	98	97	98½	95½
4	98½	98½	104	93	91½	92½
5	101	99	108	96½	99	102
6	106	98½	108½	103	101	104
7	112	99½	109	104	103	104½
8	114	107½	110½	103½	105	103½
9	118	111	111½	104	103	102½
10	105	98	94½	93	73	92
11	119½	106½	117	105	117	109
12	120½	104	117½	105	112	109
Surface Disturbance	Severe all around	Severe opposite 1 to 4 and at 11 and 12. Light elsewhere.	Some light roughness all around but more severe at 11 and 12.**	Severe opposite 2 and 11, 12. Light elsewhere.	Severe opposite 2 and light opposite 1 to 4 or 5 and 11, 12. None elsewhere	None

* Ports are numbered beginning at the shoreward end of the structure. Nos. 11 and 12 face the open lake while the others face sideways.

#Q = 1730 cfs, lake level 574.15 ft except as noted.

##Q = 1730 cfs, lake level 582.15 ft.

** With a high horizontal vane on the end, 11 and 12 showed only mild roughness.

LIST OF FIGURES

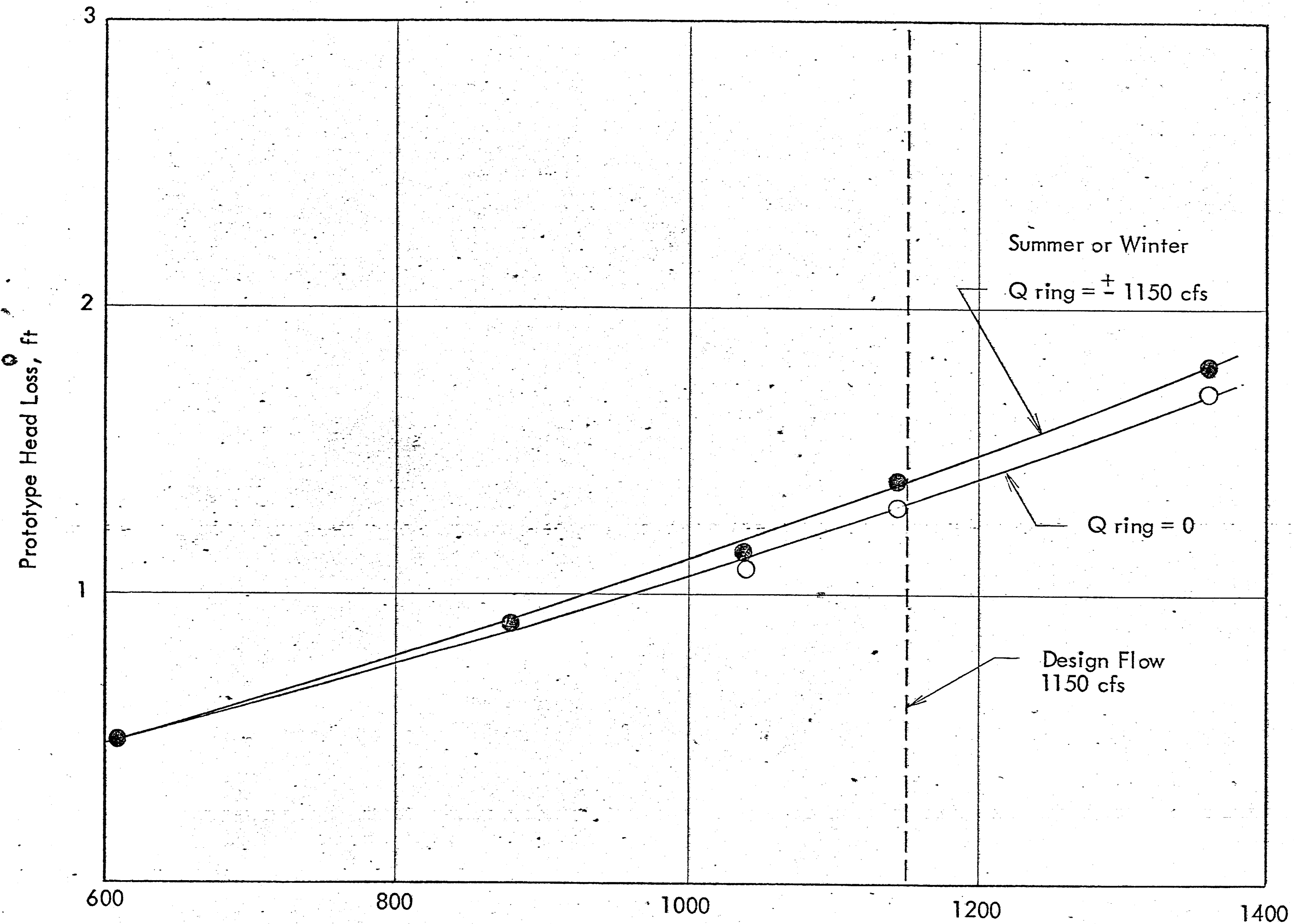


Figure 1 - Prototype Flow into Center Intake, cfs

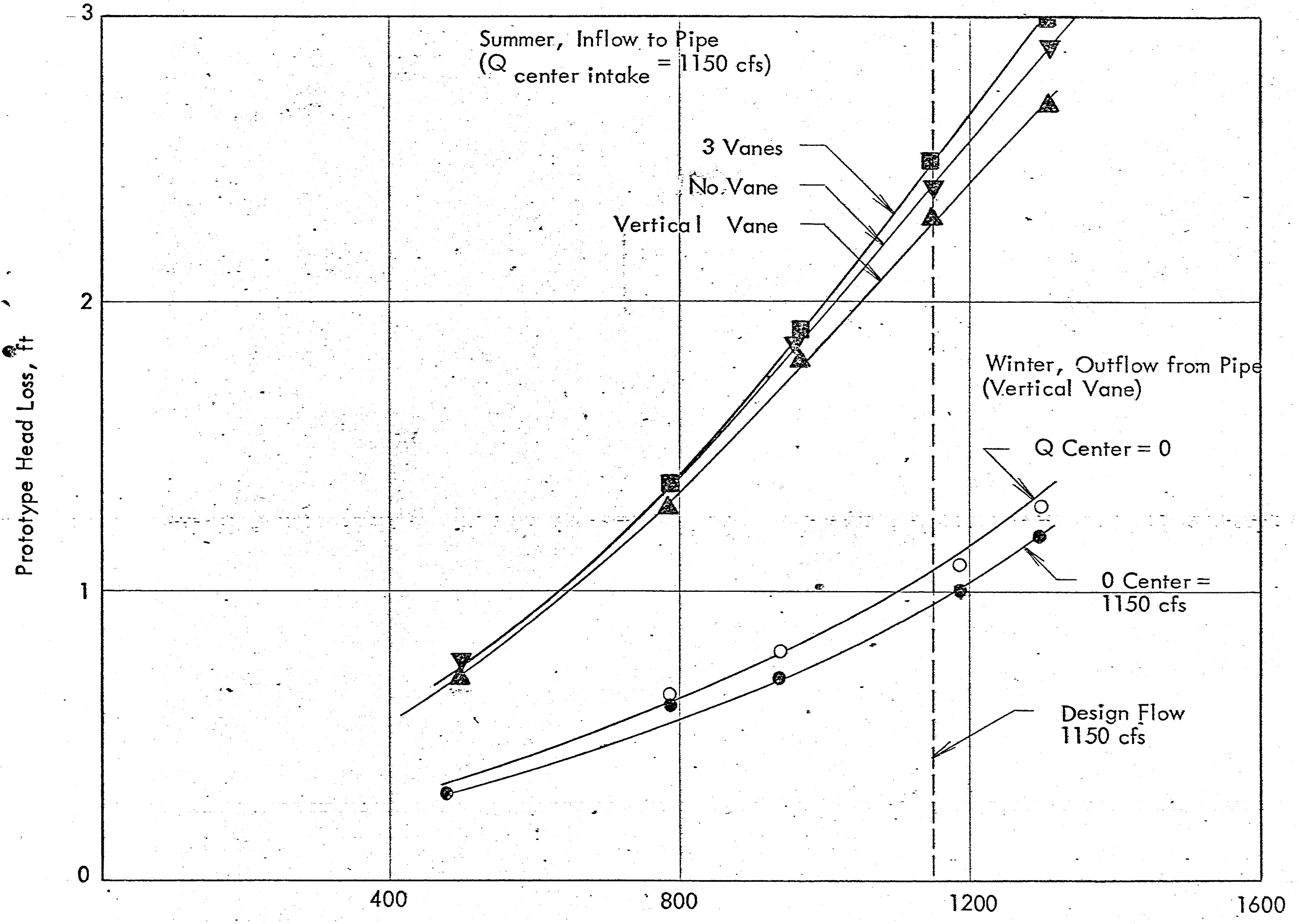


Figure 2 – Prototype Flow through Thawing Box, cfs

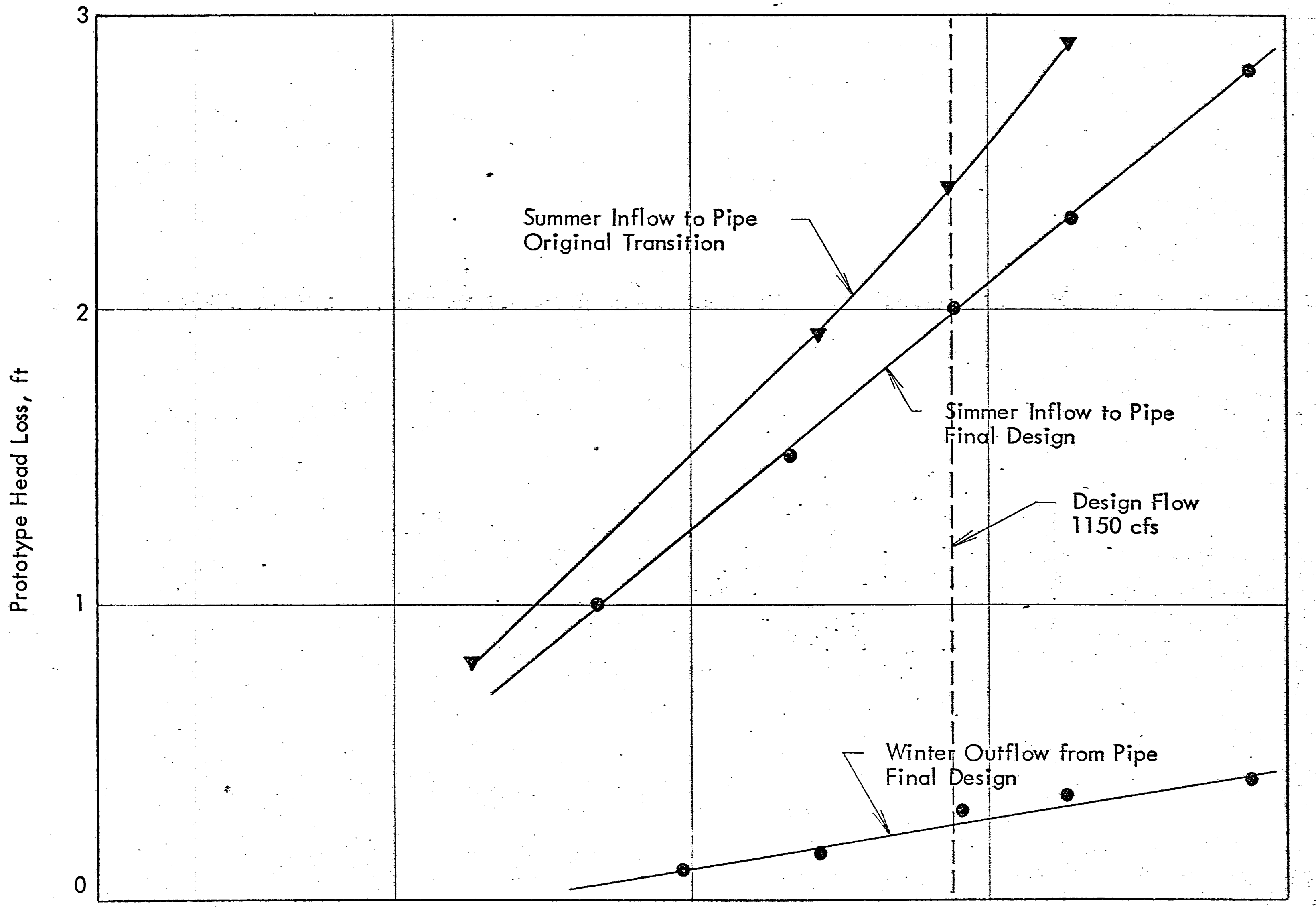
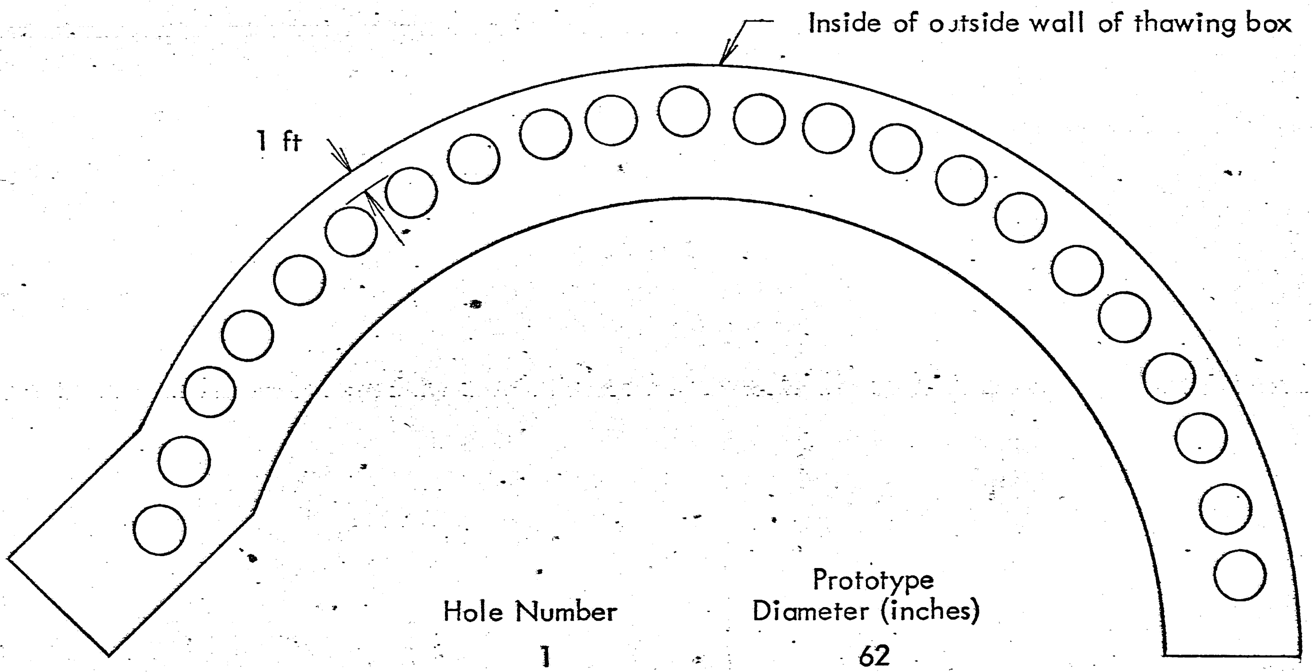


