University of Minnesota
St. Anthony Falls Hydraulic Laboratory

Project Report No. 177

EXPERIMENTAL FLOW STUDIES WITH THE DUAL-SCREEN COOLING WATER INTAKE ASSEMBLY ("RISER") FOR THE JAMES H. CAMPBELL ELECTRIC POWER GENERATING PLANT, UNIT NO. 3

by

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for

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and

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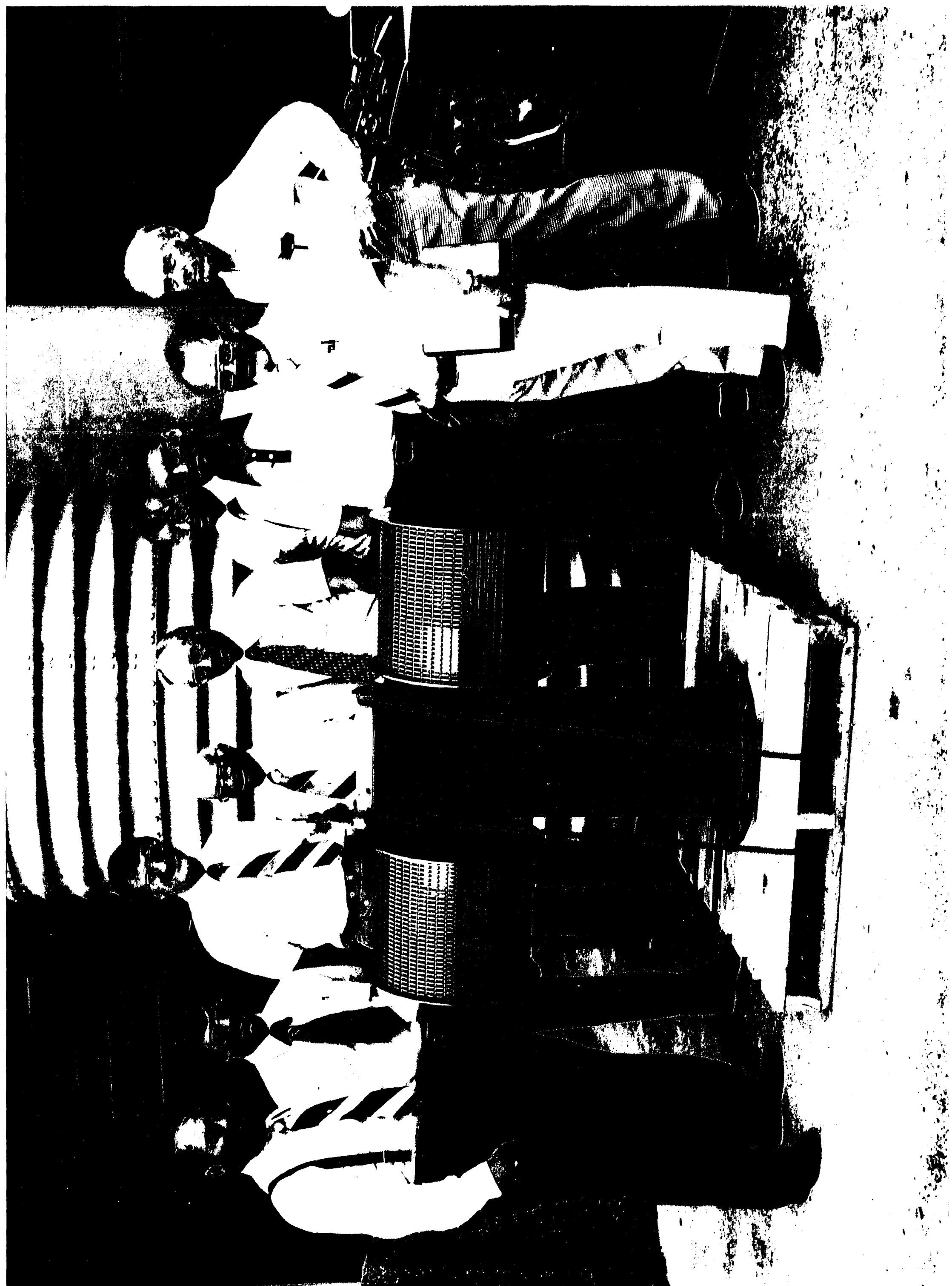
1:3 Scale Dual-Screen Assembly ("Riser")



ABSTRACT

Flow characteristics inside and outside of a dual-screen cooling water intake assembly ("riser") for the James H. Campbell Unit No. 3 were observed and measured in hydraulic models at scales of 1:3 and 1:12. Risers consist of dual cylindrical screens with horizontal axis and solid endplates mounted on a T-assembly which is supported by a 3.5 ft diameter vertical withdrawal pipe. Pressure losses within the assembly, approach flow velocity patterns and approach flow velocities on the screen surface were investigated. A total headloss coefficient of 4.6 resulting in an equivalent full-scale headloss of 8.0" of water at a withdrawal rate of 29.44 cfs through the assembly was measured in the model. Flow patterns towards single and multiple risers were observed by dye tracing techniques. Approach flow velocities were measured on the surface of the 1:3 scale riser model. The highest velocities were found near the center of the screen and the lowest ones near the projecting endplates. Maximum local velocities exceeded calculated average velocity by about 30 per cent.

CONTENTS

Listing of Studies

for the James H. Campbell

Unit No. 3 Cooling Water Intake

1. H. Stefan and A. Fu, "Headloss Characteristics of Six Profile-Wire Screen Panels," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, Project Report No. 175, September 1978, 71 pages.

2. H. Stefan and A. Fu, "Collector Well Study for the Cooling Water Intake System of the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, Project Report No. 176, November 1978, 46 pages.

3. H. Stefan, W. Q. Dahlin, J. F. Ripken, A. Wood. and T. Winterstein, "Experimental Flow Studies with the Dual-Screen Cooling Water Intake Assembly ("Riser") for the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Project Report No. 177, December 1978, 130 pages.

4. H. Stefan, C. Shanmugham, and S. Dhamotharan, "Cooling Water Manifold Intake (Header) Study for the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, Project Report No. 178, January 1979, 59 pages.

5. John M. Killen and H. Stefan, "Hydraulic Analysis of Alternative Cooling Water Intake Designs for the James H. Campbell Electric Power Generating Plant, Unit No. 3," University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, External Memorandum No. 161, December 1978, 22 pages.

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

I. INTRODUCTION

The Cooling Water Supply System of the James H. Campbell Power Generating Plant, Unit No. 3 owned by Consumer Power Company, Jackson, Michigan and designed in cooperation between Commonwealth Associates, Inc., Jackson, Michigan and Johnson Division UOP Inc., St. Paul, Minnesota, calls for the installation of 56 cylindrical screens of 4.5 ft diameter and 4 ft length in about 35 ft of water in Lake Michigan, about 3500 ft offshore.

Several elements of the Campbell Unit No. 3 cooling water intake have been studied analytically and experimentally by the authors at the St. Anthony Falls Hydraulic Laboratory in order to provide guidance in the design and to produce anticipated performance data of the intake structure. The Campbell Unit No. 3 intake differs considerably from other intake structures in the Great Lakes. It is designed for a through screen velocity on the order of 0.5 ft/sec. A 3/8 inch mesh opening is being considered. It is anticipated that the small mesh size will minimize entrainment and that the low withdrawal velocities will eliminate impingement of any fish.

The initial conceptual design[1] of the Campbell Unit No. 3 intake is shown in Fig. I-1. An 18.0 ft diameter intake pipe leads to shore. The lake water enters through 56 screens which are mounted with a horizontal axis on 28 risers. Seven risers are connected to four individual headers of 8.0 ft diameter and arranged in the shape of a cross. After passing through the screen, the water flows horizontally in a short T-assembly, down a riser and horizontally through a header into the collector well from where it exits into the intake pipe leading to the plant. The headers are buried in the lake bottom. Only the upper portions of the 28 risers carrying the screens protrude through the lake bottom.

Separate studies have been conducted for the risers, the headers and the collector well. Only the experimental study of the risers will be described herein.

Each riser of the James H. Campbell Unit No. 3 cooling water intake consists of two cylindrical profile-wire screens, 4.5 ft in diameter and

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1) The final design selected for construction is a branching pipe system. It does not use a collector well. It is described in External Memorandum No. 161 referenced as Item No. 5 on page iv.

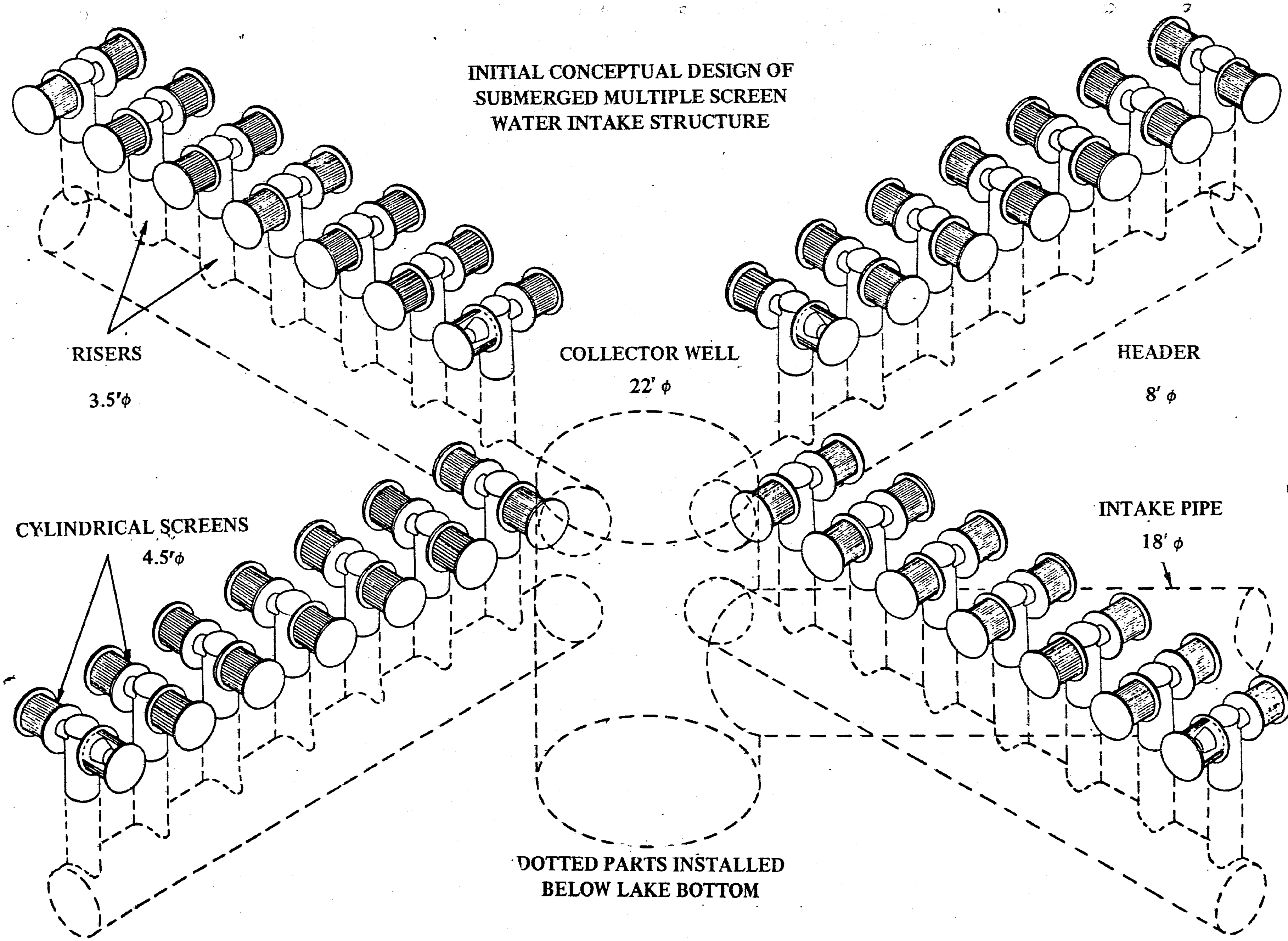


Fig. I-1. Initial Conceptual Design of the James H. Campbell Unit No. 3 Cooling Water Intake.

4.0 ft long. A nozzle projects inside the screen and withdraws the water which has passed the screens horizontally and axisymmetrically. The water enters a vertical pipe of 3.5 ft diameter which conveys it to the horizontal header. A photograph of the 1:12 scale riser model is shown in Fig. I-2.

Questions to be answered by the experimental riser study fell into two categories: One set of questions related to the internal flow field, i.e., the flow after passage of the screen, through the nozzle, the T-assembly and down the riser. The second set of questions related to the external flow field, i.e. the approach flow to the screen and the approach velocities on the screen surface.