Figure 3 - Prototype Flow Through Revised Thawing Box, cfs
($Q_{\text{center intake}}$ = 1150 cfs)



Hole Number	Prototype Diameter (inches)
1	62
2	57
3	57
4	52
5	52
6	47
7	47
8	44
9	41
10 through 22	38

Note: See Sargent and Lundy Drawing B-32 for hole locations.

Figure 4 - Hole Sizes in Thawing Box, Final Design

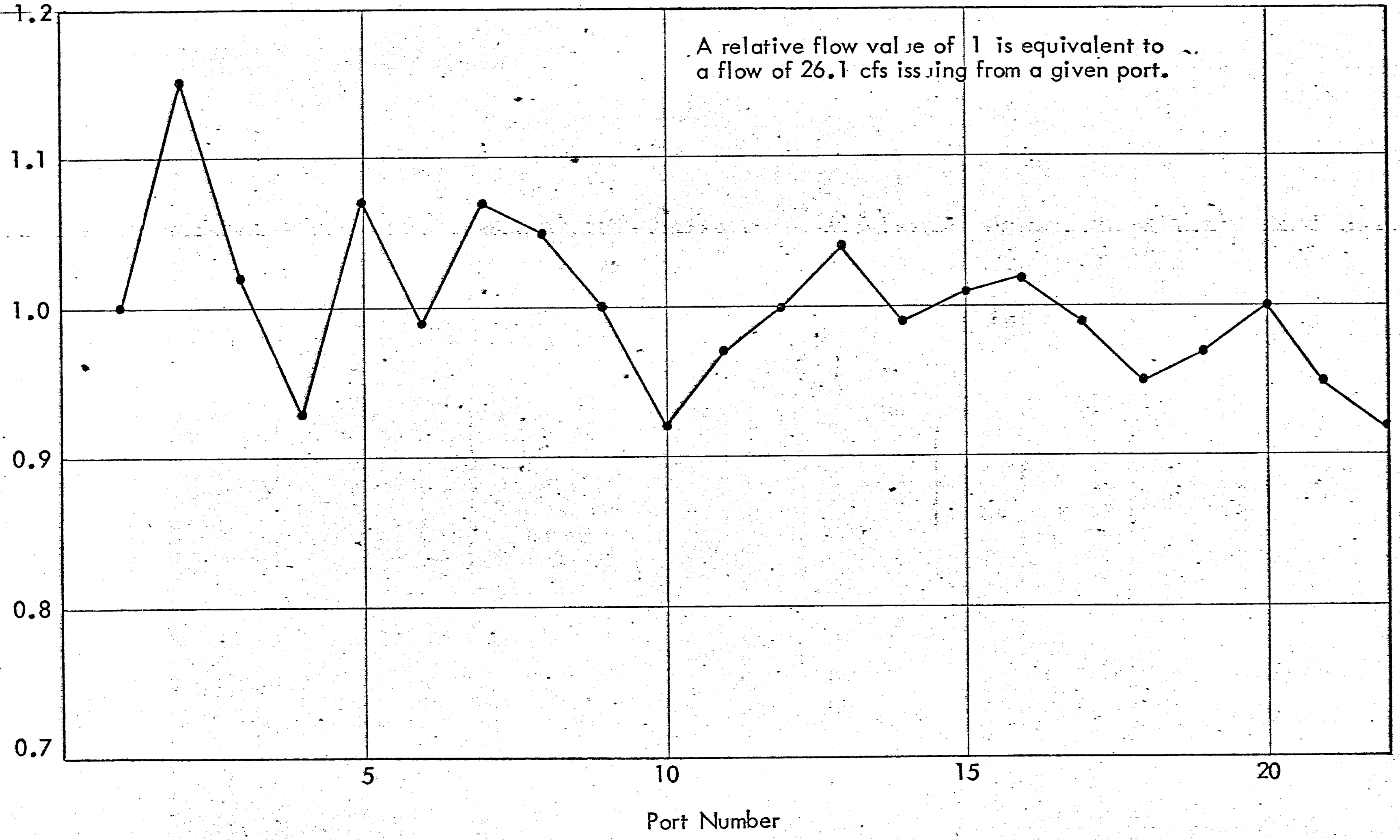


Figure 5 - Flow Distribution from Thawing Box

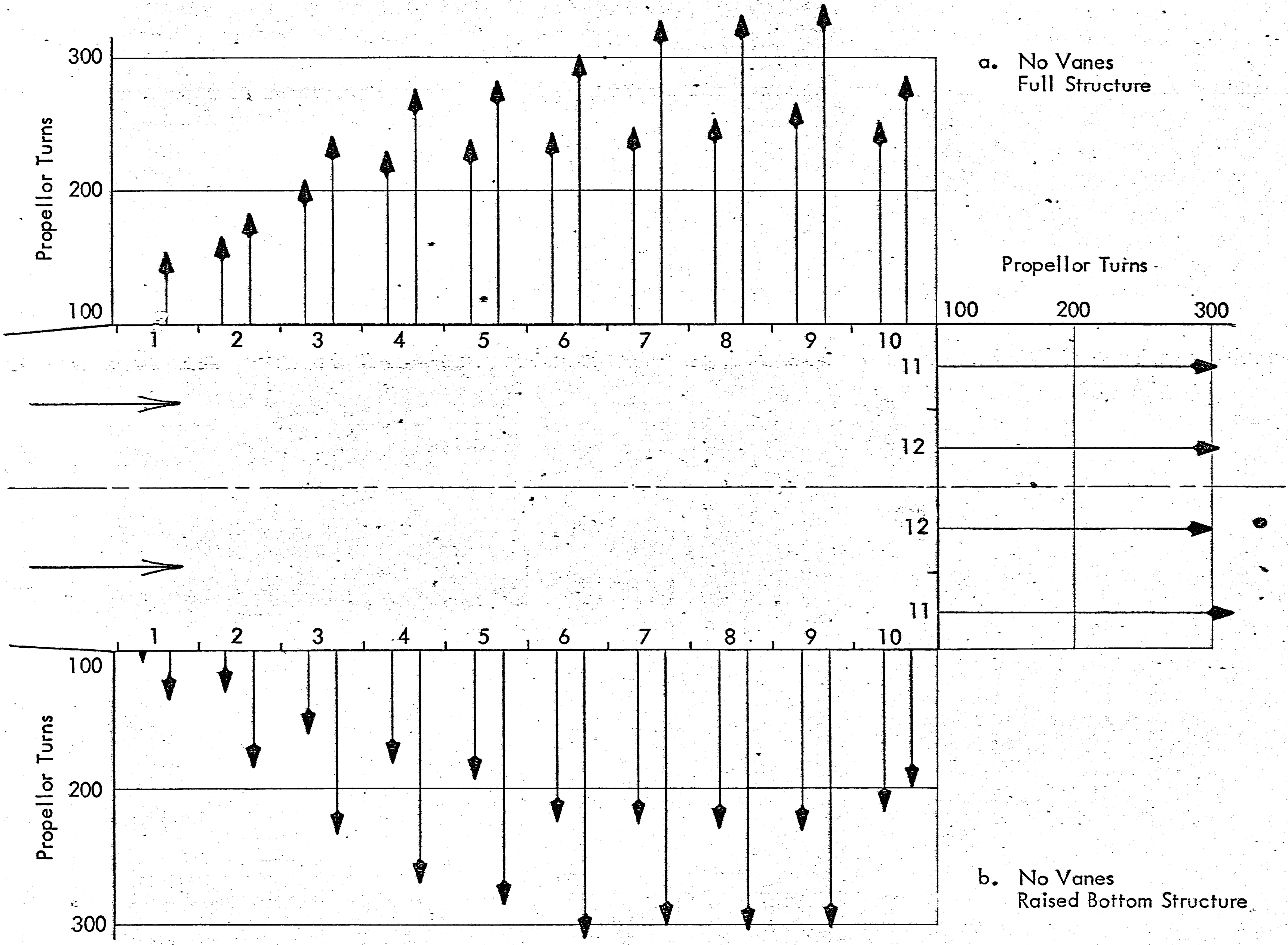


Figure 6 - Flow Distribution from Discharge Structure without Vanes

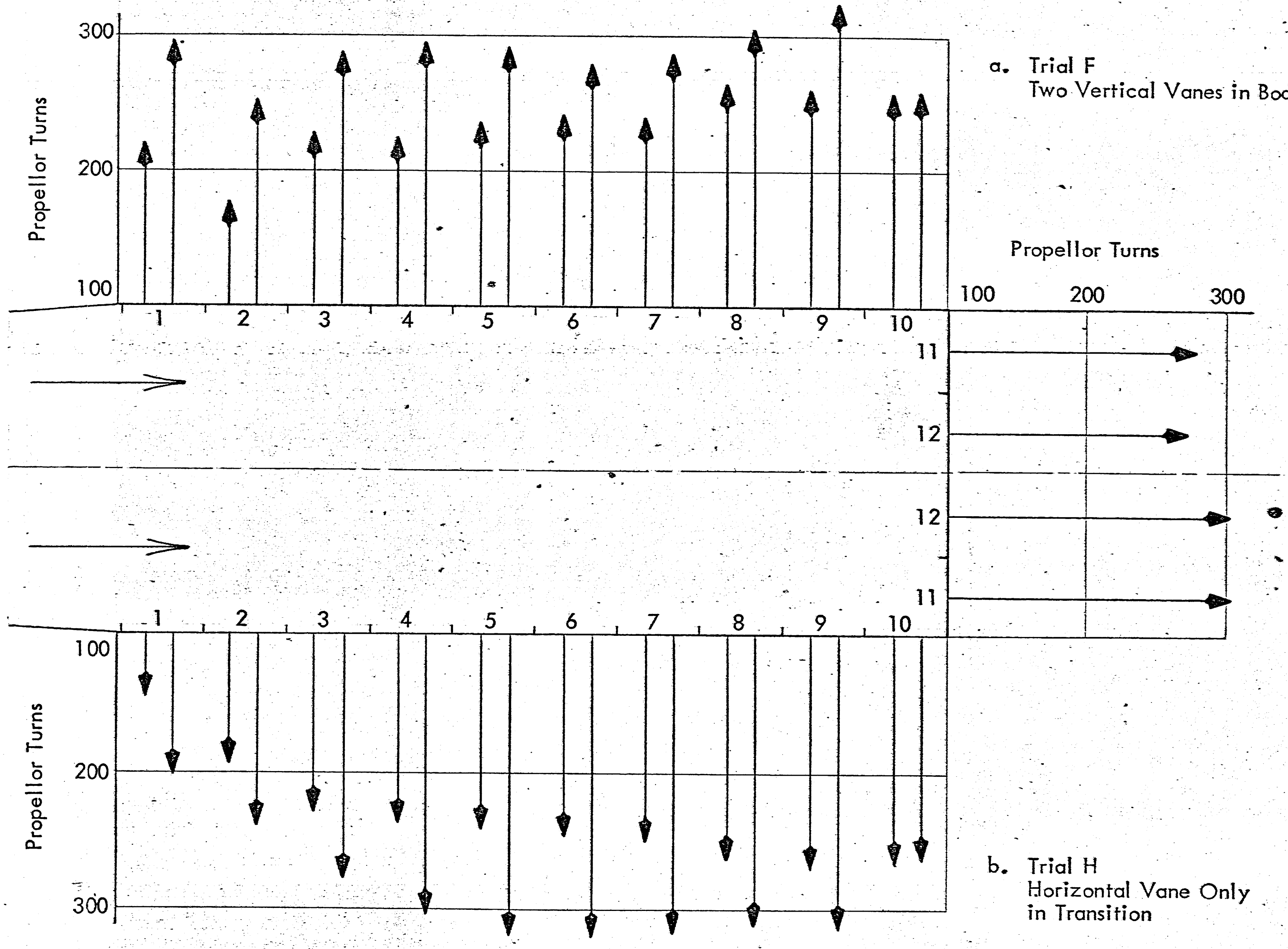


Figure 7 - Flow Distribution from Discharge Structure with Two Different Vane Patterns