Specific questions to be answered by the experimental study were as follows.

Internal Flow:

a. What will be the total headloss of the flow through a riser unit?

b. Will a vortex form inside the vertical riser pipe due to the collision of the two diametrically opposed jets?

c. Will the flow into the withdrawal nozzle inside the screen reattach to the wall or will it remain a separated jet?

d. What will be the pressure distribution inside the riser?

External Flow:

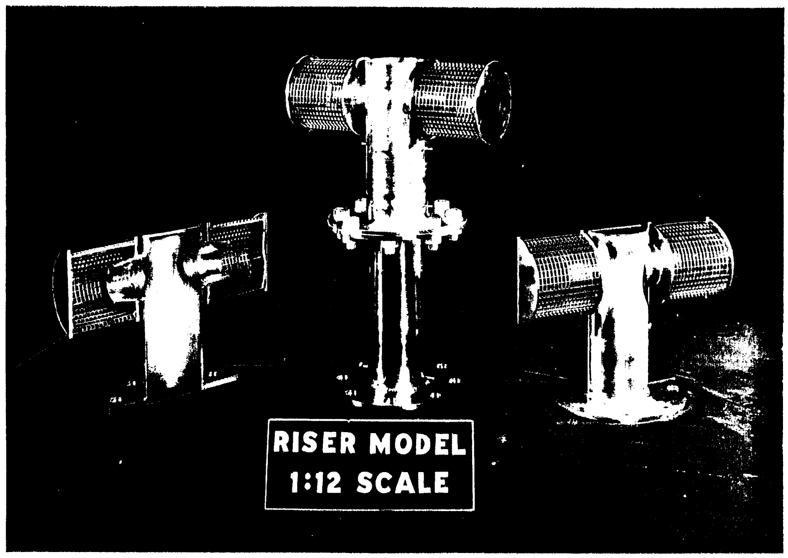
e. Will the flow field into the two intake screens for static lake conditions be symmetrical?

f. Will there be separated flow regions anywhere near the screen, the vertical riser pipe, or the lake bottom?

g. Will the velocity distribution over the screen surface be as uniform as predicted by the potential flow computer models.

It was specified that the above questions should be investigated only for static lake conditions. The results of the study would therefore apply strictly only when lake currents are absent or slow, and when lake surface conditions are calm. Frequency distributions of current velocities measured at the site have been analyzed elsewhere. It can be expected that the assumption of static lake conditions is of little consequence for the internal flow, including the measurement of pressure changes (headloss)

Fig. I-2. Stainless Steel Scale Models (1:12) of Complete Riser and Half-Risers.


RISER MODEL
1:12 SCALE

through the risers. On the other hand, the external flow field towards a screen will be very much affected by any external current as some pictures to be presented will show. Nevertheless, it was specified that the effect of lake currents on intake flow fields should not be investigated at this time. Observations of flows and velocity measurements were therefore made in laboratory tanks which were held under static conditions as nearly as is possible.

It was also specified that in the laboratory experiments, the screens were to be held free of any debris. All measurements were therefore made with perfectly clean screens. No clogged or partially clogged screen surfaces were investigated. To provide answers to the above given set of questions, experiments were conducted with a 1:12 and a 1:3 scale model of the riser. The experimental facilities and installations, the procedures and the results will be presented in the following sections, first with reference to all questions regarding the internal flow, then with reference to the external flow field.

II. PRESSURE MEASUREMENTS IN THE 1:12 SCALE RISER MODEL

1. Objective

The objective of the pressure measurements in the 1:12 scale riser model was to determine by experiment the pressure distribution in the flow through a single intake riser. In particular, the total pressure change between the ambient lake and the foot of the riser was to be measured.

2. Laboratory Experimental Set-up

The 1:12 scale model of the riser was built and supplied by Johnson Division UOP Inc. (Fig. II-1). The model was manufactured in two parts. The upper part was the portion which would protrude above the lake bottom. The lower part, essentially an extension, would represent the portion buried in the lake bottom. The stainless steel models in all-welded construction are shown in Fig. II-2. The model was fitted with sets of 1/16 inch pressure taps at five stations. At each station four pressure taps were spaced 90° apart

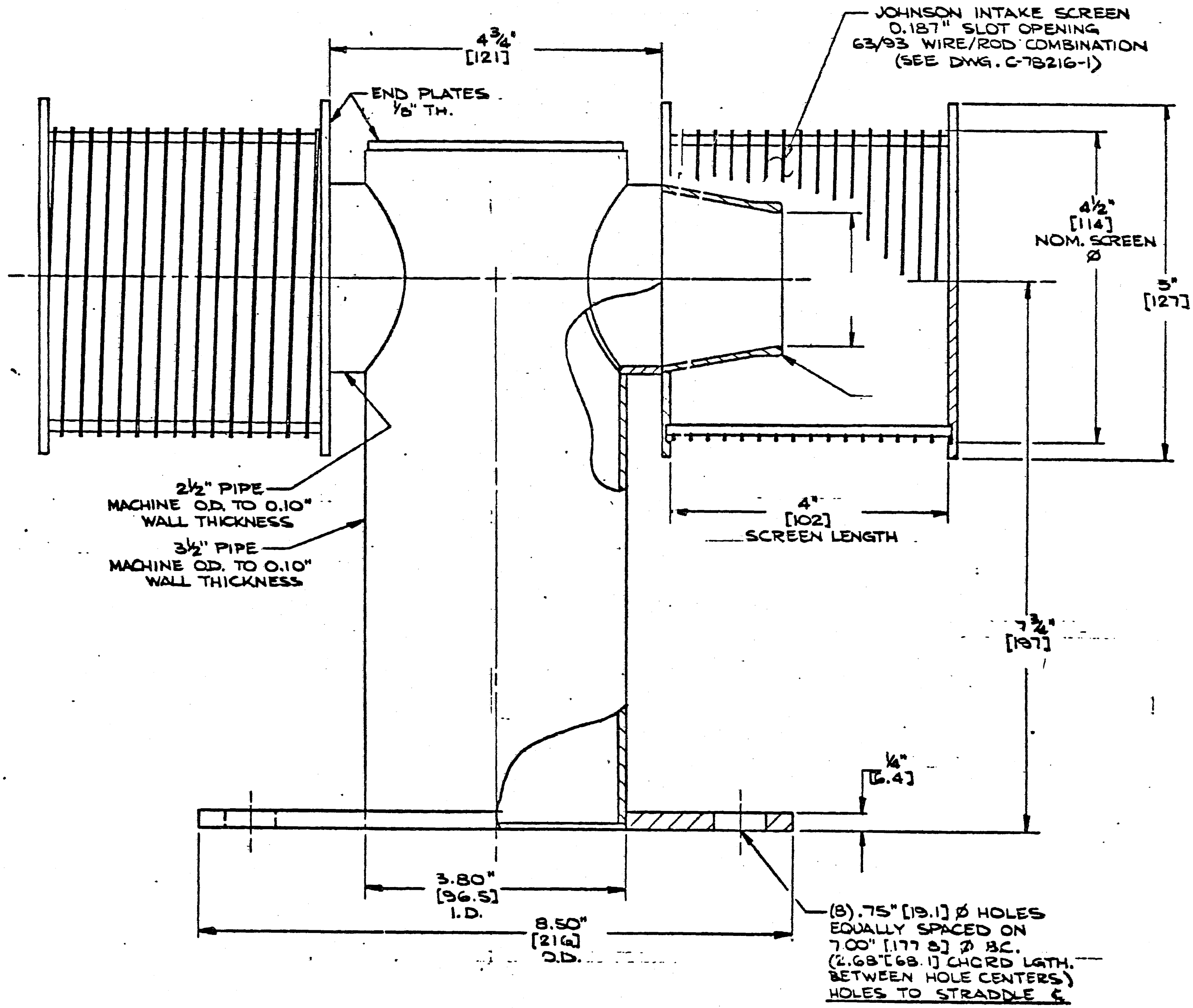
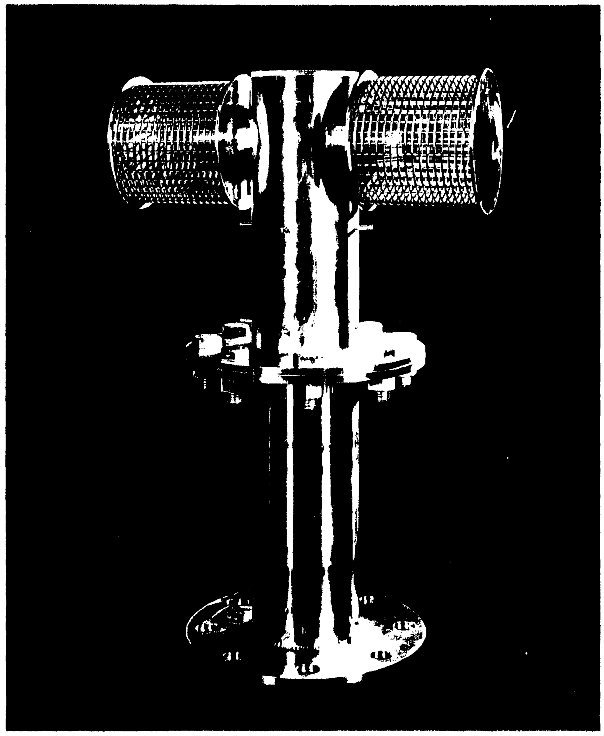


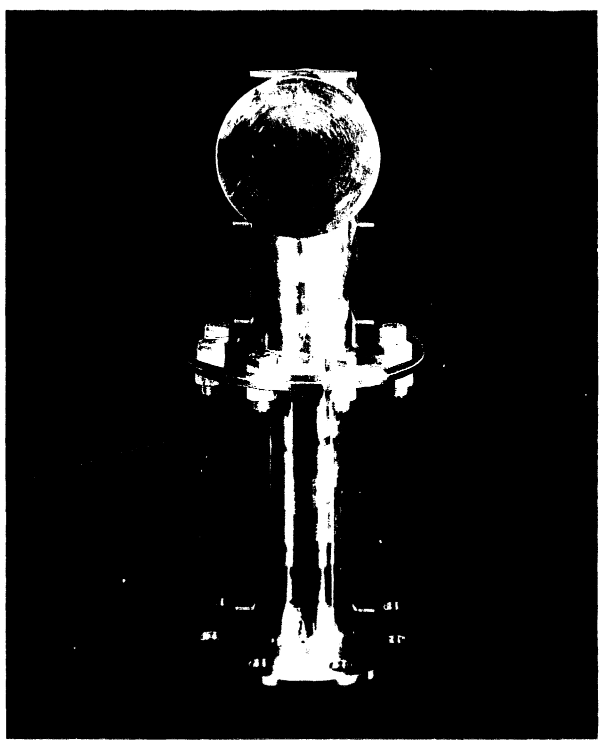
Fig. II-1. Scale Model (1:12) of Intake Riser

Side View of Complete 1:12 Scale
Stainless Steel Riser Model

End View of the Complete 1:12 Scale
Stainless Steel Riser Model

Fig. II-2. Side View and End View of the Complete 1:12 Scale Stainless Steel Riser Model.





around the circumference. The four pressure taps were interconnected using stainless steel nipples and a ring of tygon tubing. The location of the five stations is identified in Fig. II-3.

Two ambient static pressure taps were also used; one located midway between the head of the flume and the model and the other at the bulkhead near the end of the flume. Leads from these seven taps were taken to a manometer board where the piezometric pressure at each of the stations could be read on a scale of 1/10 of an inch.

The 1:12 scale model of the single riser was installed in the 20 inch glass-walled flume in the St. Anthony Falls Hydraulic Laboratory. The flume is 36 inches deep and the model was fully submerged. River water was supplied to the flume through a 3 inch diameter pipe and made to flow over the sharp crested weir installed at the head of the flume. The head over the weir was measured with a hook gauge (least count = 0.0001 ft) set up in a stilling well on the side of the flume. A rating curve established previously was used to determine the flow rate for any measured head over the weir. The water supply section of the experimental flume is shown in Fig. II-4.

To produce a pool, a wooden bulkhead was erected at the end of the first flume section. Its top was about 2 inches below the rim of the flume so that it could serve as an emergency overflow. The riser model was bolted to a hollow box 20" x 69" x 3", which in turn was fixed to the floor of the flume. This box, serving as a false bottom for the flume, extended beyond the downstream bulkhead. Water withdrawn through the riser model into the box was drained through five 2-1/2 inch diameter pipes mounted on the downstream end of the box. The rate of withdrawal could be controlled by a valve at the end of each of the 2-1/2 inch diameter pipes. The water was finally discharged into the drain at the end of the flume. Fig. II-5 shows the arrangement of the model in the flume.

A maximum flow rate of about 0.35 cfs could be used in the model set-up with all five valves on the withdrawal pipes fully open and without water overflowing over the bulkhead at the end of the flume.

The model was operated at flow rates varying between 0.1 and 0.35 cfs, corresponding to prototype flow rates in the range of 14.4 cfs to 50.4 cfs.

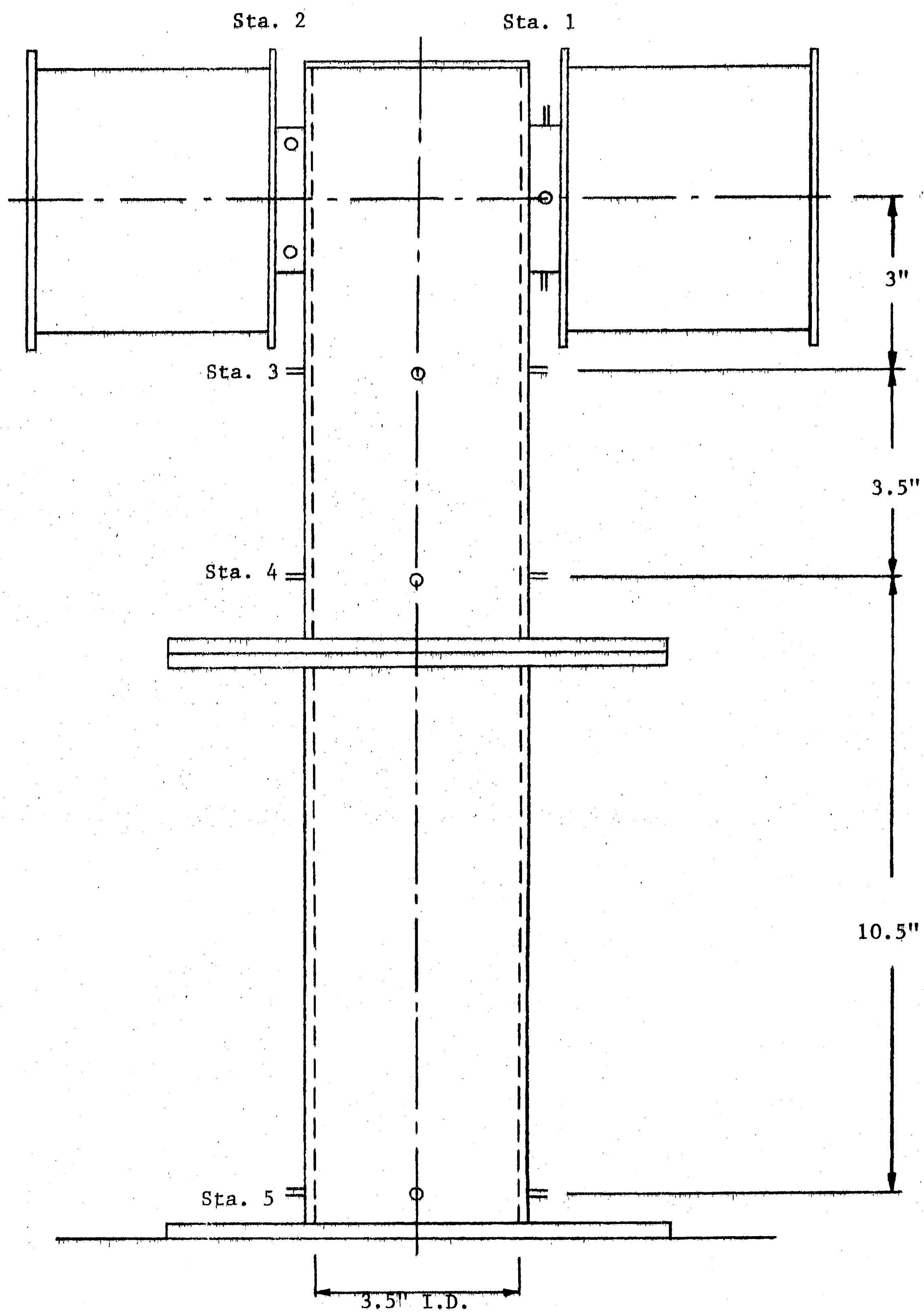


Fig. II-3. Location of Pressure Taps on the 1:12 Riser Model.

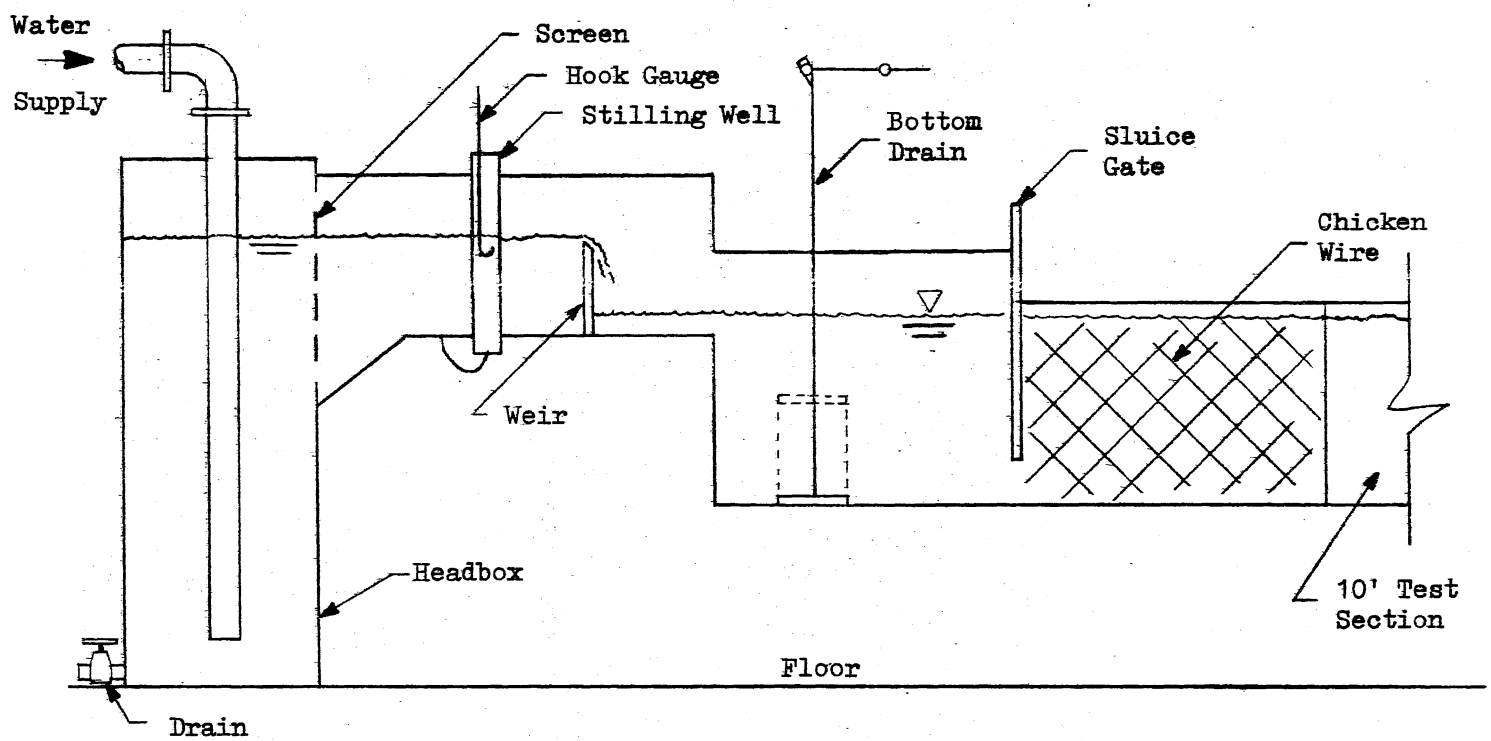


Fig. II-4 - Water Supply and Flow Metering Installation
for 20" Glass-Walled Laboratory Flume.

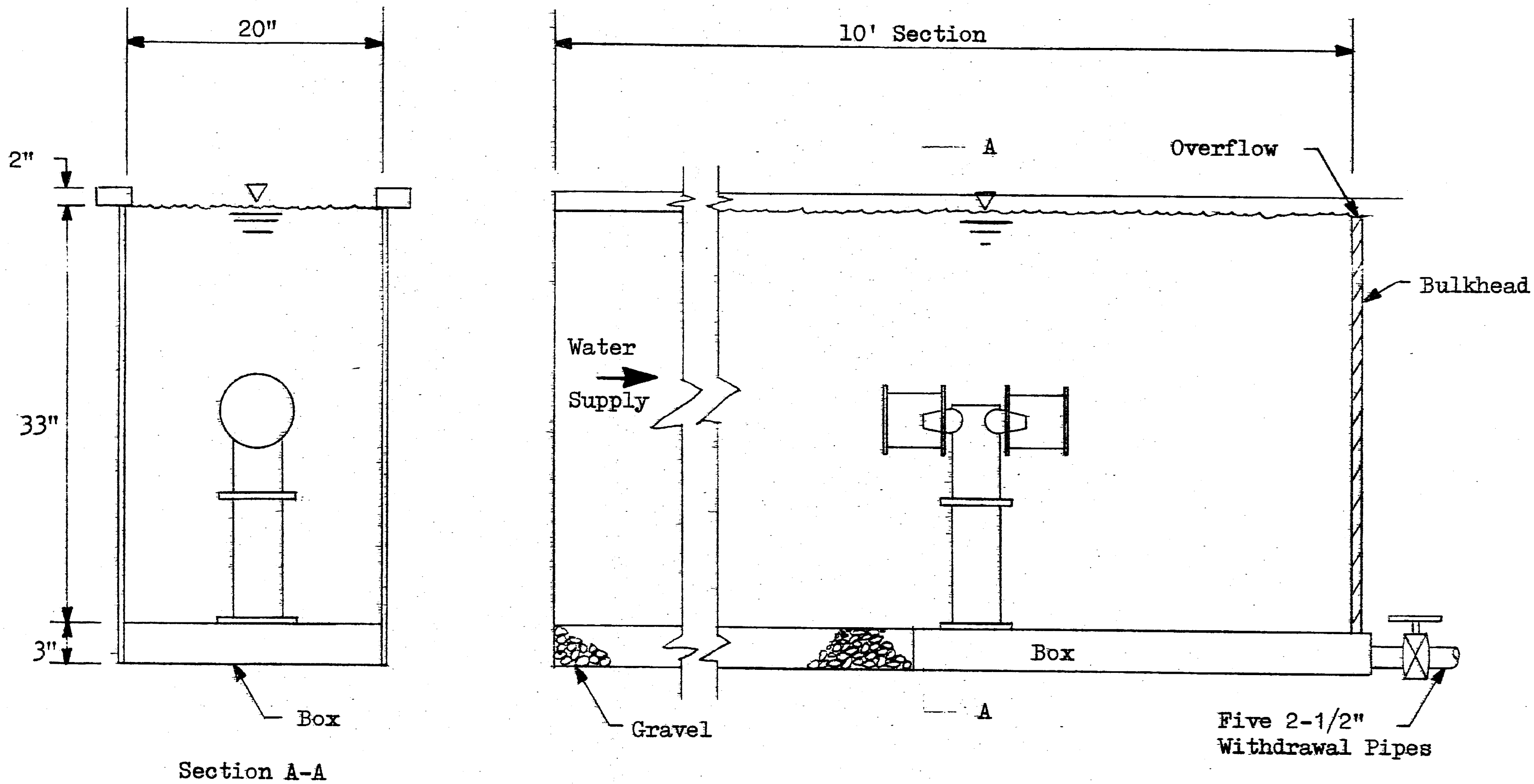


Fig. II-5 - Glass-Walled Flume Test Section with 1:12 Scale Single Riser Installed for Piezometric Pressure Tests.

For each flow rate the withdrawal pipe valves were adjusted to hold the water level in the flume about 1 inch below the top edge of the bulkhead at the end of the flume. The set of piezometer tube readings on the manometer board corresponding to the five stations and the two ambient static pressure taps was read at least four times so that the mean of those readings would give time-averaged values of the piezometric pressures even when they had been fluctuating. Such fluctuations, when present, amounted to no more than 3/10 to 5/10 of an inch.

3. Results

The measured loss of piezometric head between the ambient and each of the stations 1 to 5 on the model for various flow rates is summarized in Table II-1. As station 5 is located near the bottom of the riser, the loss between the ambient and that station represents the maximum loss occurring in the riser.

A graphical presentation of the data in Table II-1 is given in Section III, Figs. III-11 through III-15.