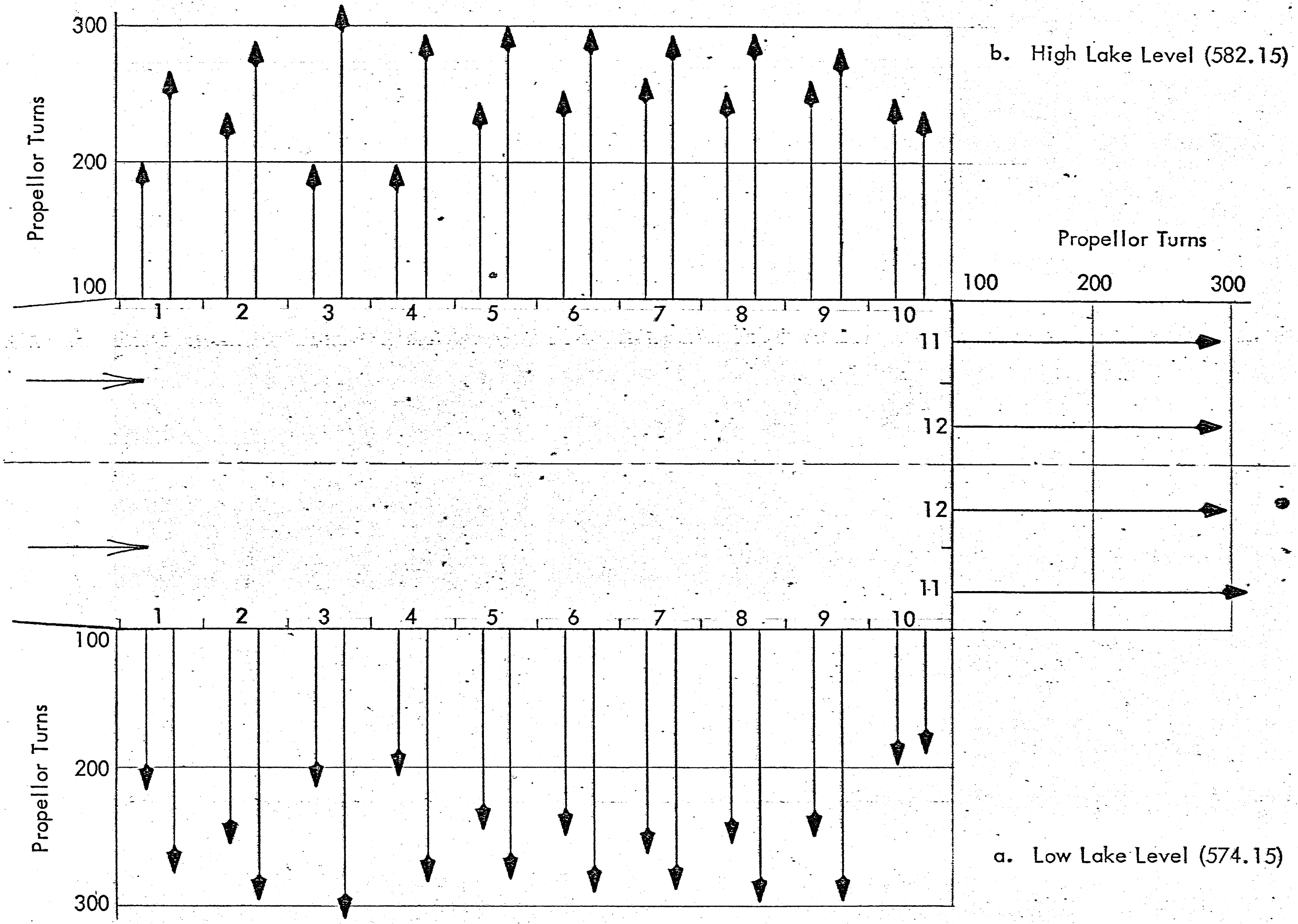


Figure 8 - Flow Distribution for Recommended Discharge Structure

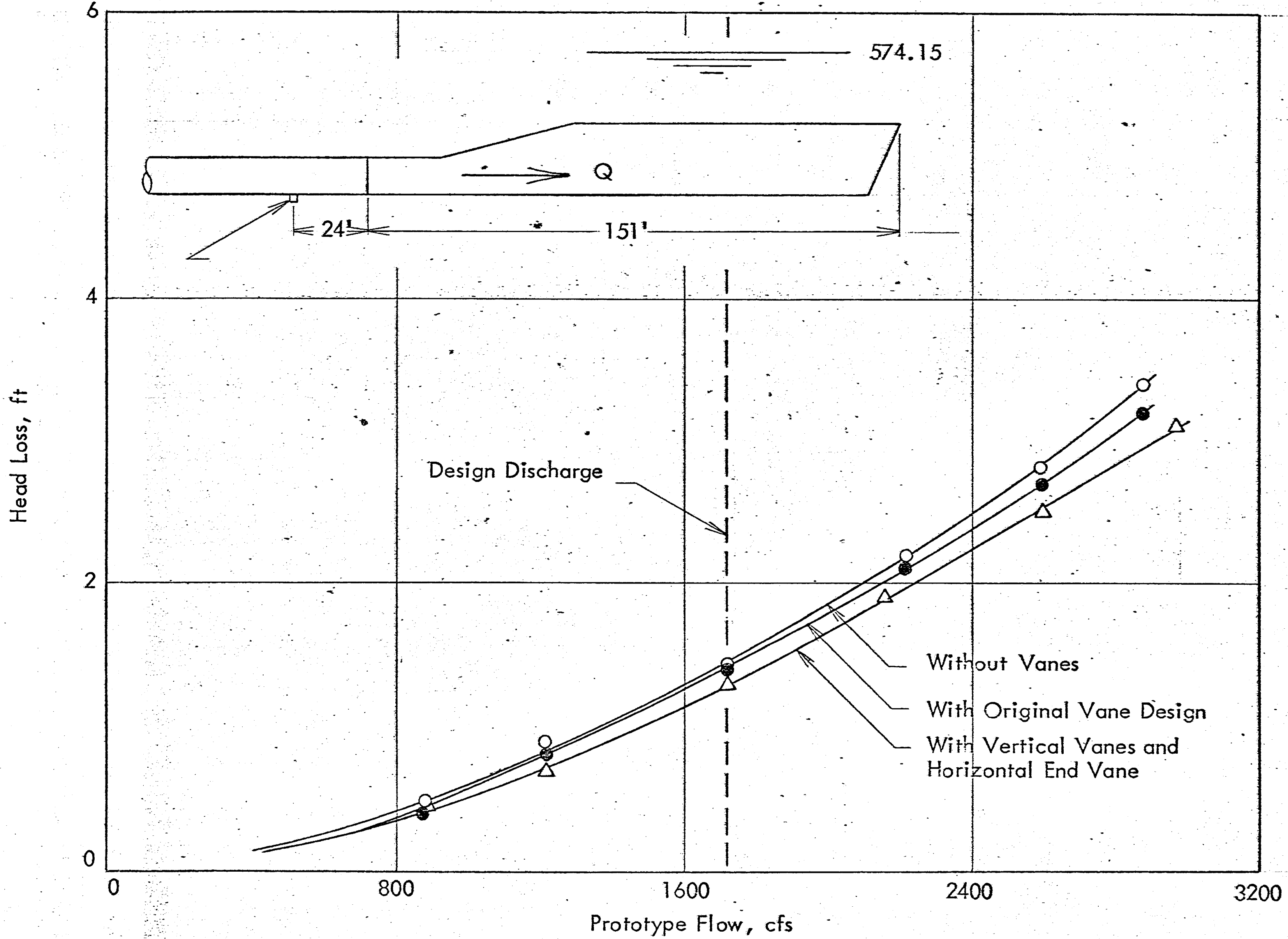


Figure 9 - Head Loss in Flow from Discharge Structure

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PHOTO 1 (189-65) The Model Basin (Discharge Structure in Place)

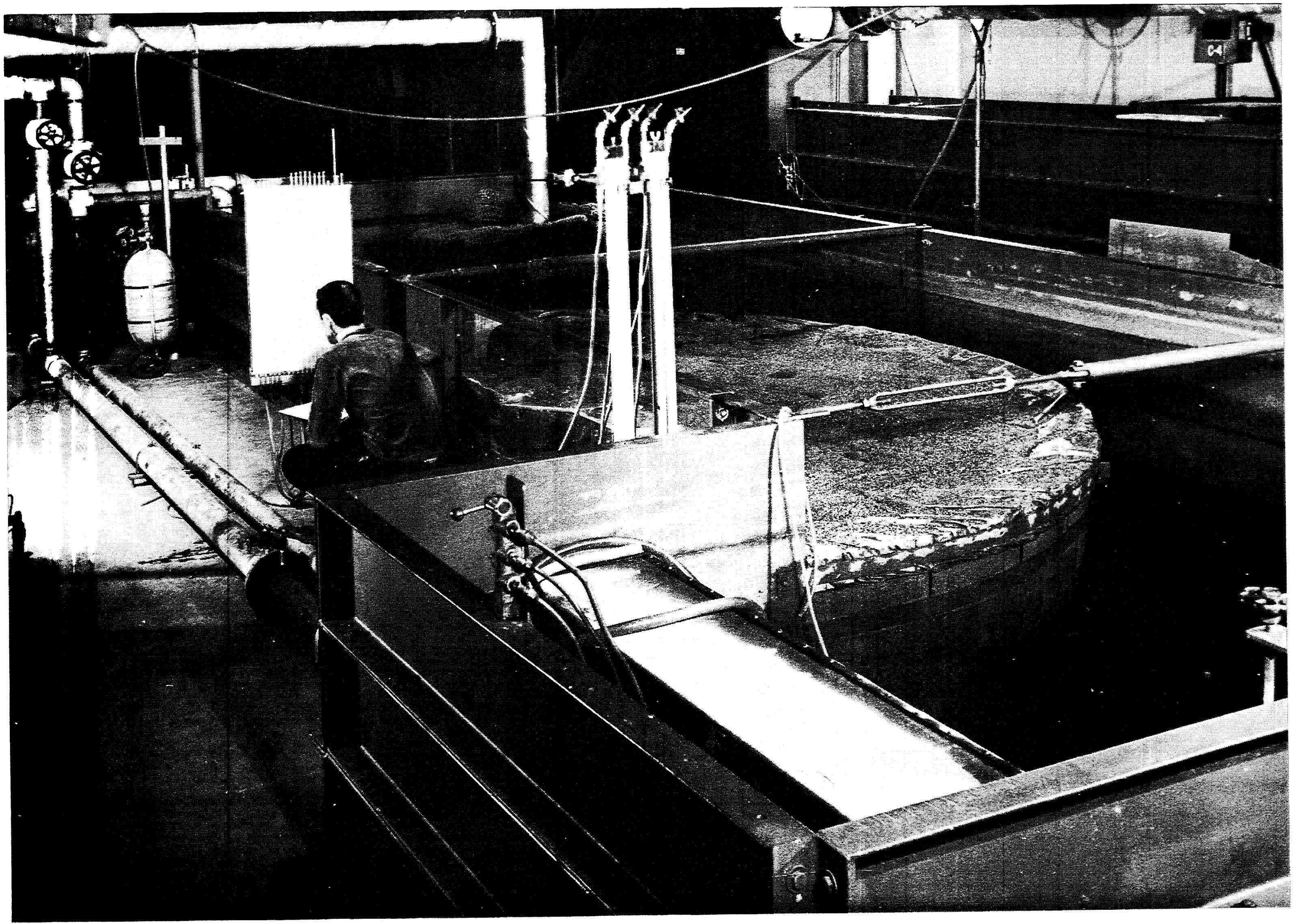


Photo 1

PHOTO. 2 (189-119) The Basin in Operation with the Intake Structure Installed.