The velocity head at the bottom of the riser at station 5 will be used to normalize the piezometric pressure loss at the various stations and arrive at the value of the piezometric pressure drop coefficient defined by the equation

$$K_{pi} = \frac{(p_o/\gamma + Z_o) - (p_i/\gamma + Z_i)}{V_5^2/2g} \qquad (1)$$

where

p = static pressure,

Z = elevation,

γ = specific weight of water,

g = acceleration due to gravity, and

V_5 = mean velocity at station 5.

Subscript o refers to the ambient and subscript i refers to the station number.

The Reynolds number computed for the flow cross-section at station 5 was used as the dimensionless parameter with reference to which the piezometric

TABLE II-1

Piezometric Head Loss in the 1:12 Riser Model.

Flow Rate Q cfs	Piezometric Head Loss in Inches of Water				
	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
0.332	29.2	28.3	28.1	28.3	28.1
0.330	29.2	28.5	28.0	28.3	28.2
0.311	26.5	26.1	25.8	26.0	25.8
0.310	25.5	25.2	24.7	25.0	24.8
0.295	24.5	24.0	23.6	23.8	23.7
0.290	24.0	23.8	23.2	23.5	23.3
0.283	22.4	22.0	21.6	21.7	21.6
0.263	20.7	20.3	20.0	20.2	20.0
0.263	20.3	19.9	19.7	19.8	19.7
0.238	17.4	16.9	16.6	16.8	16.7
0.238	17.4	16.6	16.4	16.6	16.4
0.217	13.8	13.6	13.3	13.4	13.2
0.215	14.0	13.6	13.5	13.6	13.5
0.200	12.6	12.3	12.1	12.1	12.0
0.195	12.6	12.4	12.2	12.1	11.9
0.172	10.1	9.7	9.7	9.6	9.5
0.171	10.6	10.4	10.1	10.1	9.9
0.145	8.6	8.5	8.3	8.3	8.1
0.140	7.5	7.2	7.2	7.2	7.0
0.117	6.1	6.0	5.8	5.8	5.6
0.111	4.1	4.0	4.0	4.0	3.9

headloss coefficients of the riser will be studied and presented. This Reynolds number is defined as

$$R_{e_5} = \frac{V_5 D_5}{\nu} \qquad (2)$$

where D_5 is the diameter of the flow cross-section at station 5 and ν is the kinematic viscosity of water.

The values of the piezometric pressure loss coefficients for station 2 to 5 are given in Table II-2. The same data is shown plotted in Section III, Figs. III-15 through III-18.

The results indicate that the piezometric headloss through the riser is substantial and that it is also Reynolds number dependent.

Much of the headloss in the riser is caused by the flow from the projecting cone-shaped pipe inlet inside the screen into the vertical riser. Computations show that the riser headloss is very sensitive to the contraction coefficient, and the contraction coefficient of a separated flow is sometimes related to the flow Reynolds number. The piezometric pressure drop coefficients representative of the prototype, must be determined at the proper Reynolds number. For water temperatures between 32°F and 70°F, and a withdrawal rate of 29.4 cfs per riser, the prototype Reynolds number will vary from 500,000 to 1,000,000. Straight line extrapolation of the available data gives loss coefficients from 2.6 to 3.6. However, a straight line extrapolation is probably too optimistic. As Reynolds numbers get higher, the piezometric pressure drop coefficient, K_p, will tend towards an asymptotic and constant value. An extension of the data base was necessary before a definitive value of K_p for the prototype could be given. Data from a 1:3 scale model described in the next section provided such an extension.

TABLE II-2

Piezometric Pressure Loss Coefficient for Stations
1 to 5 in the 1:12 Riser Model.

Reynolds Number Re_5 (10^5)	Piezometric Pressure Loss Coefficient				
	Sta. 1	Sta. 2	Sta. 3	Sta. 4	Sta. 5
1.44	6.34	6.15	6.11	6.15	6.11
1.39	6.42	6.26	6.16	6.22	6.20
1.35	6.57	6.45	6.40	6.45	6.39
1.30	6.38	6.30	6.16	6.23	6.18
1.28	6.76	6.61	6.48	6.54	6.52
1.22	6.84	6.76	6.61	6.70	6.64
1.20	6.72	6.57	6.45	6.48	6.46
1.14	7.15	7.03	6.91	6.98	6.93
1.11	7.03	6.88	6.81	6.85	6.82
1.03	7.38	7.15	7.03	7.11	7.06
1.01	7.38	7.03	6.94	7.03	6.94
0.93	7.26	7.03	6.99	7.04	7.00
0.92	7.03	6.91	6.76	6.81	6.72
0.85	7.95	7.80	7.68	7.62	7.50
0.85	7.53	7.38	7.26	7.26	7.19
0.74	8.68	8.49	8.27	8.27	8.11
0.73	8.18	7.84	7.88	7.80	7.69
0.63	9.83	9.72	9.46	9.46	9.23
0.59	9.14	8.80	8.76	8.76	8.56
0.51	10.68	10.53	10.16	10.16	9.80
0.47	7.95	7.76	7.79	7.79	7.58

III. PRESSURE MEASUREMENTS IN THE 1:3 SINGLE RISER MODEL

1. Objective

Pressure measurement tests were undertaken with the 1:3 scale riser model in order to extend the data base previously established by the 1:12 scale model tests; specifically to establish a definitive value of K_p, the piezometric pressure drop coefficient for the prototype. It was found by previous tests that the value for K_p is dependent upon the Reynolds number and that for the prototype, with water temperatures between 32°F and 70°F, and a withdrawal rate of 29.4 cfs per riser, the Reynolds number will vary from 500,000 to 1,000,000. Straight line extrapolation of existing data is probably inappropriate, for as Reynolds numbers get higher, the piezometric pressure drop coefficient, K_p, will tend towards an asymtotic and constant value. Therefore the value K_p, representative of the prototype, must be determined at the proper Reynolds number. At design flows in the 1:3 riser of 2.0 cfs to 6.4 cfs, at a water temperature of 70°F, the Reynolds number will vary from 200,000 to 700,000, well within the range experienced in the prototype.

2. Laboratory Experimental Set-up

The 1:3 single riser model was installed in the volumetric measuring basin at the St. Anthony Falls Hydraulic Laboratory. Fig. III-1 is a plan view of the facility and shows its general structure and orientation to the Laboratory proper. Fig. III-2 is a plan view of the installation of the 1:3 riser model in the facility. Water was supplied for the tests via the 20 inch main and 12 inch supply pipes shown. Fig. III-3 is a general photograph of the facility and Fig. III-4 is a close-up of the 1:3 riser installation. Fig. III-5 is a section view of the test set-up.

The water surface in the experimental tank was 2'6" above the axis of the screens. At a scale of 1:3 that dimension is the same as the distance from the lake bottom to the screen intakes in Lake Michigan (7.5 ft). It may therefore be considered that the effect of the free surface in the model and the lake bottom in the prototype represent similar flow confining boundaries for the external approach flow field to the screens, although a free boundary and a fixed one are not exactly the same in all respects.

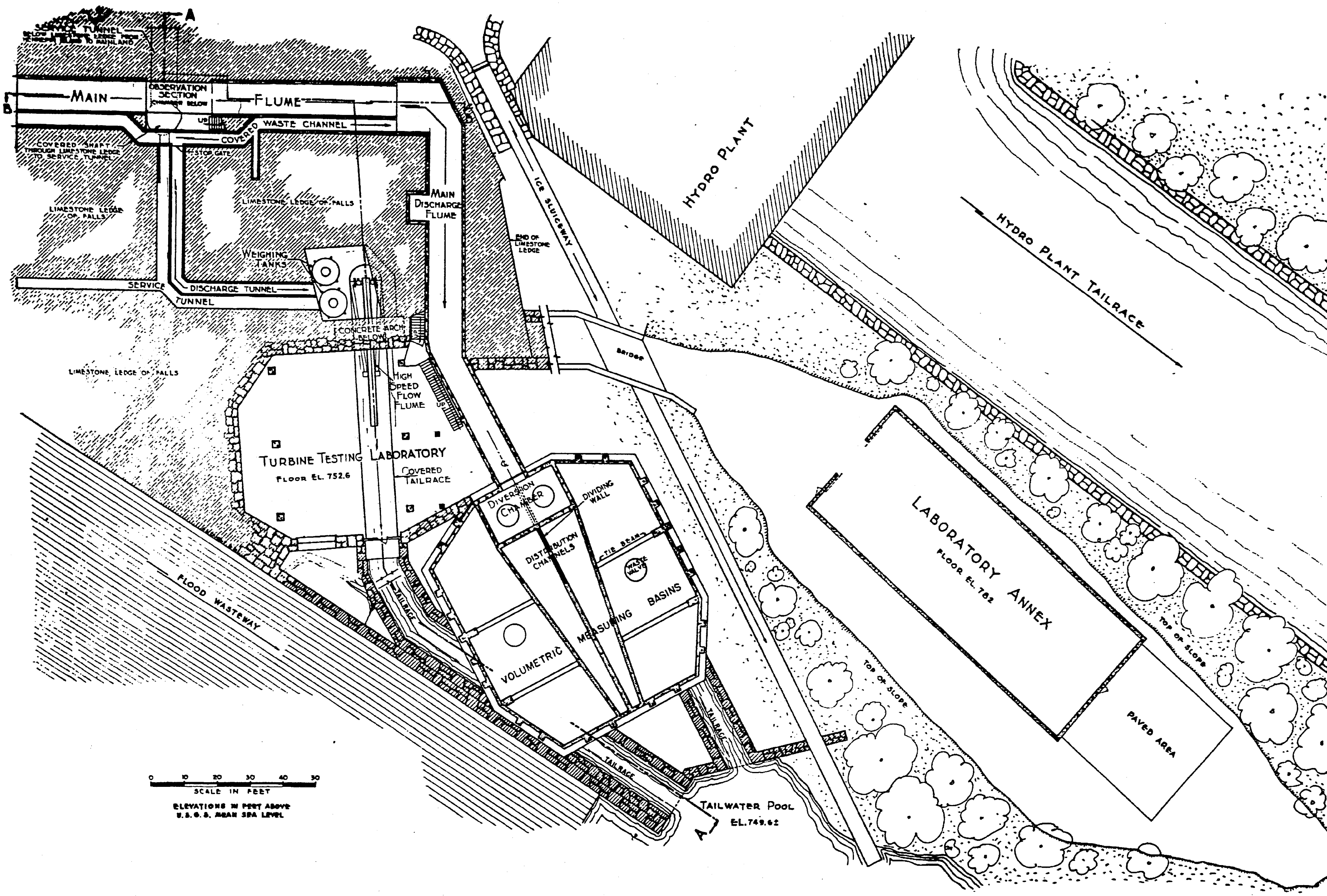


Fig. III-1. Plan View of Volumetric Measuring Basins.

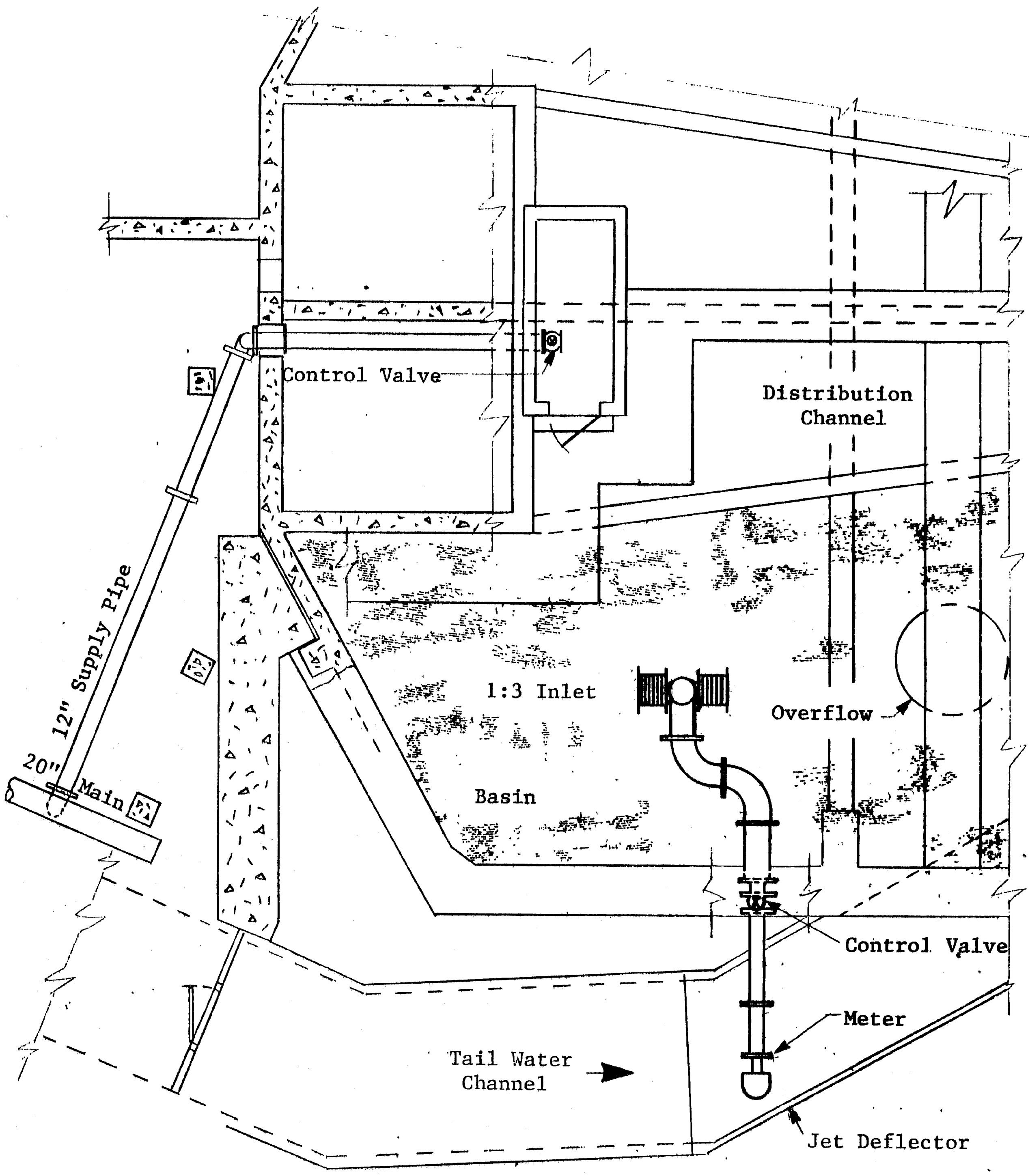


Fig. III-2. Plan View of General Installation of 1:3 Riser Model.

Fig. III-3. General View of the Volumetric Measuring Basins.

Fig. III-4. View of the 1:3 Riser Installation in the Basin.

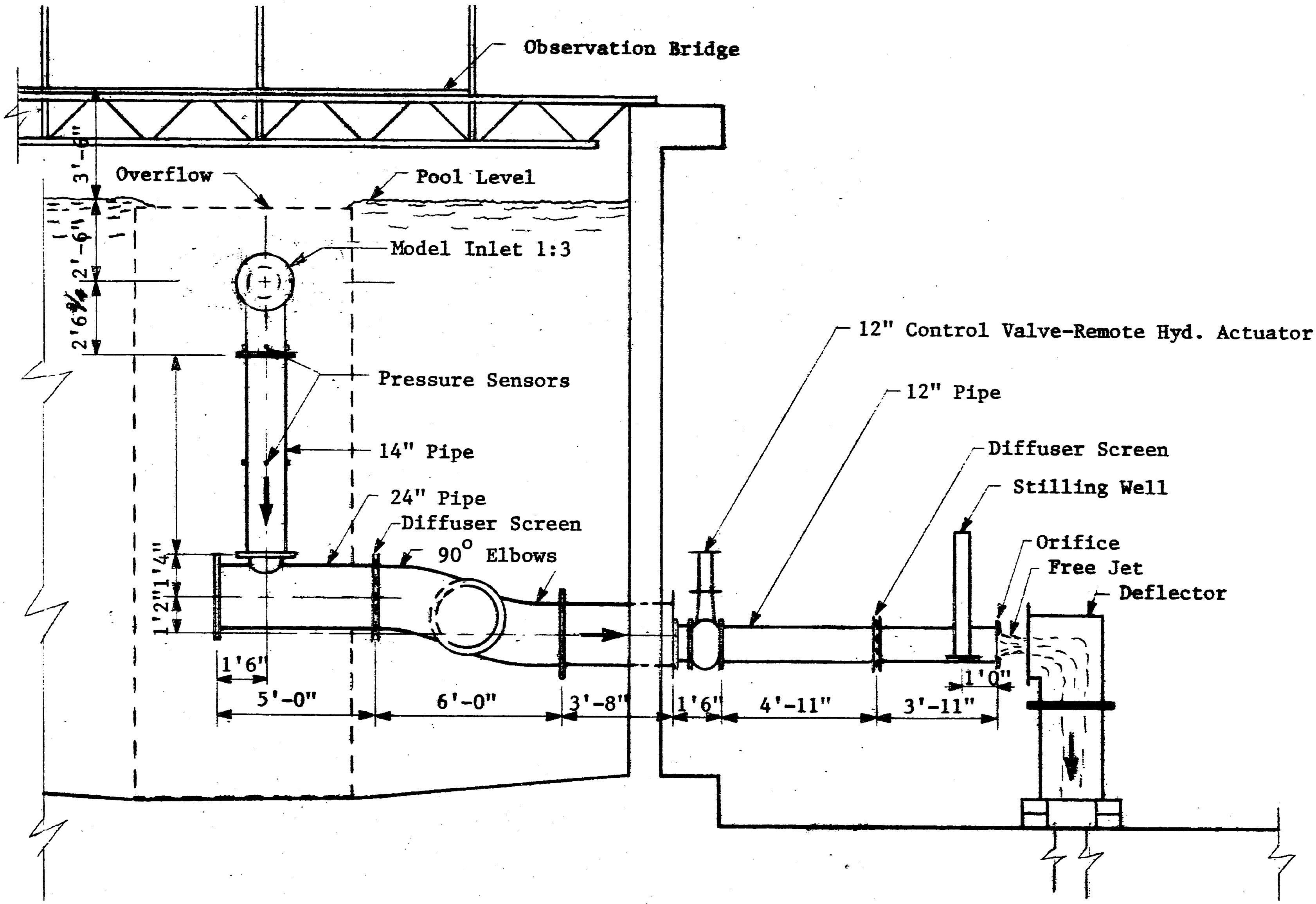


Fig. III-5. Section View of Test Set-Up for the 1:3 Scale Single Riser Model.

Flow through the 1:3 riser was controlled by a 12 inch remote hydraulically operated control valve and the discharge measured by a 9-1/2 inch free discharge orifice in the 12 inch line. Accuracy of measurement was ± 1%. Pool elevation and thus the total head on the model was kept at a relatively constant level throughout the course of the test by means of overflow into the main drain valve of the volumetric measuring basin. Fluctuation in pool elevation was estimated at a maximum of 3 in. from low to high discharge, representing less than 2% change in total head.

Diffuser screens were used at appropriate locations along the discharge piping in order to produce uniformity of velocity distributions upstream from the flow measuring device.

Piezometric pressures were measured at five locations identified in Fig. III-6. One additional static pressure tap was located in the pool. The results from station 5 give the cumulative effects of energy losses along the riser; the others give intermediate values.

At every station pressures were sensed through four interconnected wall taps. Each station was connected to a manometer board located in the control house above the basin. A constant suction head on the order of 7 ft was applied to the manometer board.

The test water was drawn directly from the Mississippi River. With the exception of the screening of debris through a mechanical travelling screen of 3/8 inch mesh, the water was used in its natural state. The water carried a small amount of color and suspended organic and mineral solids. The water temperature during the test period was about 70°F.

Figs. III-7 and III-8 are close-up views of the riser installation. Fig. III-9 illustrates the discharge plumbing and shows the hydraulically operated control valve and the free discharge orifice. The flow control and metering unit was assembled in the Laboratory and calibrated using the 40,000 lb weighing tanks. The unit was subsequently installed on the outside test facility as shown in Fig. III-5 and Fig. III-9.

Fig. III-10 shows pool conditions during normal operations and the overflow into the main drain valve of the volumetric measuring basin.

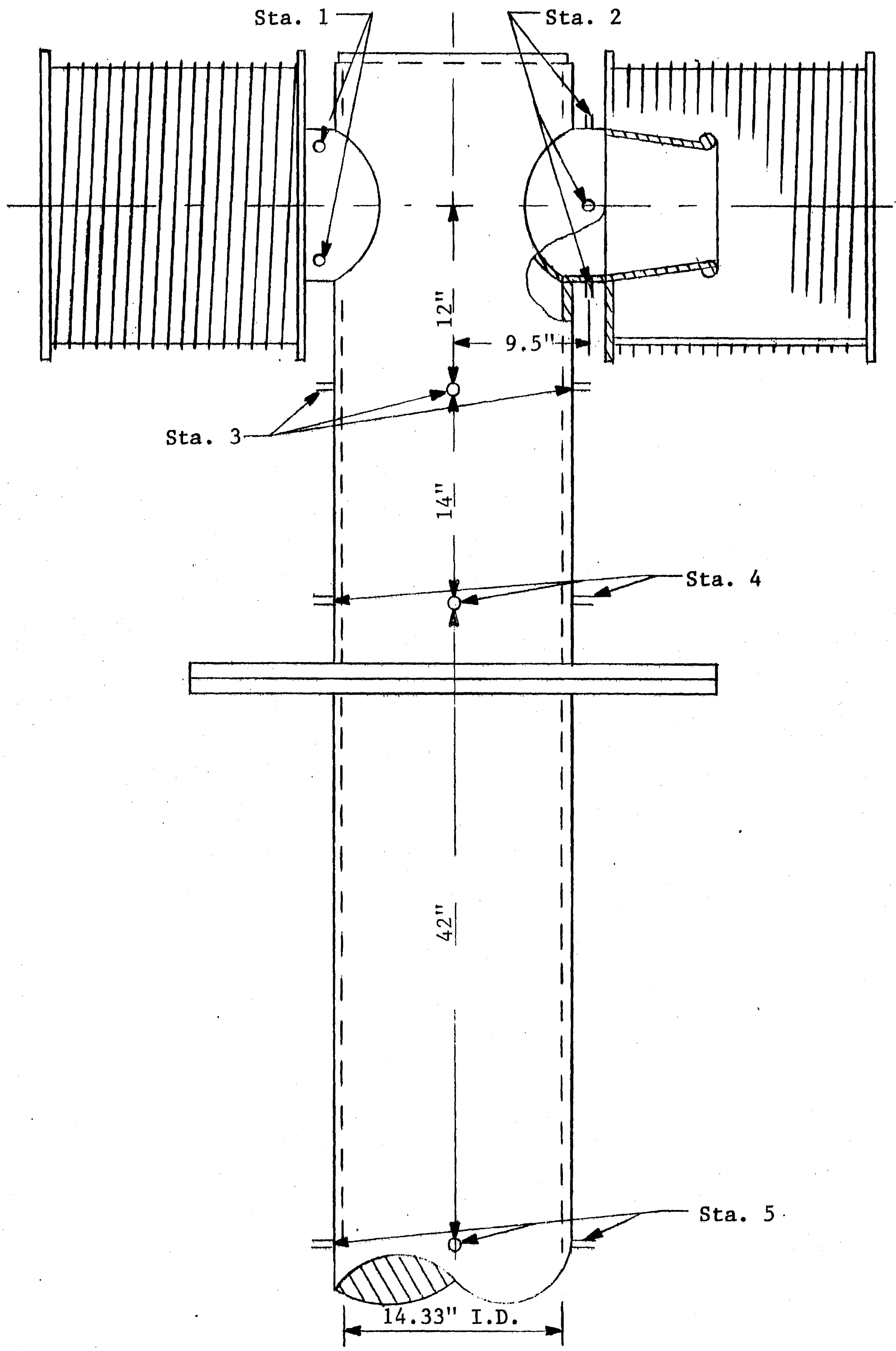


Fig. III-6. Location of Pressure Taps on the 1:3 Riser Model.

Fig. III-7. Close-up of Riser Installation.

Fig. III-8. Close-up of Riser Installation.

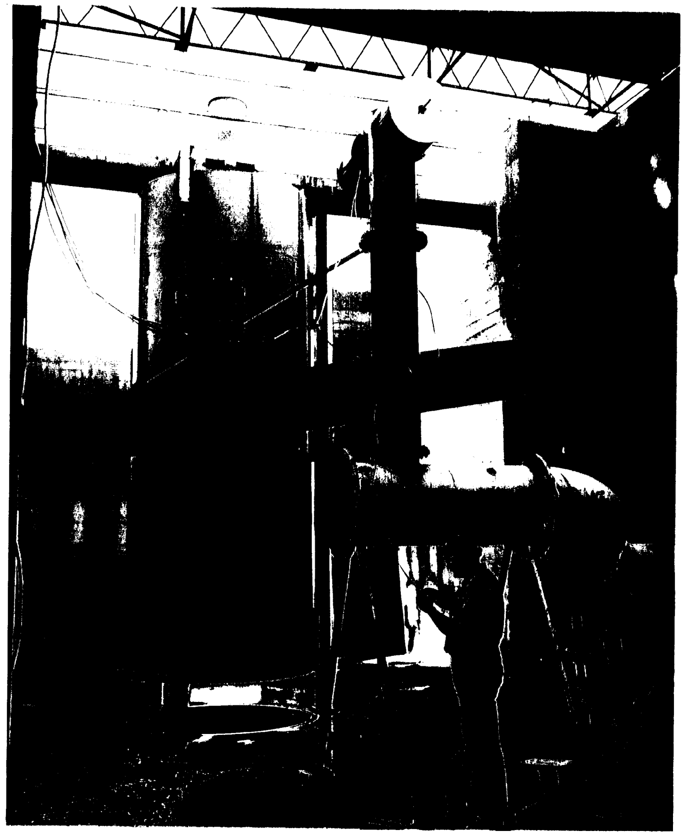


Fig. III-9. Discharge Plumbing.