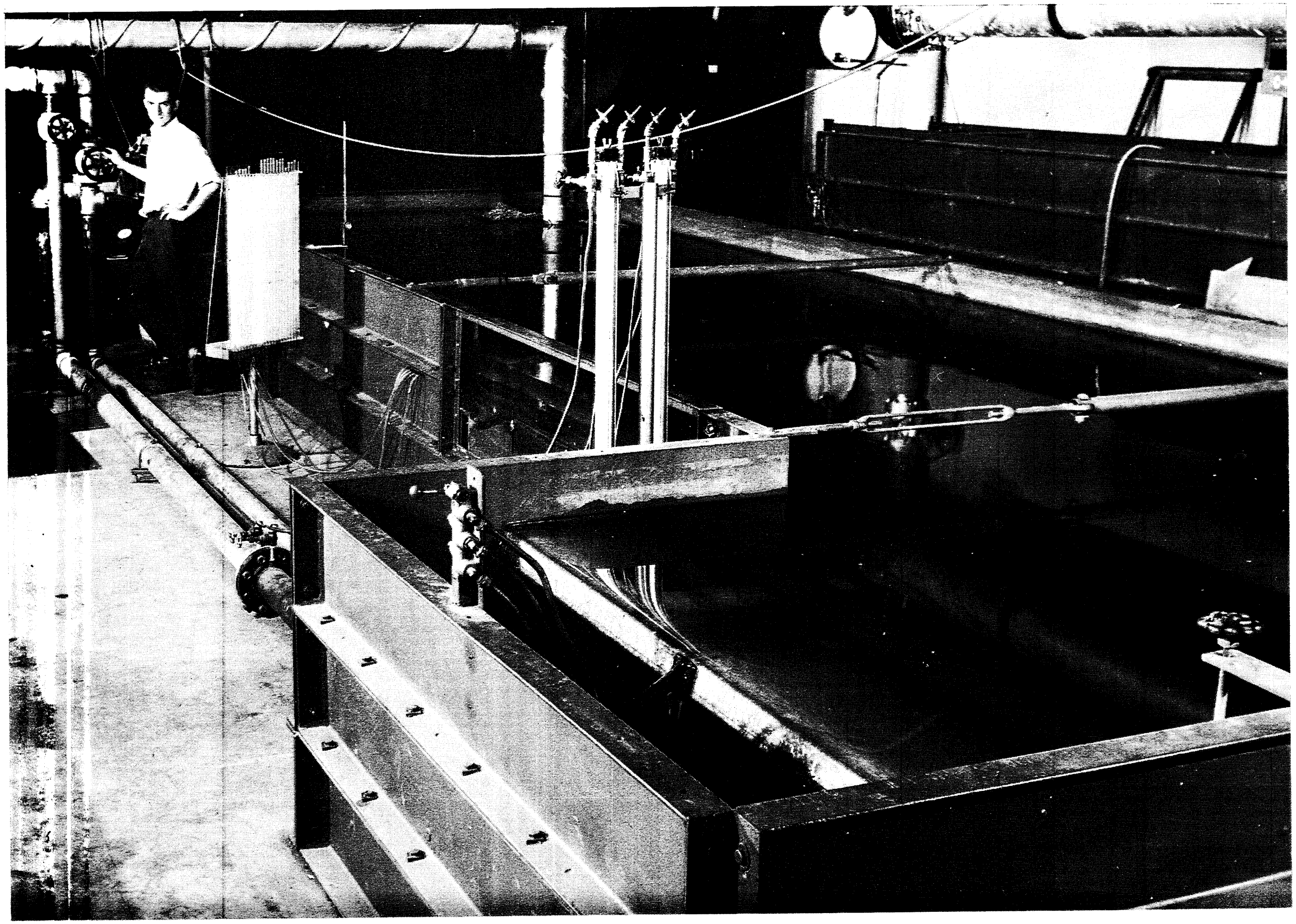
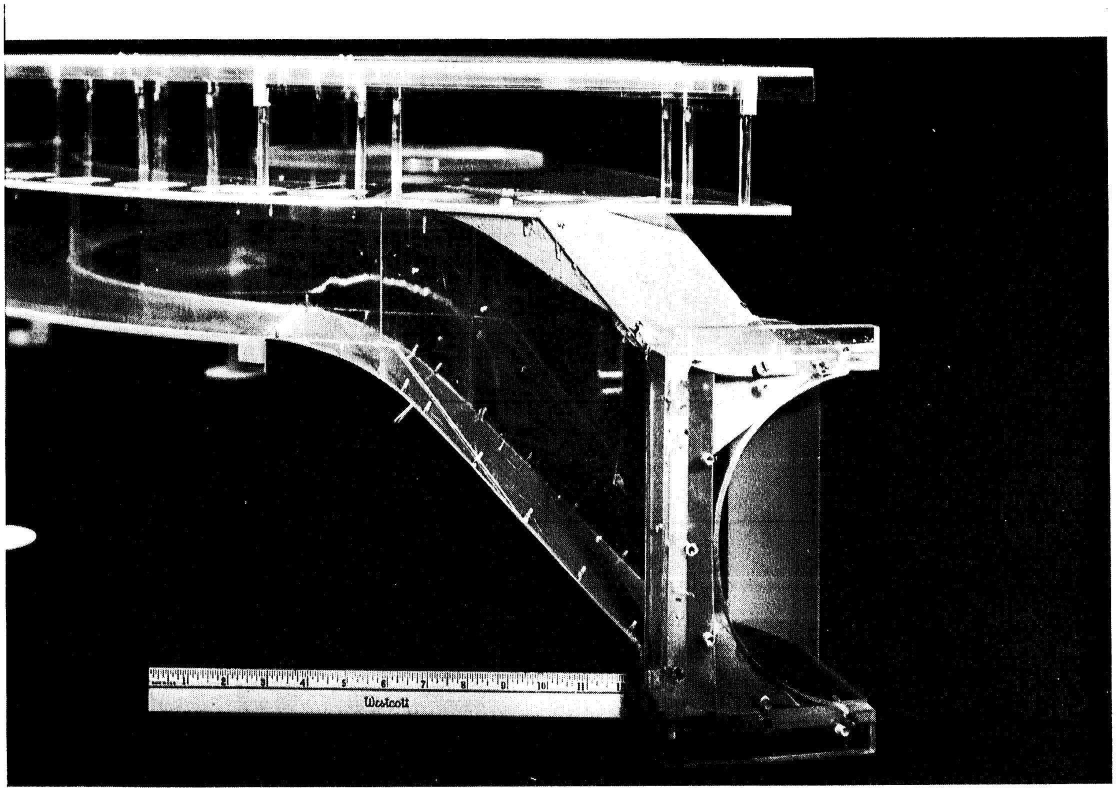


Photo 2

PHOTO 3 (189-104) Two View of the Final Intake Structure Model.

PHOTO 3 (189-101)



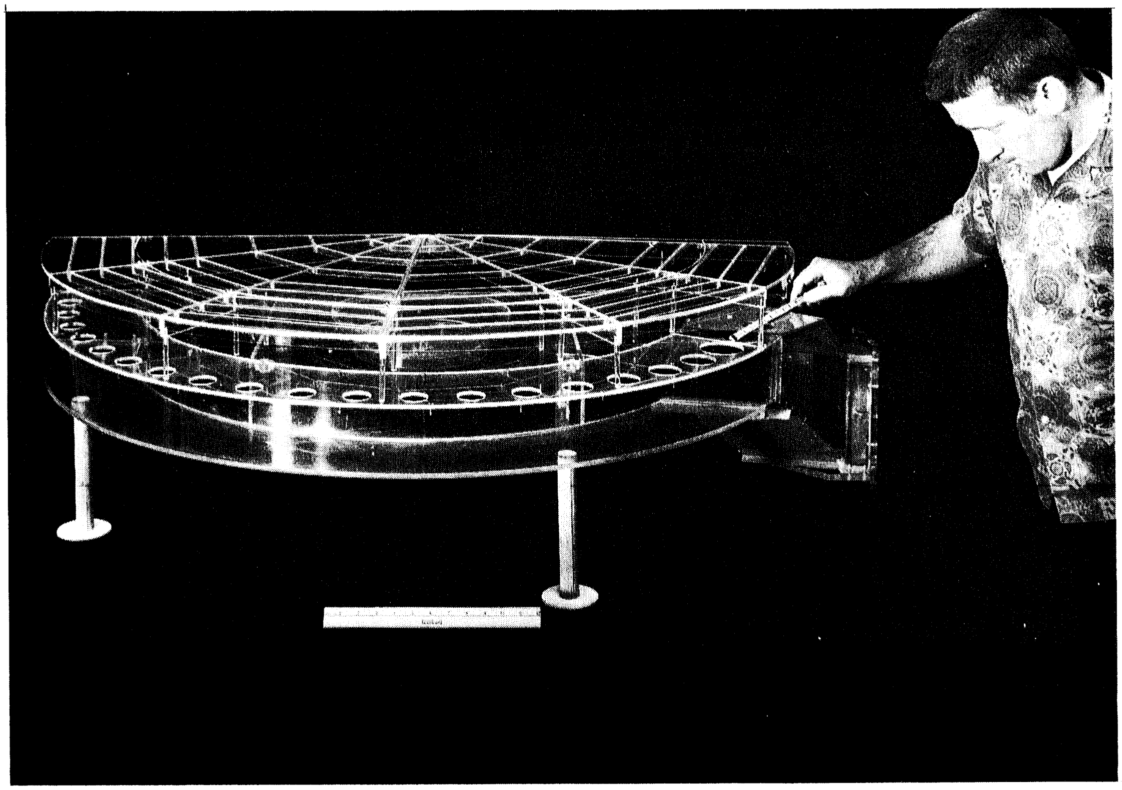


Photo 3

PHOTO 4 (189-96) The Final Intake Structure Half-Model Installed in the Basin without Roof.

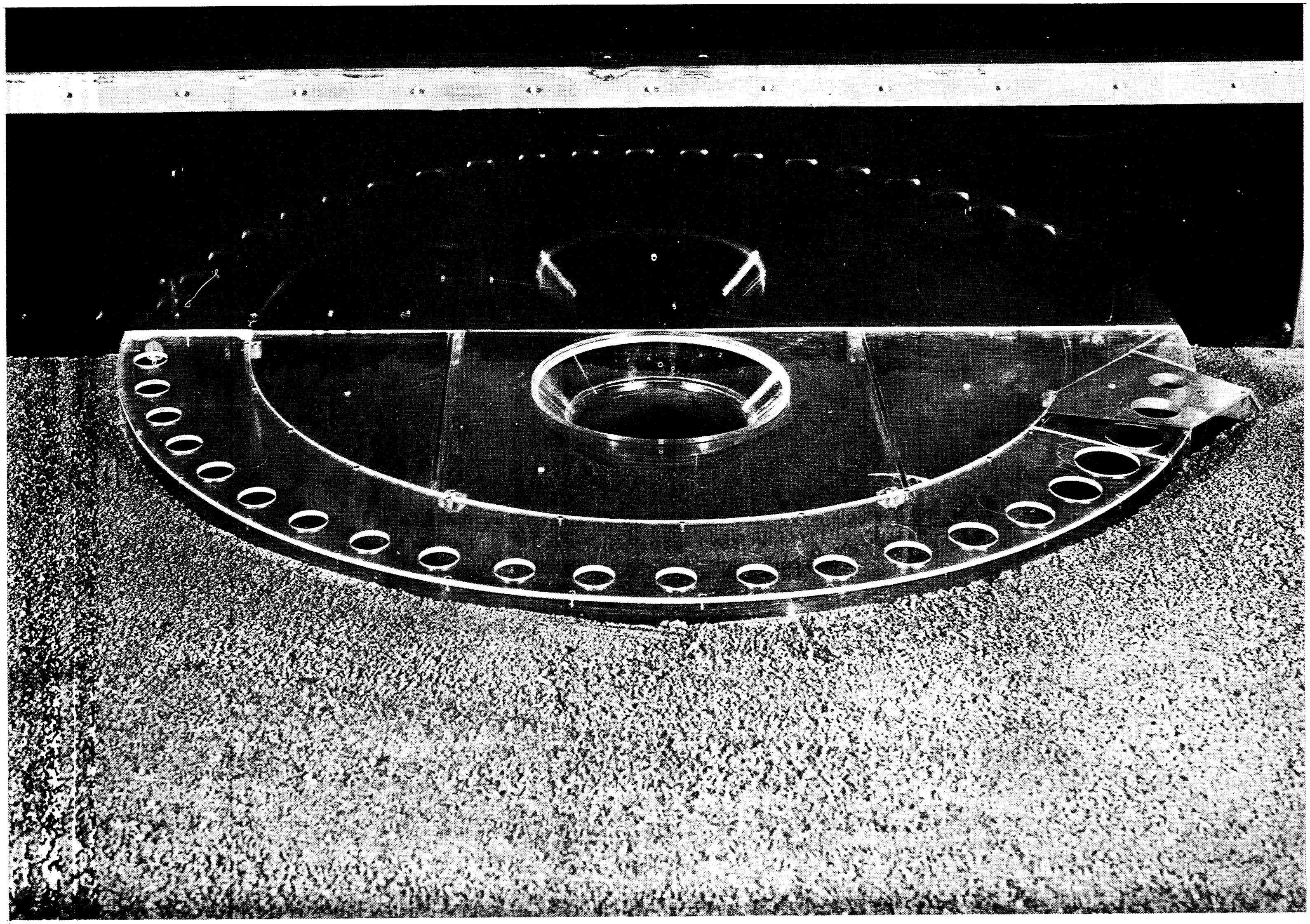


Photo 4

PHOTO 5 (189-63, 189-61, 189-59) Vortex Pattens
Over Intake Structure without Roof

Lake Elev. 574 ft

Lake Elev. 578 ft

Lake Elev. 582 ft

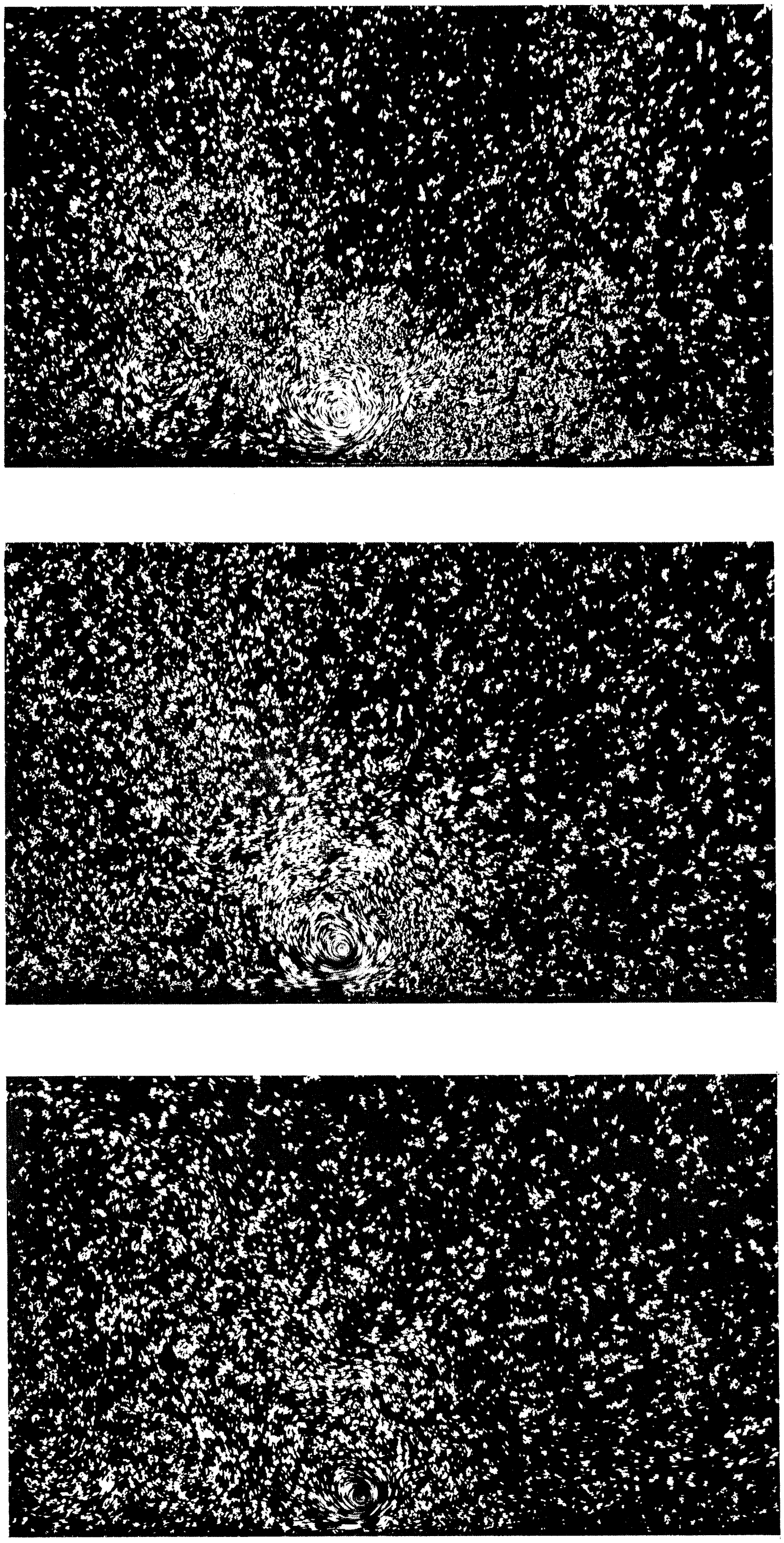


Photo 5

PHOTO 6 (189-35, 189-33, 189-31) Vortex Patterns
Over Intake Structure with Partial Roof

Lake Elev. 574 ft

Lake Elev. 578 ft

Lake Elev. 582 ft

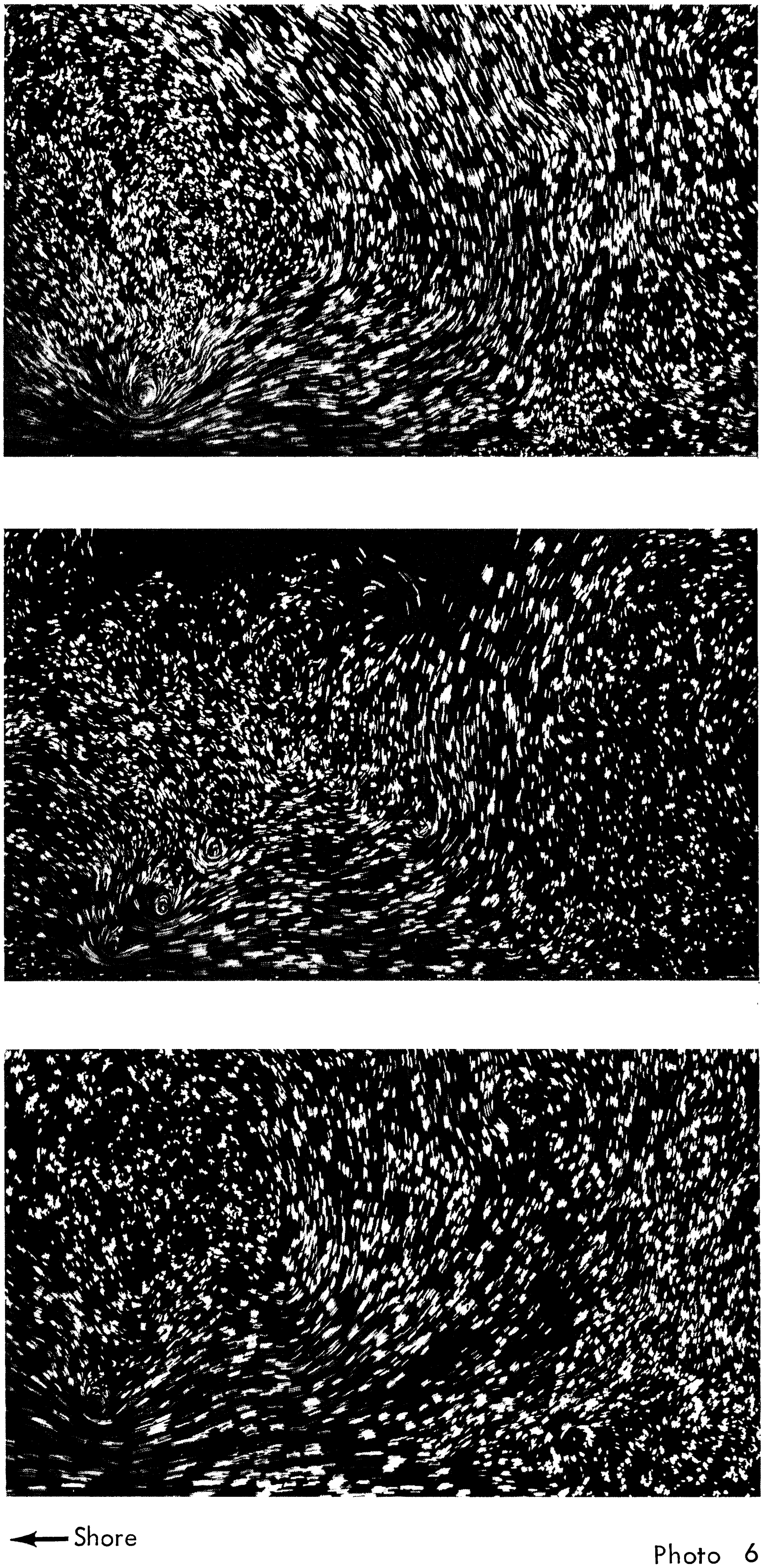


Photo 6

PHOTO 7 (189-53, 189-54, 189-57) Vortex Patterns Over Intake Structure with Full Roof

Lake Elev. 574 ft

Lake Elev. 578 ft

Lake Elev. 582 ft

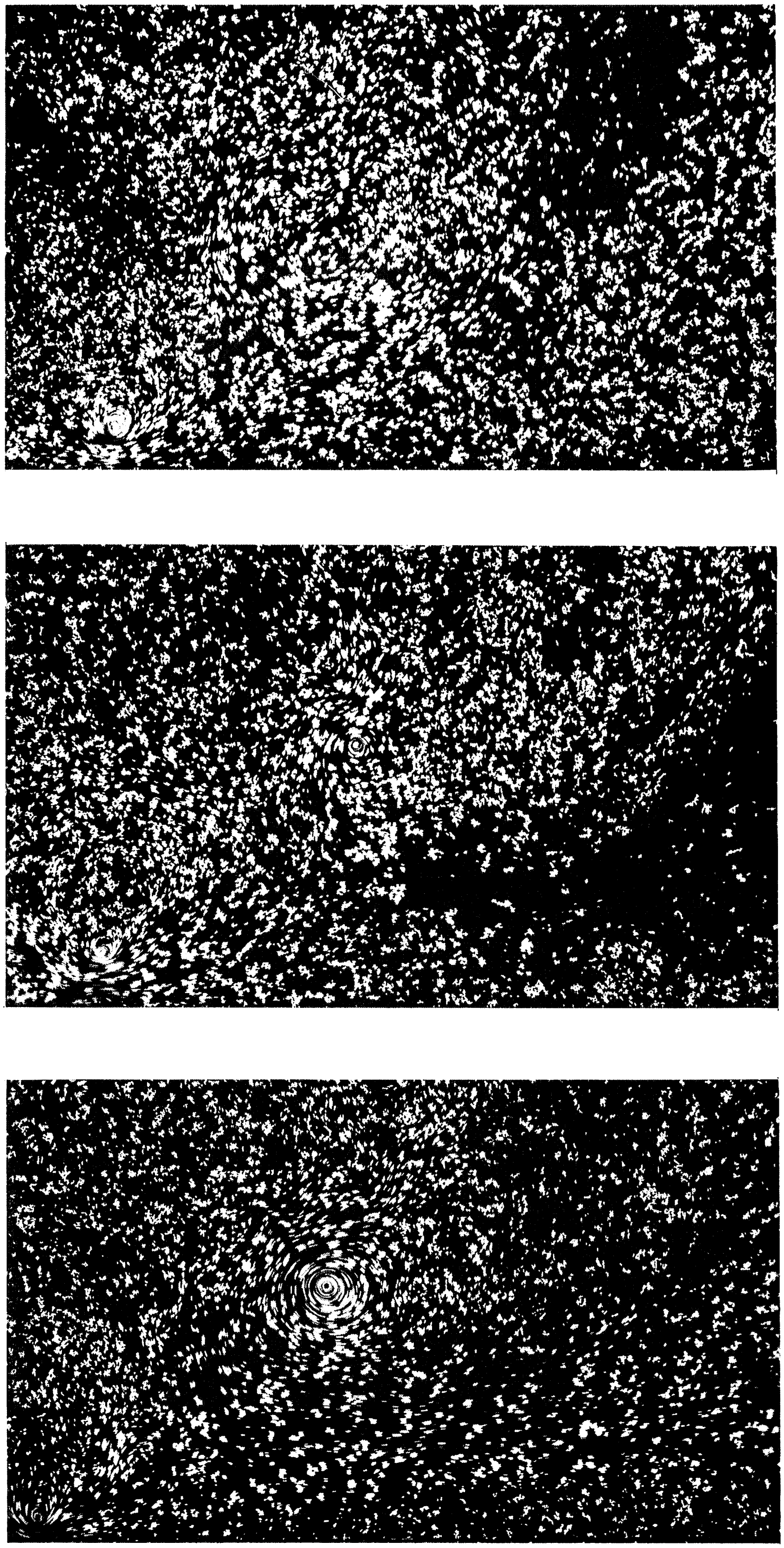


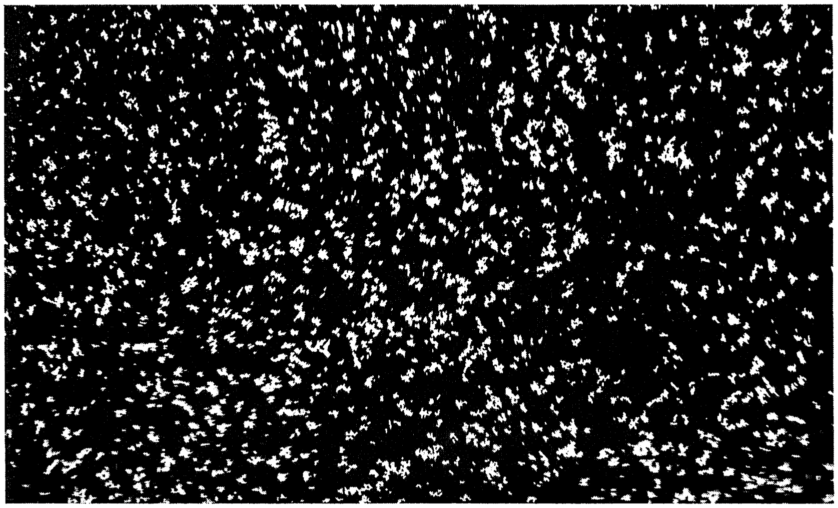
Photo 7

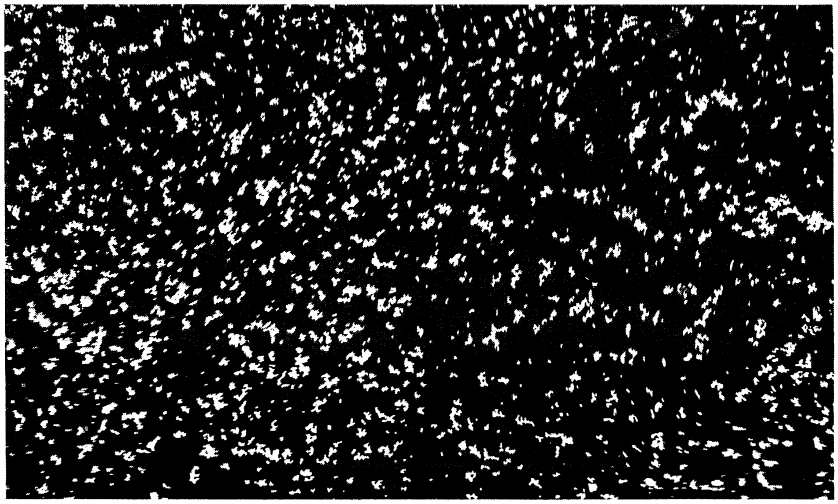
PHOTO 8 (189-22, 189-20, 189-18) Flow Pattern with Full Roof during Winter Operation