Fig. III-10. Pool Conditions During Operation.

3. Procedures

Tests were begun by opening the supply valve fully and filling the volumetric measuring basin. When the basin was full and an overflow condition existed, the control valve on the riser was opened completely to discharge any trapped air in the system. After a period of time, the main supply valve was slowly closed down until the overflow was reduced to a very low level, thus reducing overall turbulence in the basin to a minimum. The main control valve for the riser was then closed, the manometers purged of air, and the zero checked.

A run was then initiated by opening the main riser control valve a small amount so that a low discharge was established. Generally through the course of these tests, data were taken from lower to higher discharge. The flow was then allowed to stabilize for a minimum of ten minutes and deflections on the manometer board read and recorded. During the course of the test, specifically at higher discharges, all manometer pressures were sometimes seen to concurrently drop abruptly and then rise back toward normal values. Periodically throughout the course of a day's run, water temperature was measured and recorded. After the piezometric pressures had been read, the discharge was increased by a small increment and the procedure repeated. This was continued until the maximum discharge had been attained.

4. Results

As stated previously in the description of the 1:12 scale riser tests, much of the headloss in the riser occurs between stations 1(or 2) and 3. Piezometric headloss data are presented in Figs. III-11 through III-14.

The piezometric pressure drop data have been reduced to dimensionless coefficients using Eq. 1 and plotted versus Reynolds number in Figs. III-15 through III-18. Both 1:12 and 1:3 riser data are plotted on the same graph.

At high Reynolds numbers the piezometric pressure drop coefficient, K_p, becomes nearly asymtotic. For station 5 it assumes a constant value of about 5.6 as seen in Fig. III-18. This value for K_p will be representative of the total piezometric headloss in prototype operation.

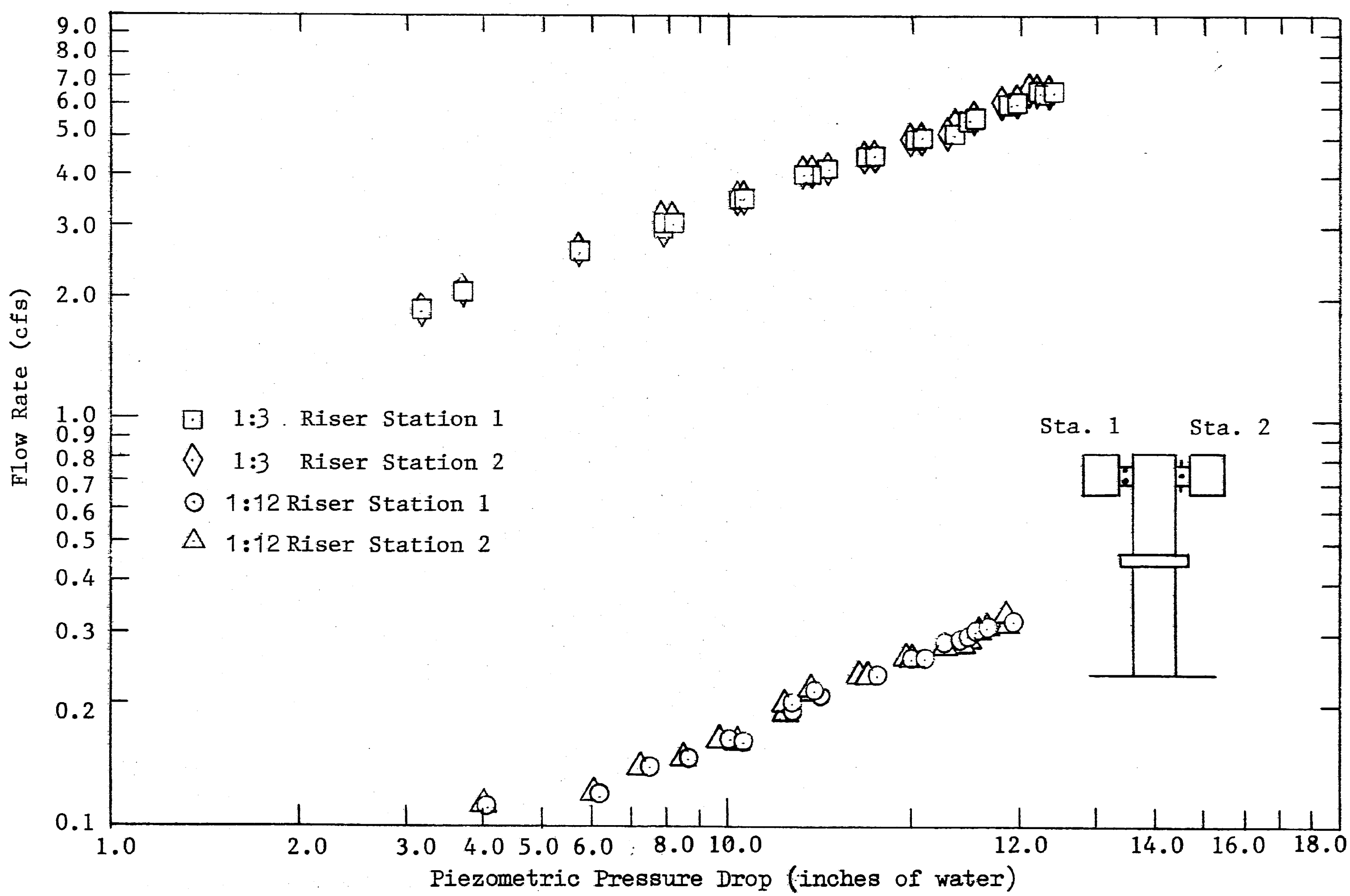


Fig. III-11. Piezometric Pressure Drop (Inches of Water) Between Ambient and Stations 1 and 2 (1:12 and 1:3 Riser Models).

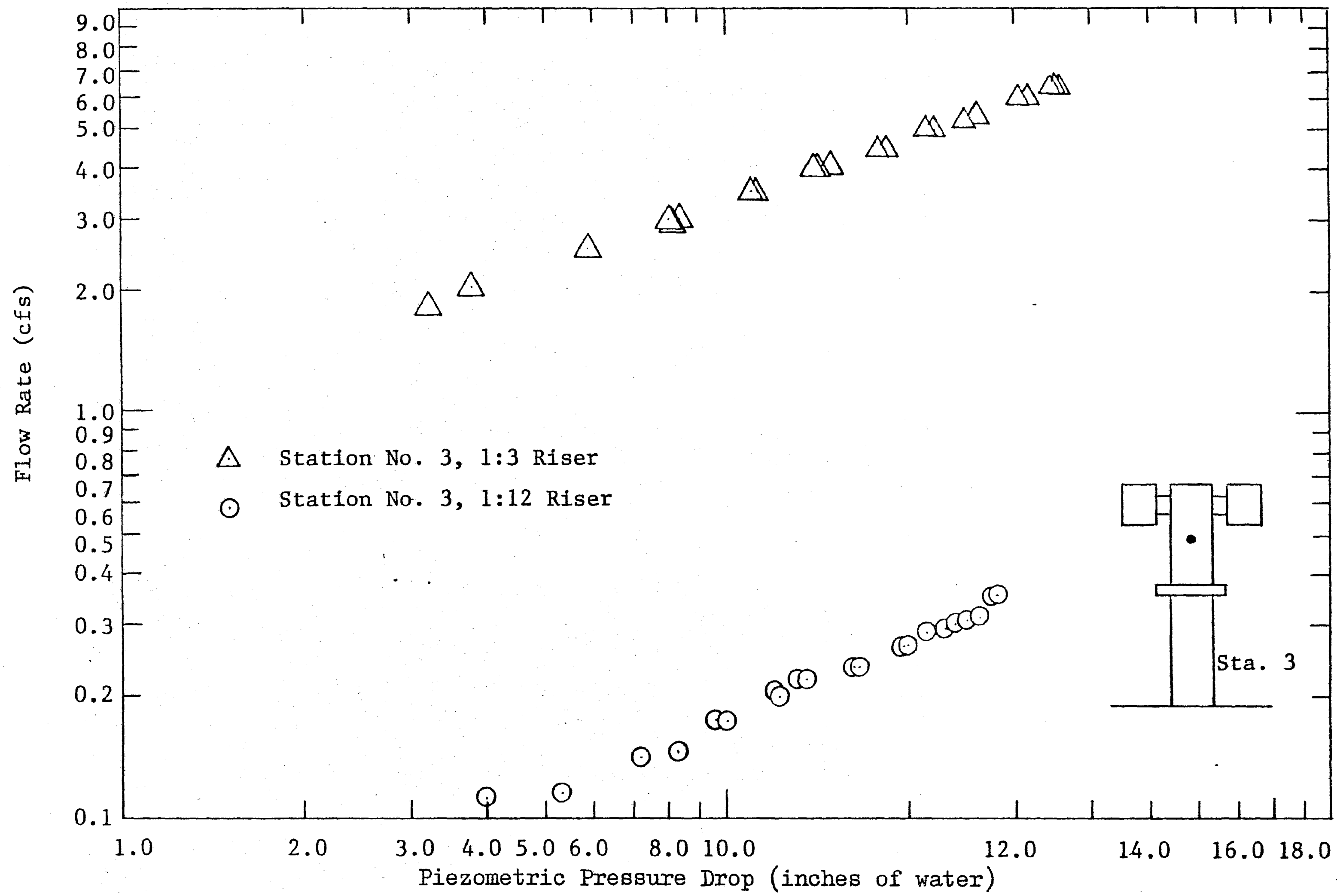


Fig. III-12. Piezometric Pressure Drop (Inches of Water) Between Ambient and Station 3 (1:12 and 1:3 Riser Models).

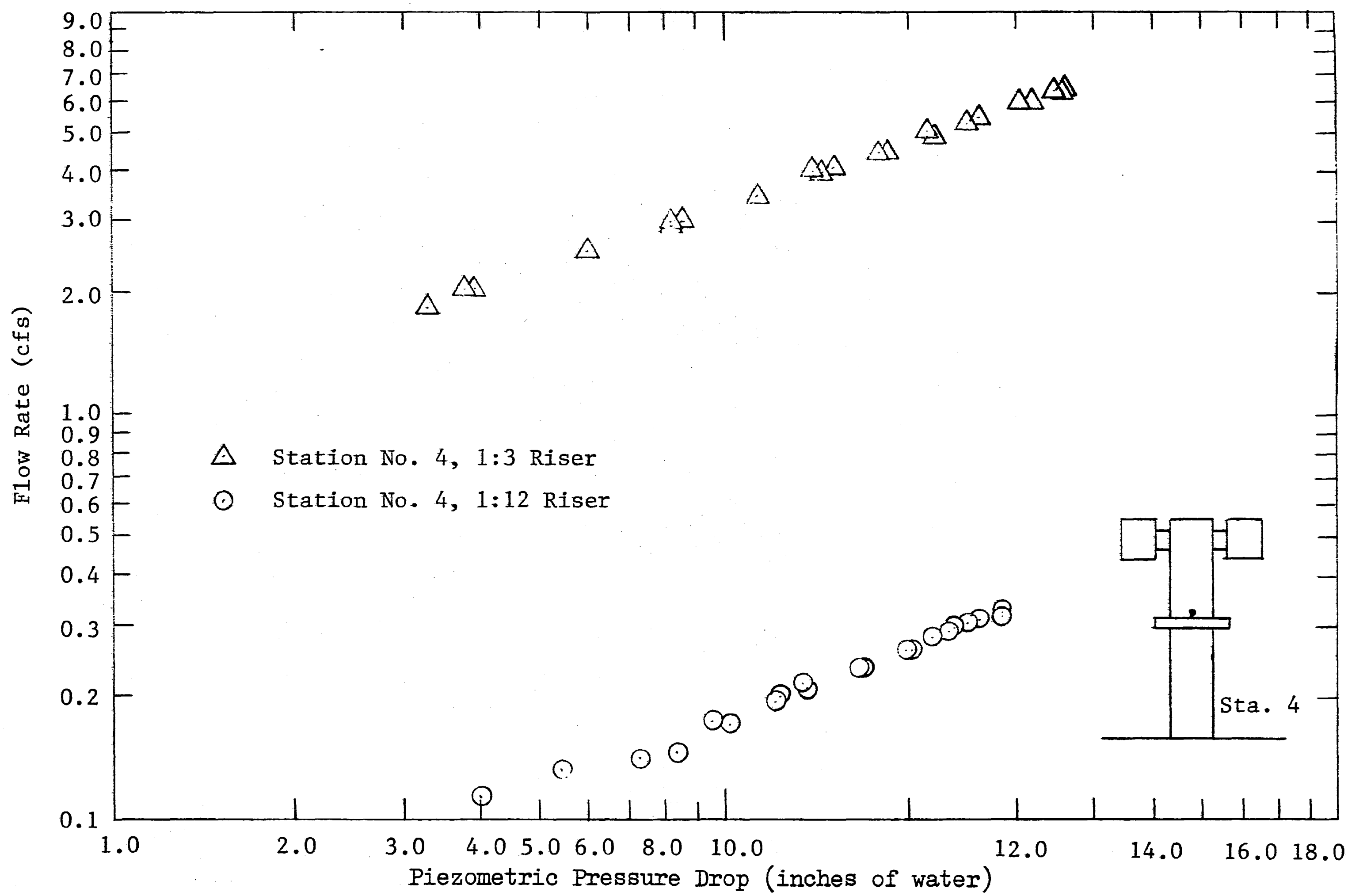


Fig. III-13. Piezometric Pressure Drop (Inches of Water) Between Ambient and Station 4 (1:12 and 1:3 Riser Models).

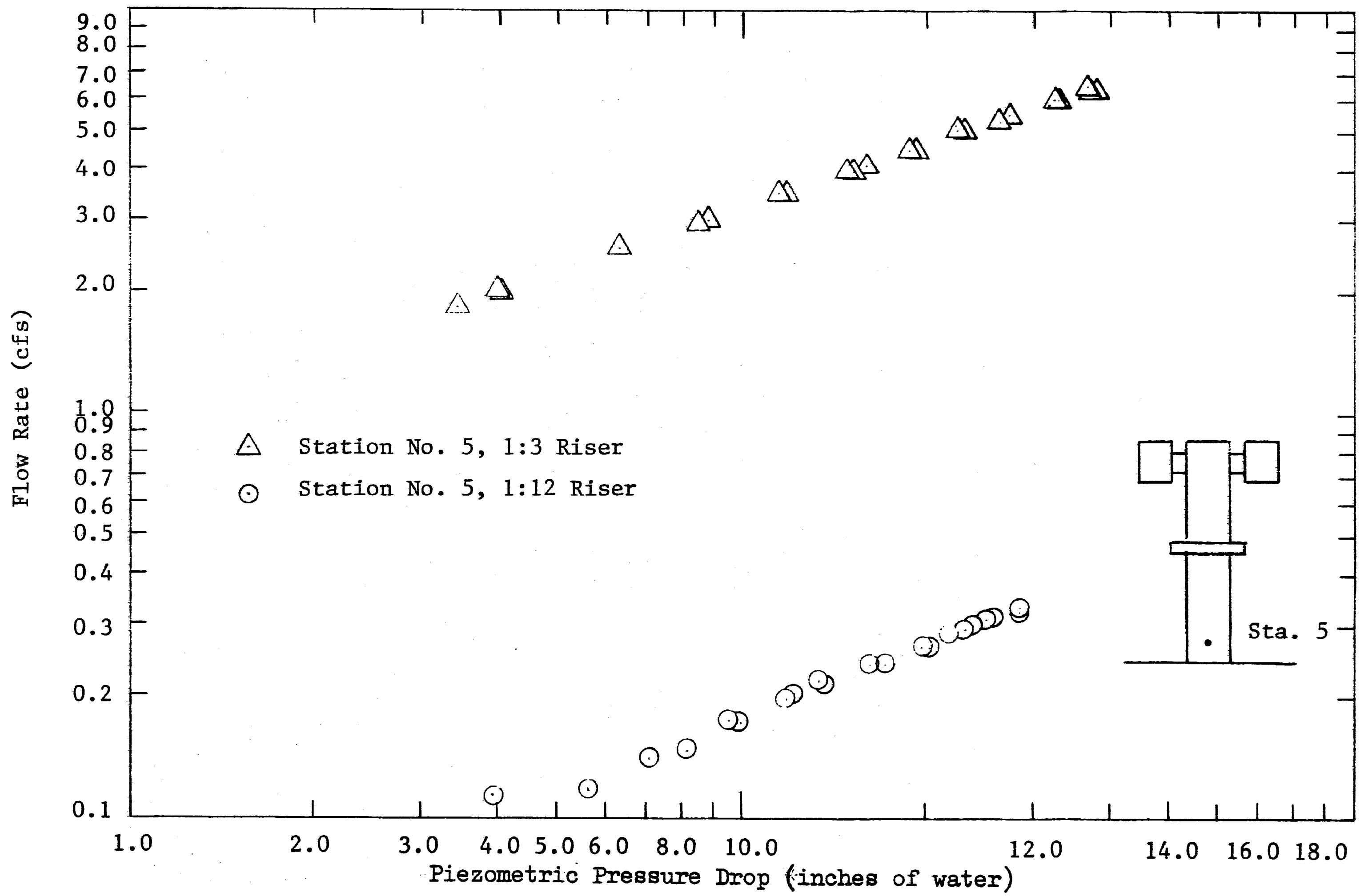


Fig. III-14. Piezometric Pressure Drop (Inches of Water) Between Ambient and Station 5 (1:12 and 1:3 Riser Models).

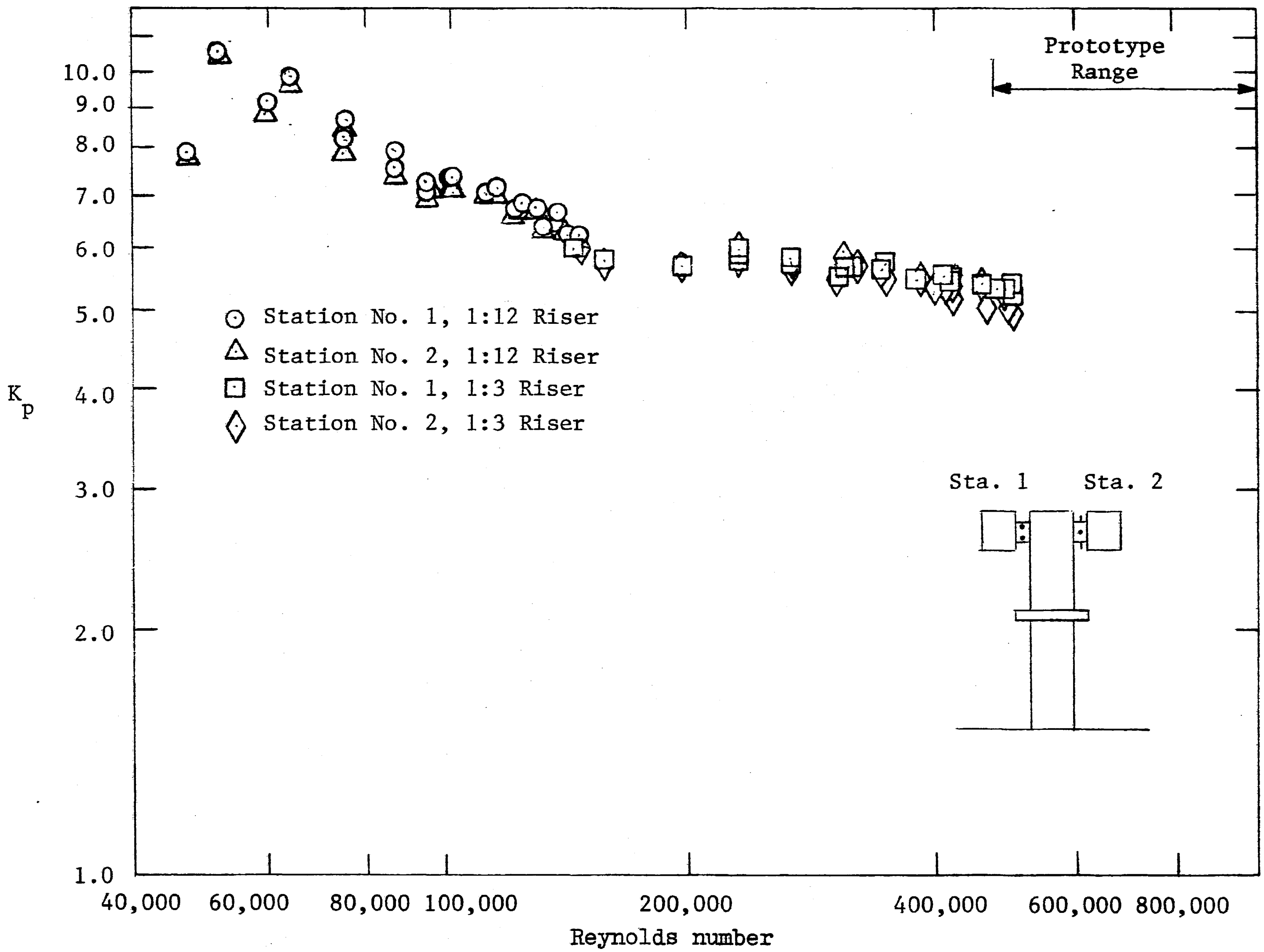


Fig. III-15. Piezometric Pressure Loss Coefficient vs. Reynolds Number at Stations 1 and 2 in the 1:3 Riser Model and 1:12 Riser Model.

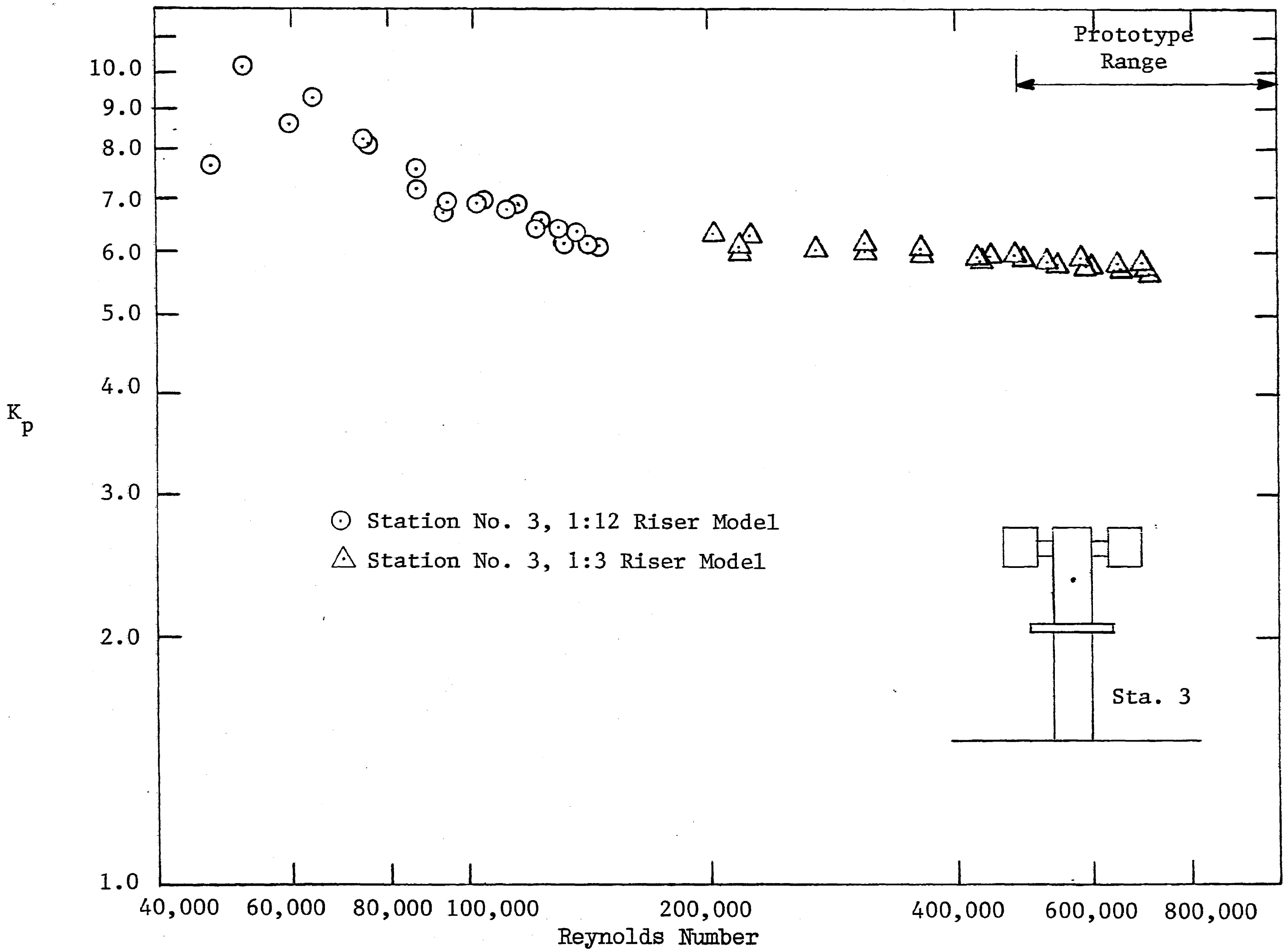


Fig. III-16. Piezometric Pressure Loss Coefficient vs. Reynolds Number at Sta. 3 in the 1:3 Riser Model and 1:12 Riser Model.