Lake Elev. 574 ft

Lake Elev. 578 ft

Lake Elev 582 ft





← Shore

Photo 8

PHOTO 9 (189-50, 189-47, 189-44) Distribution of Flow from Thawing Box with Full Roof

Lake Elev. 574 ft

Lake Elev. 578 ft

Lake Elev. 582 ft

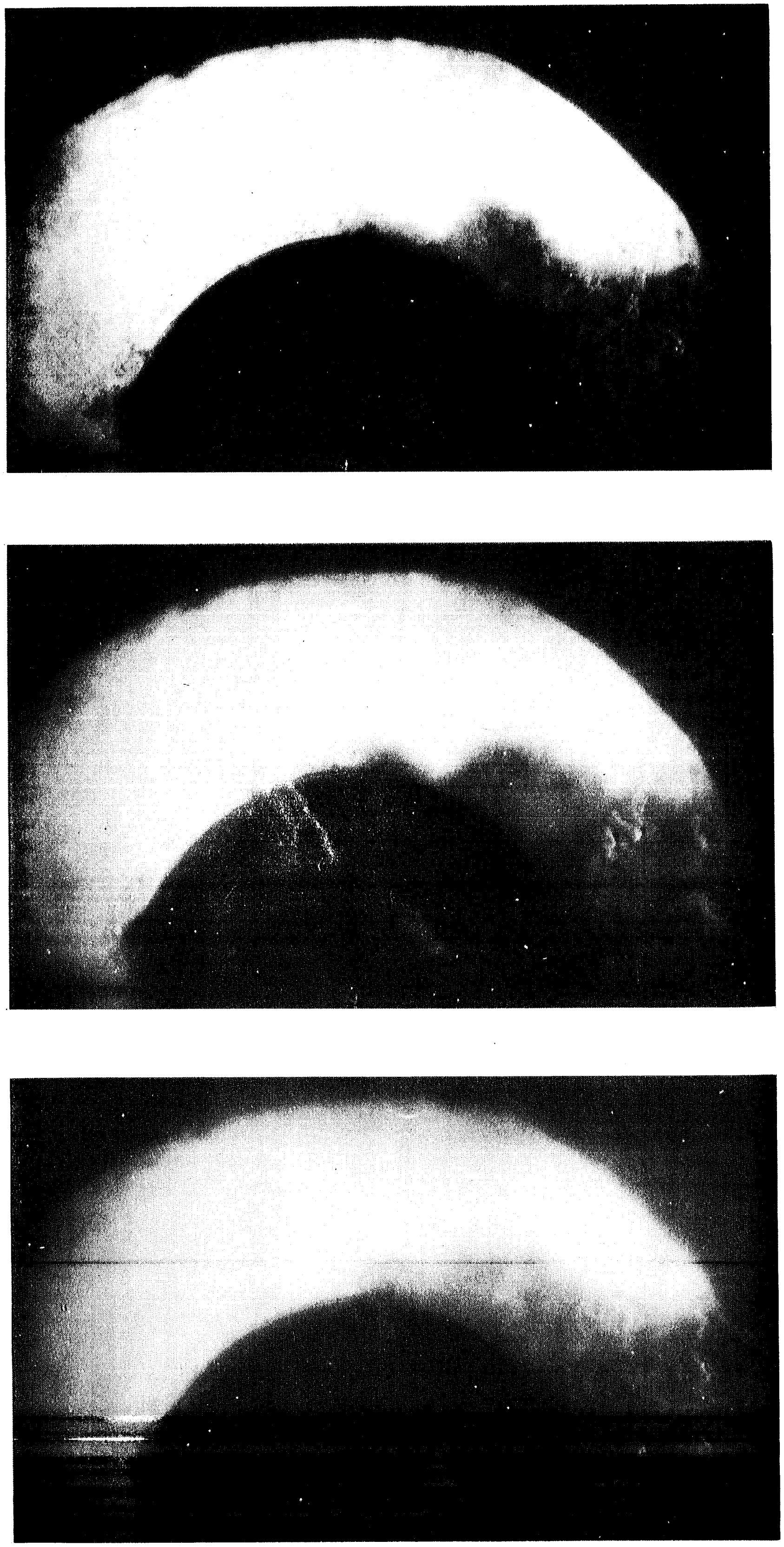


Photo 9

PHOTO 10 (189-66) Discharge Structure Half Model in Basin with Water Flow

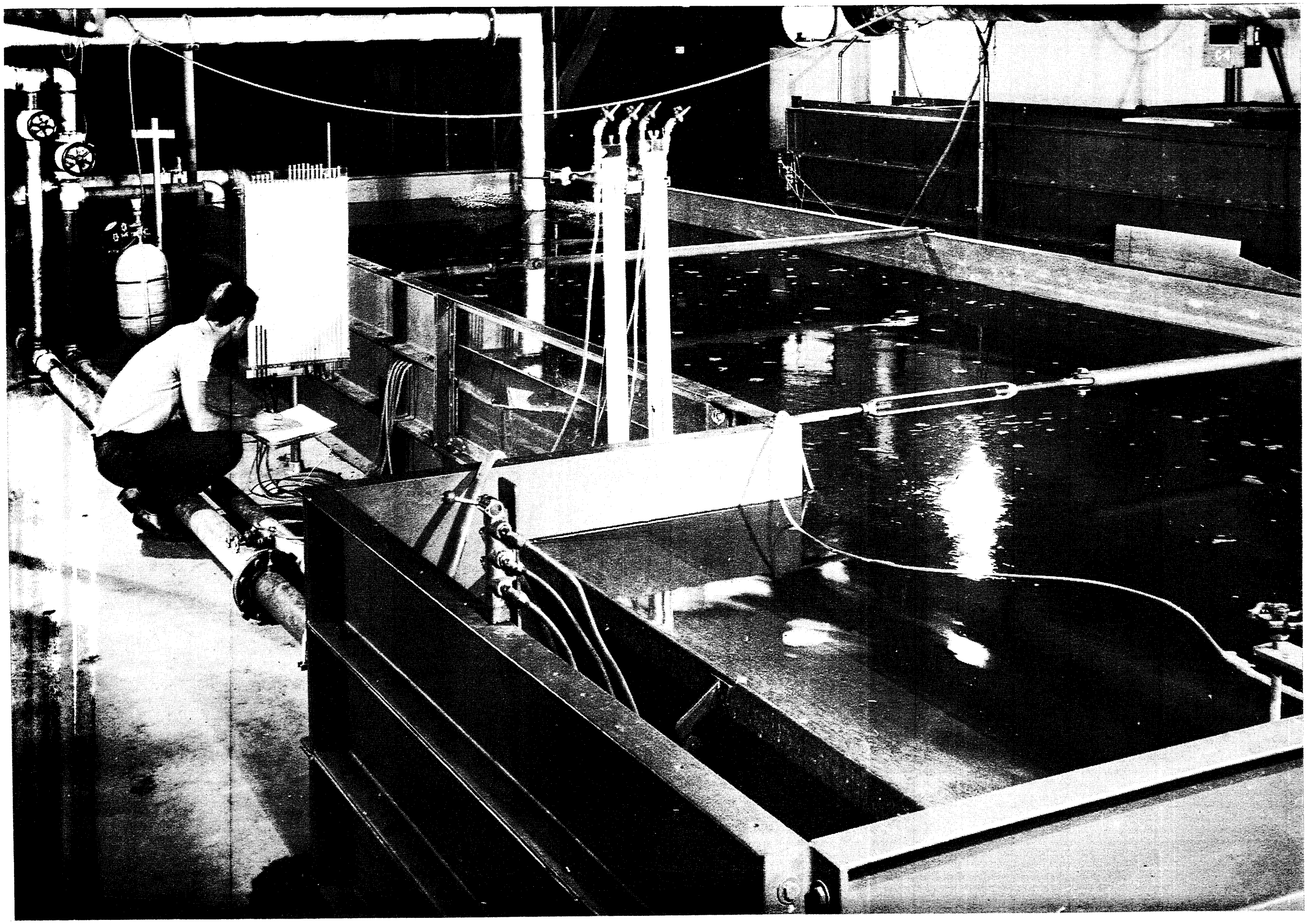


Photo 10

PHOTO 11 (189-80) Side View of Half Model of Discharge Structure (with Trial F Vanes in Place).

Photo 11

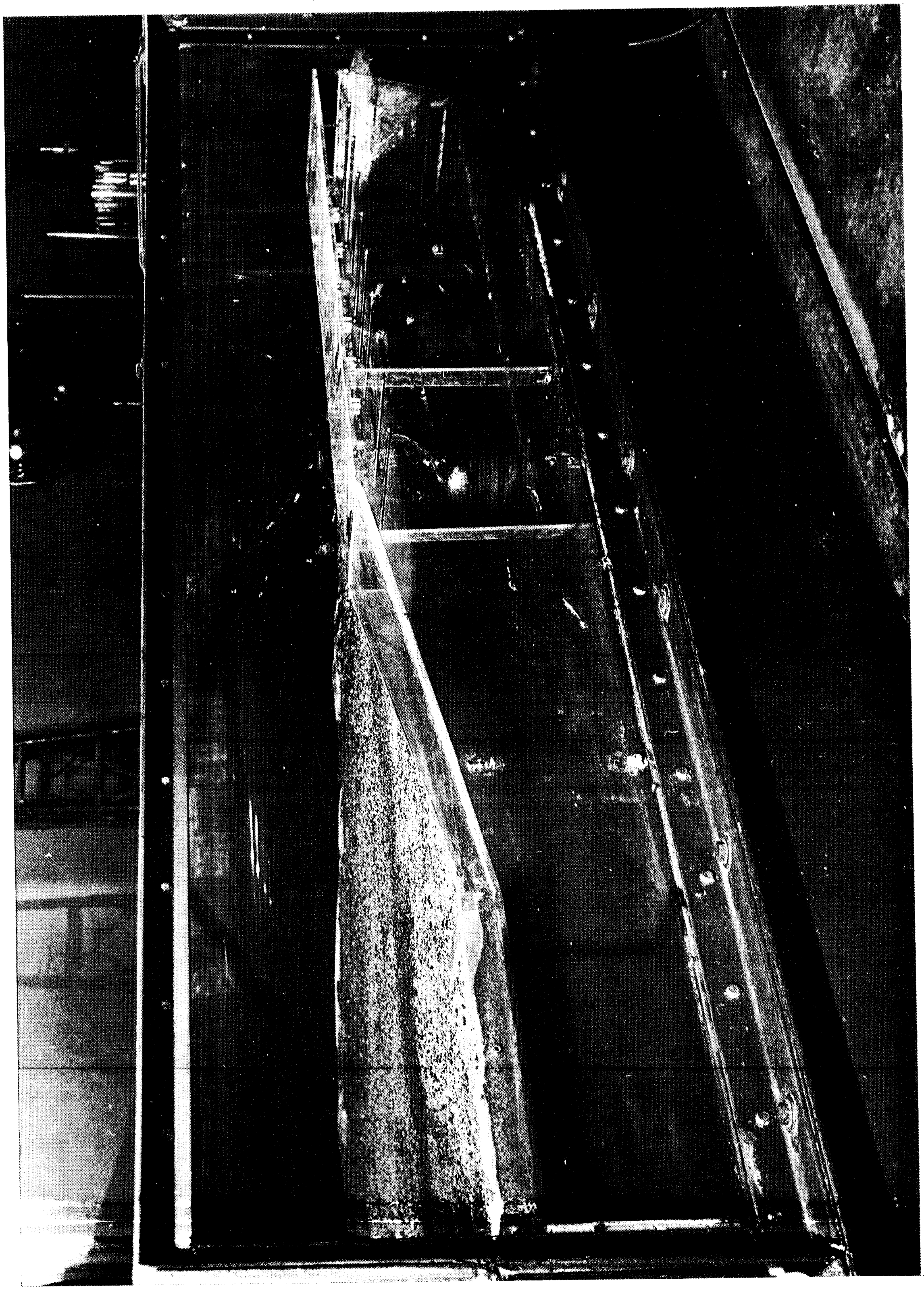
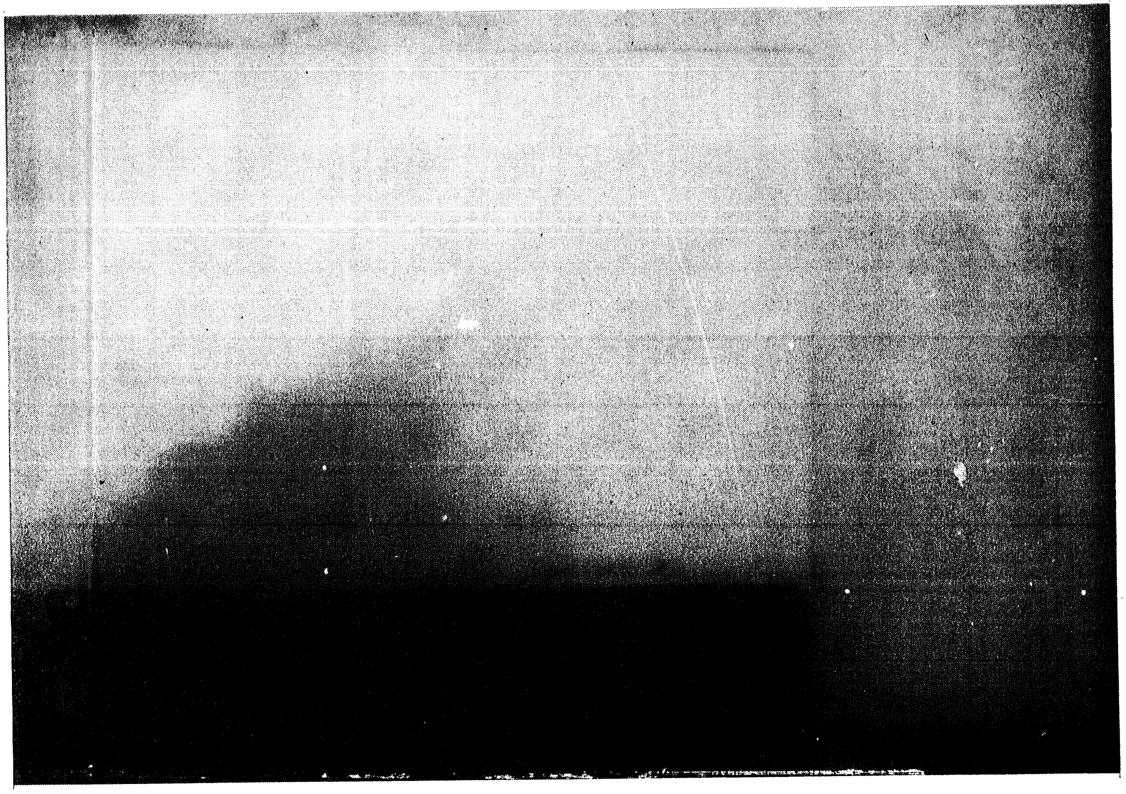
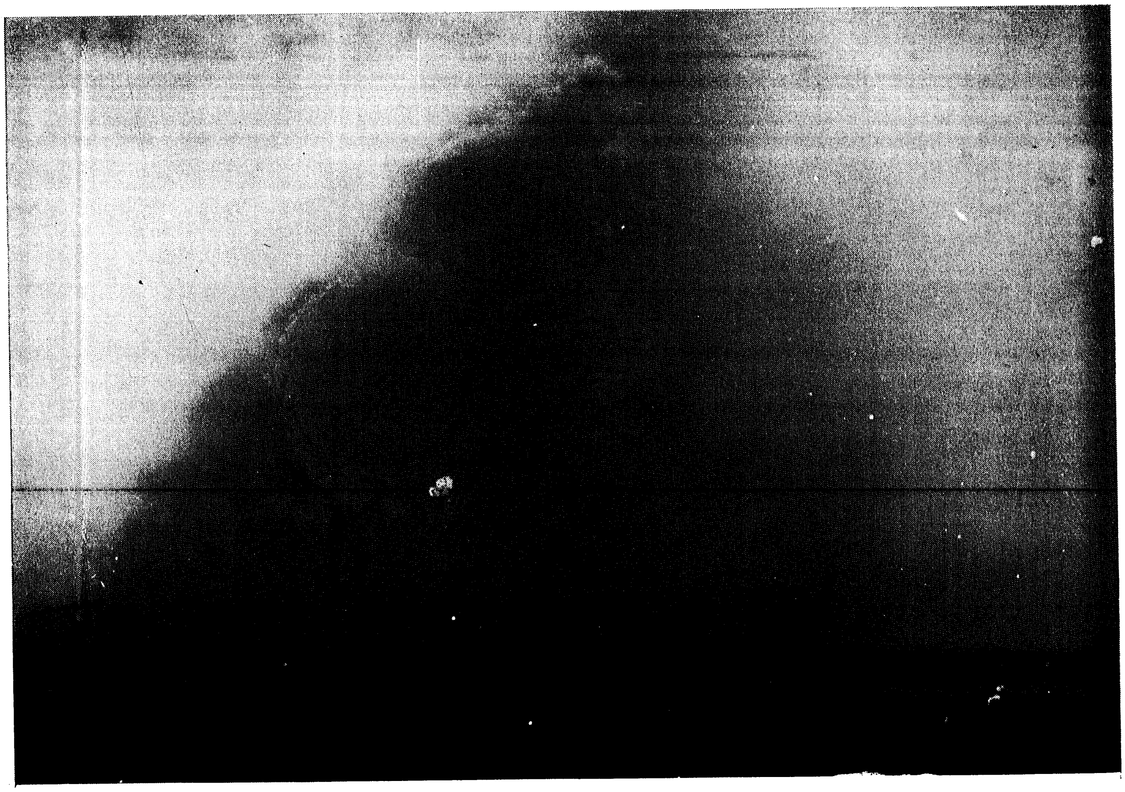


PHOTO 12 (189-73) Dye-marked Discharge. 1725 cfs, Lake Elevation 582 ft -- Just after Dye Injection.

(189-74) -- A Few Moments Later.



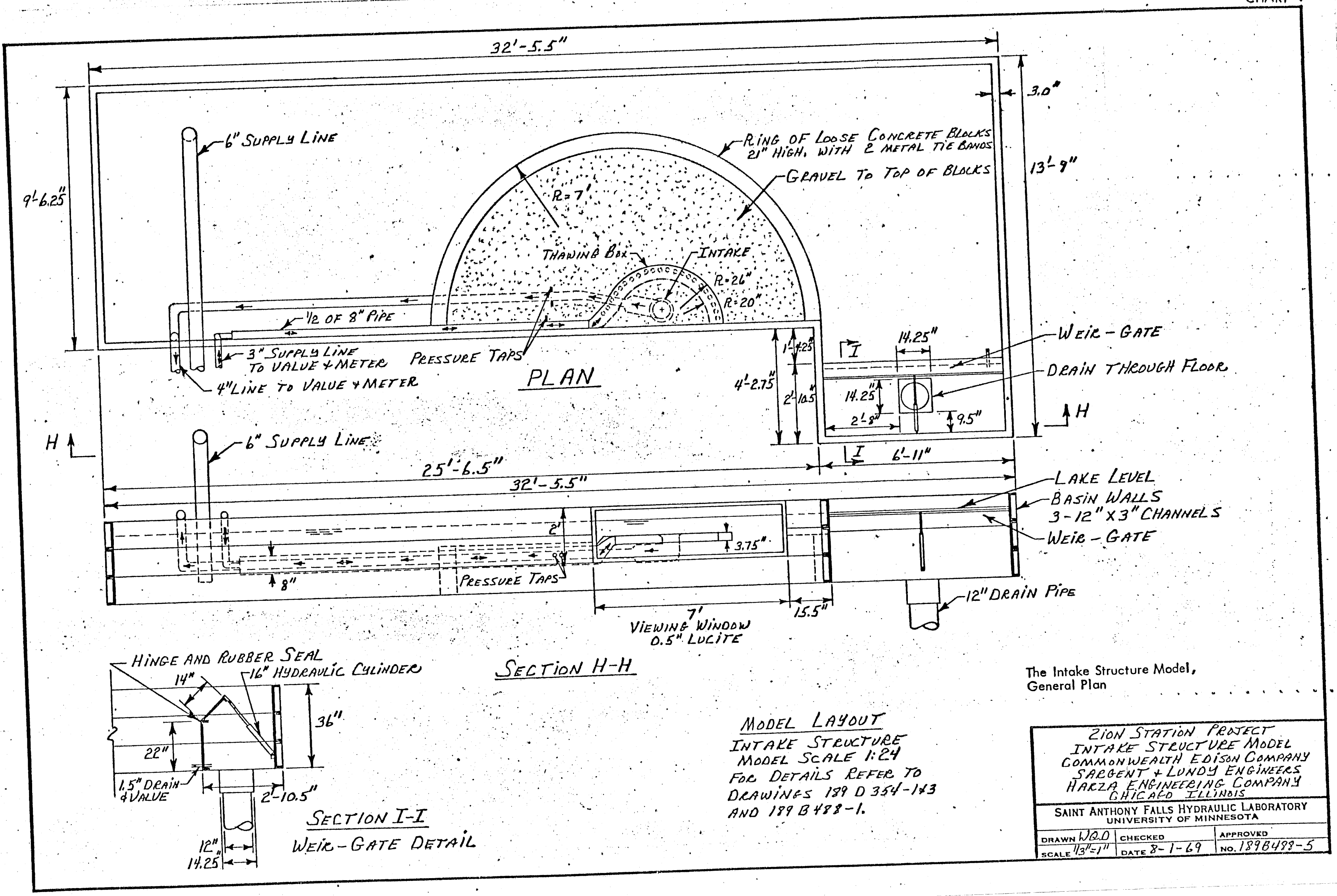


← Shore

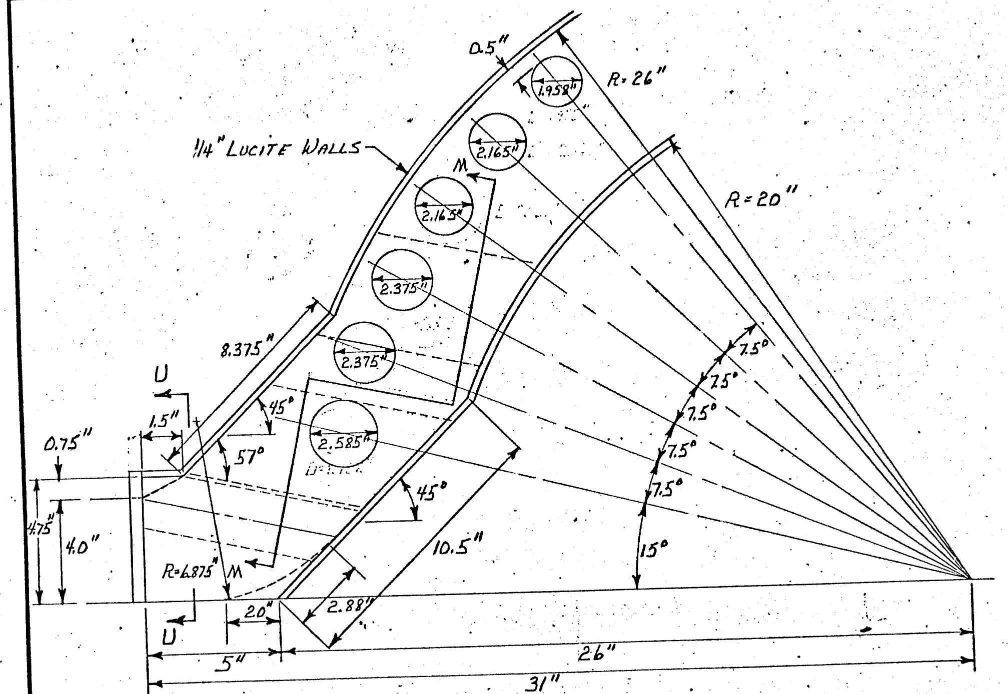
Photo 12

LIST OF CHARTS

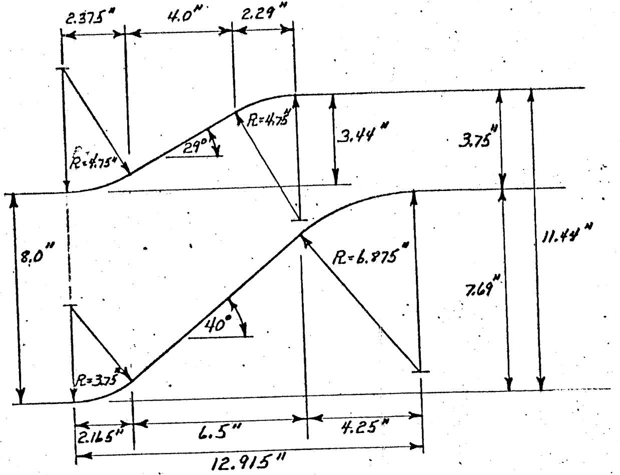
CHART 1



The Intake Structure Model,
General Plan

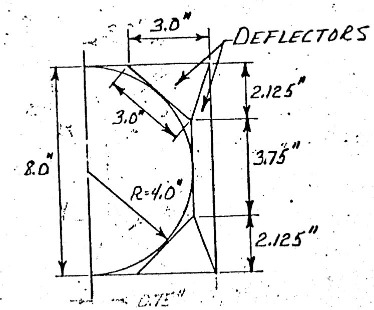


PLAN
SCALE - 1/4"-1"



SECTION M-M
SCALE - 1/4"=1"

REVISED TOP AND BOTTOM OF TRANSITION TO BE SHAPED FROM 22 GAGE SHEET METAL AND FITTED TO INLET AND THAWING BOX. SECTION SIMILAR TO SECTION M-M ON CEC DWG. B-36 REVISED 7-2-69.



SECTION U-U 1/4"=1"

SHOP DRAWING

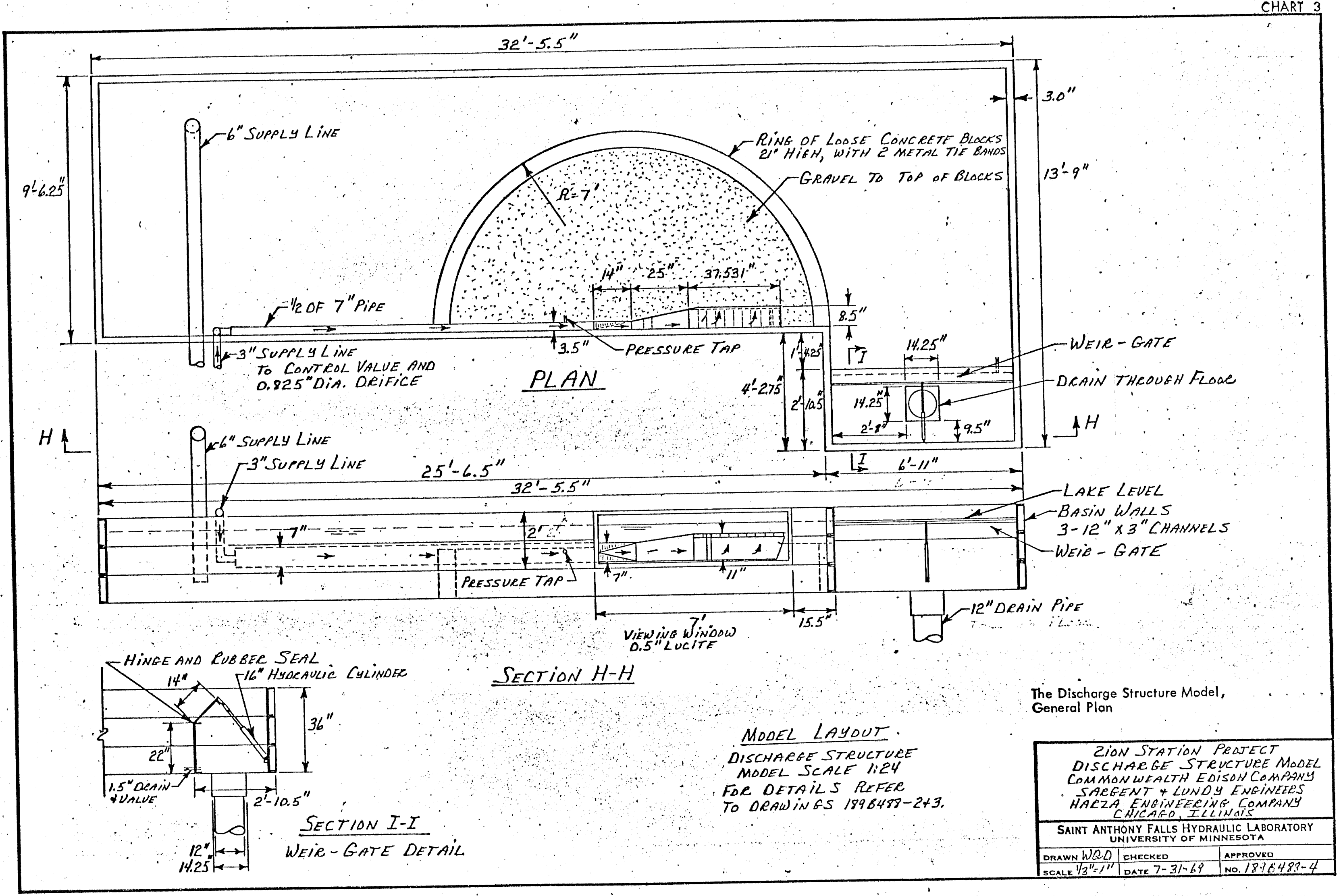
REVISION OF INTAKE STRUCTURE TRANSITION BETWEEN INTAKE PIPE AND THAWING BOX.
MODEL SCALE: 1:24 (1"=2')

Detail of Transition from Center Pipe to Thawing Box

ZION STATION PROJECT
INTAKE STRUCTURE
COMMONWEALTH EDISON COMPANY
SARGENT & LUNDY ENGINEERS
HAZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE 1/4"=1"	DATE 7-21-69	NO. 189B 488-1



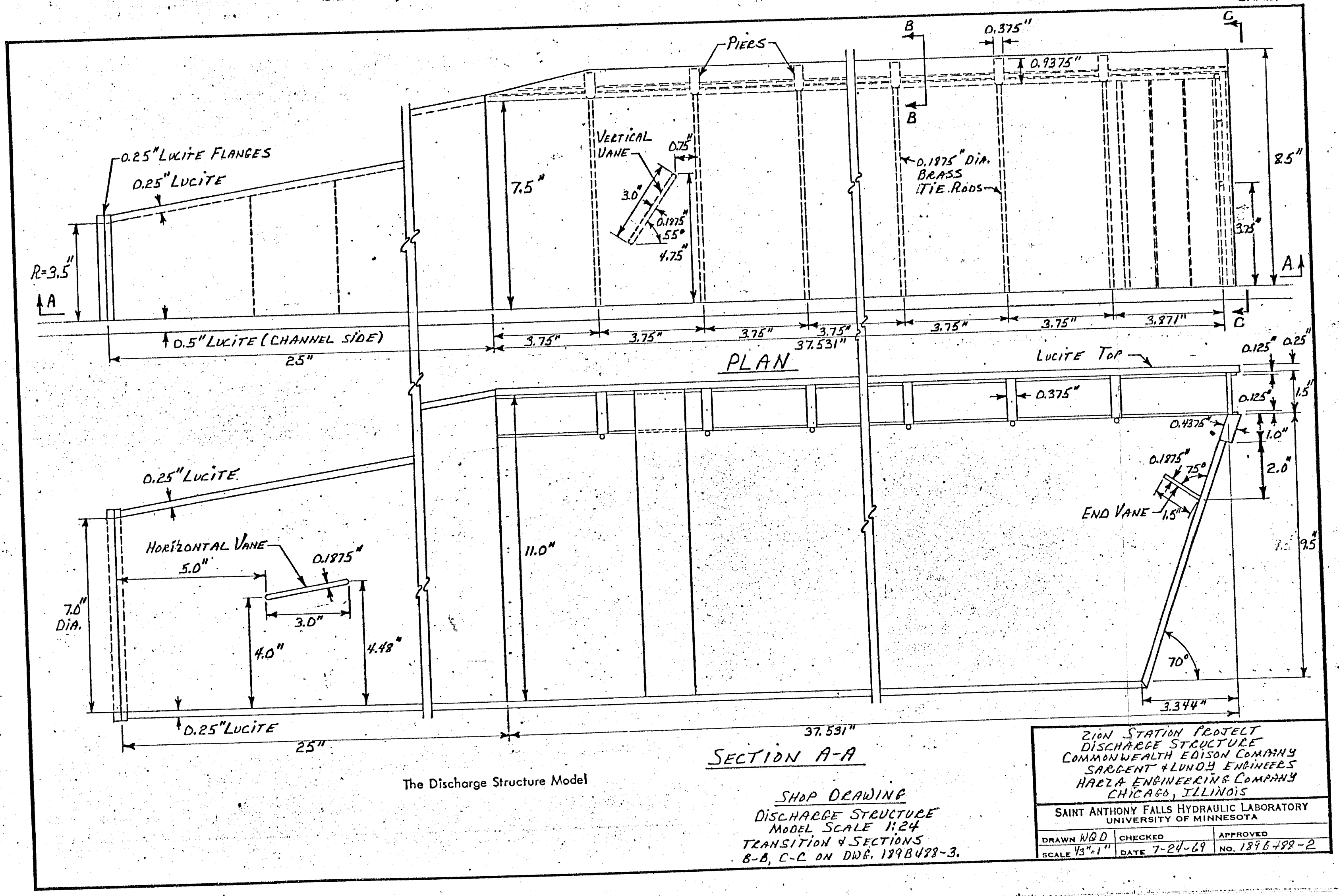
The Discharge Structure Model, General Plan

ZION STATION PROJECT
DISCHARGE STRUCTURE MODEL
COMMONWEALTH EDISON COMPANY
SARGENT + LUNDY ENGINEERS
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE 1/3"=1'	DATE 7-31-69	NO. 1898488-4

CHART 4



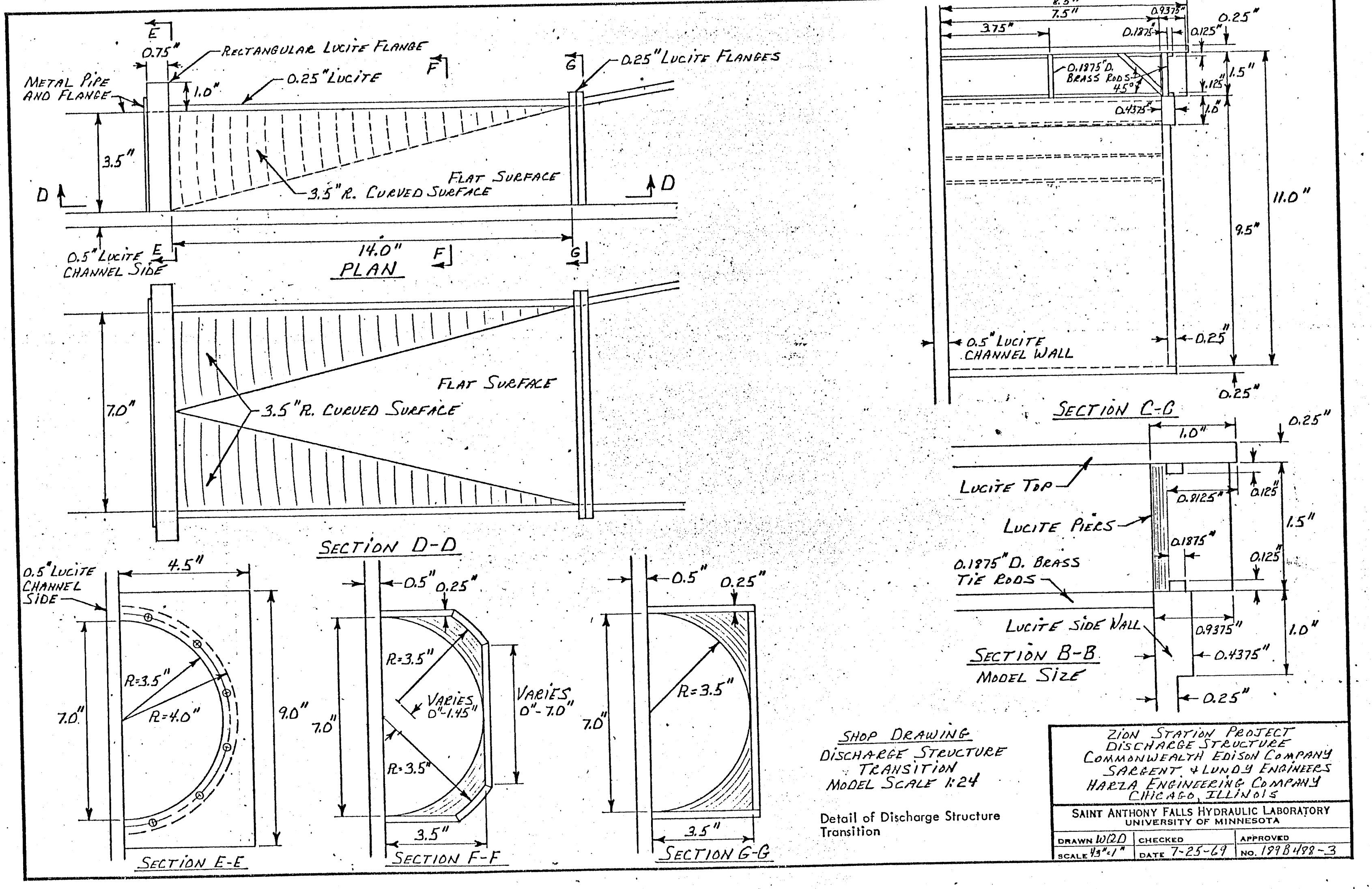
The Discharge Structure Model

SHOP DRAWING
DISCHARGE STRUCTURE
MODEL SCALE 1:24
TRANSITION & SECTIONS
B-B, C-C ON DWG. 189B488-3.

ZION STATION PROJECT
DISCHARGE STRUCTURE
COMMONWEALTH EDISON COMPANY
SARGENT & LUNDY ENGINEERS
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE 1/3"=1"	DATE 7-24-69	NO. 189B488-2



SHOP DRAWING
DISCHARGE STRUCTURE
TRANSITION
MODEL SCALE 1:24

Detail of Discharge Structure Transition

ZION STATION PROJECT
DISCHARGE STRUCTURE
COMMONWEALTH EDISON COMPANY
SARGENT & LUNDY ENGINEERS
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

SAINT ANTHONY FALLS HYDRAULIC LABORATORY
UNIVERSITY OF MINNESOTA

DRAWN WQD	CHECKED	APPROVED
SCALE 4.5"=1"	DATE 7-25-69	NO. 199B488-3