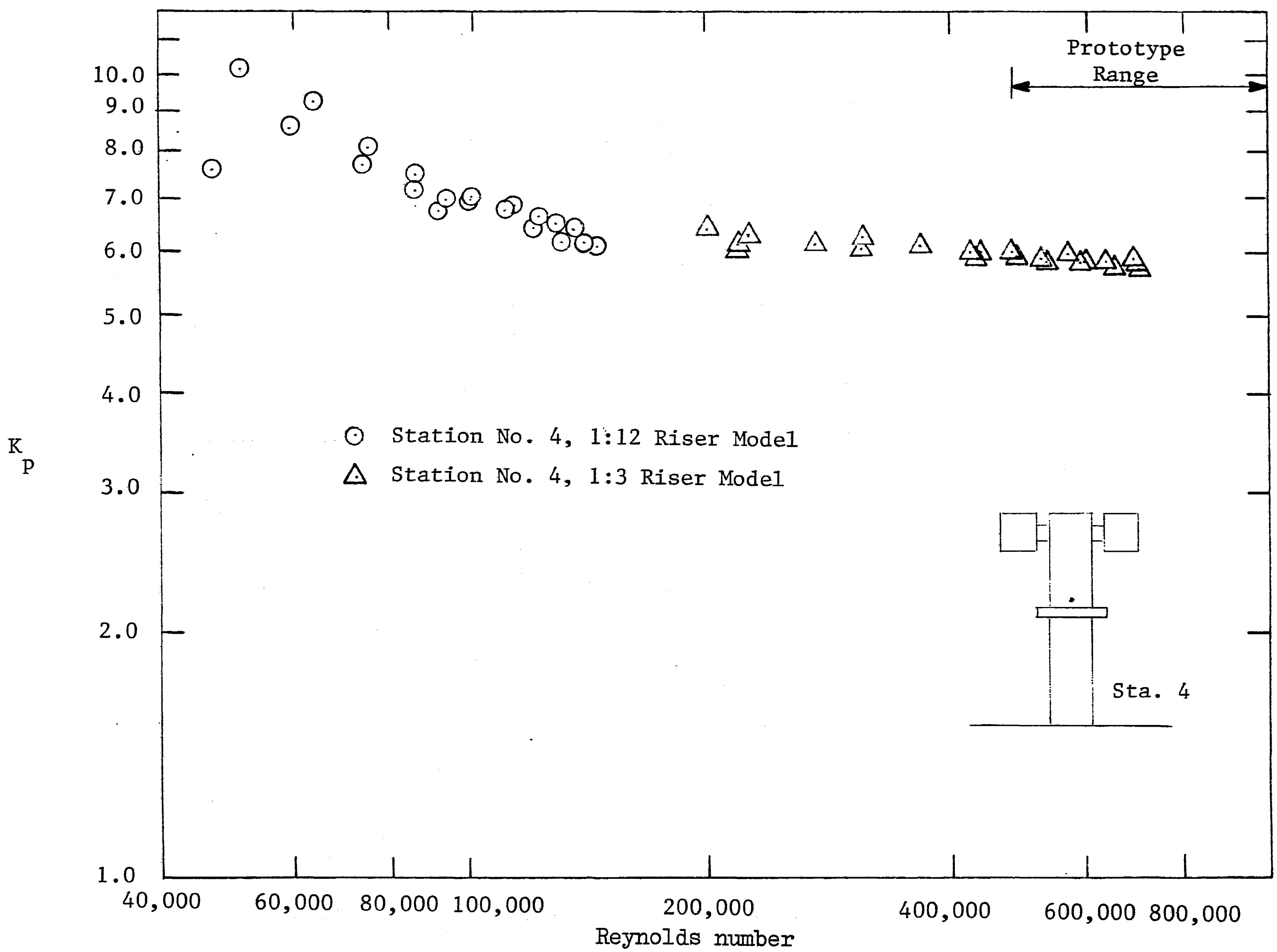


Fig. III-17. - Piezometric Pressure Loss Coefficient vs. Reynolds Number at Sta. 4 in the 1:3 Riser Model and 1:12 Riser Model.

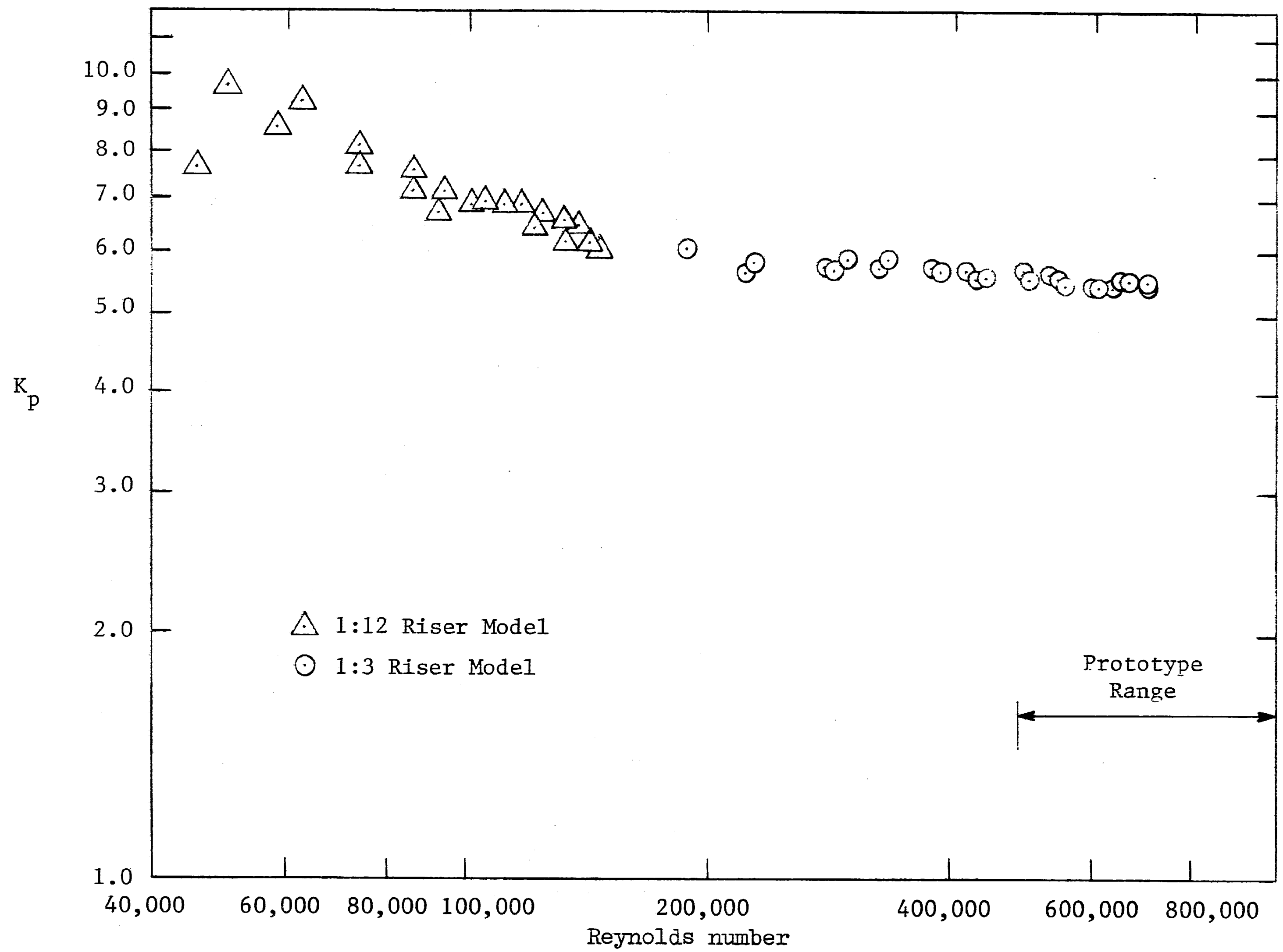


Fig. III-18. Piezometric Pressure Loss Coefficient vs. Reynolds Number at Sta. 5 in the 1:3 Riser Model and 1:12 Riser Model.

IV. APPLICATION OF MODEL PRESSURE DATA TO FULL-SCALE RISER

The prototype design flow in a single riser is 29.44 cfs in a pipe of 42 in. diameter at station 5. The mean flow velocity $V_5 = 3.06$ ft/sec. Using the piezometric pressure loss coefficients from Figs. III-16 through III-18, the piezometric pressure heads at stations 1 through 5 are computed to be as follows:

Station No.	K_p	Piezometric head with reference to lake stage (inches of water)
1, 2	5.2	-9.1
3	5.7	-9.9
4	5.8	-10.1
5	5.6	-9.8

The total energy headloss from the lake through the riser to station 5 will be 8.0 inches.

If the flow in a riser differs from the design flow, the piezometric pressure head and the total energy headloss can be recomputed with the coefficients from Figs. III-16 through III-18.

V. FLOW VISUALIZATION EXPERIMENTS WITH THE 1:12 SCALE RISER MODELS

1. Objective

The cooling water intake for the Campbell Power Plant on Lake Michigan is unique in that it consists of seven screened risers on each of four headers, with the headers conveying the water to a central collector well and a withdrawal pipe. The overall model program was concerned with detailed information on the various components of the system such as headloss through the screens, the risers, the headers, the collector well, and the withdrawal pipe, and the measurement of velocities by the riser screen using a current meter. These studies were intended to give results of a quantitative nature. The objective of the program described in this section was to conduct flow visualization experiments and to qualitatively observe the flow streamlines and velocity patterns to the risers. It was convenient to conduct these studies in one of the Laboratory's glass-sided channels with a model scale of 1:12. Flow observations were made using red dye, red unity oil, and paper confetti to show the flow and velocity patterns. The results were documented by photography.

The prototype discharge is 29.44 cfs per riser. The model discharge was computed to be 1/144 th of the prototype or 0.204 cfs per full riser. This would make the velocity values identical in model and prototype. In the first tests with the two half risers and one full riser the model discharge was 0.408 cfs, and for the half riser tests it was 0.102 cfs.

Observations were made with symmetrical flow (S) in which the flow entered the test section uniformly from both left and right, and asymmetrically (AS1) in which all the flow entered from the left. In some tests the asymmetrical flow (AS2) was increased by about 50%. The excess flow spilled over the bulkhead.

2. Laboratory Experimental Set-up

The 1:12 riser model was installed in the St. Anthony Falls Hydraulic Laboratory 20-in. wide glass-sided channel. For the first visual experiments the riser geometry consisted of a one-half riser against the front glass panel, a full riser in the center of the channel, and a one-half riser against the back panel. The long axis of the screens was oriented parallel to the channel sides as shown in the sketch on Fig. V-1 and the photos of Fig. V-2. The riser models were fabricated by the Johnson Division UOP, Inc. and installed by Laboratory shop personnel. The riser models were installed in the center of one glass panel for good visibility and on a false floor, providing a box under the models. The flow drawn into the screen intakes would pass through the box to five 2-1/2 in. withdrawal pipes and control valves, which were used to adjust the outflow equal to the inflow and maintain a constant depth of water simulating the lake (Fig. V-1). The inflow from the Laboratory supply channel enters the 20-in. test channel through a 12 in. supply line and control valve and flows over a calibrated weir used for metering purposes (Fig. II-4). The inflow passes under a sluice gate into the test section (left side of Fig. V-1). A bulkhead at the downstream end of the test section (right side in Fig. V-1), confines the water in the test section simulating the lake. To better represent the prototype situation where flow to the intakes would come from all directions, two pumps were installed in the test section at the upstream end, or left, to pump one-half of the inflow through overhead pipe lines to the downstream end, or right, thus providing symmetrical water supply to the screen intakes. For

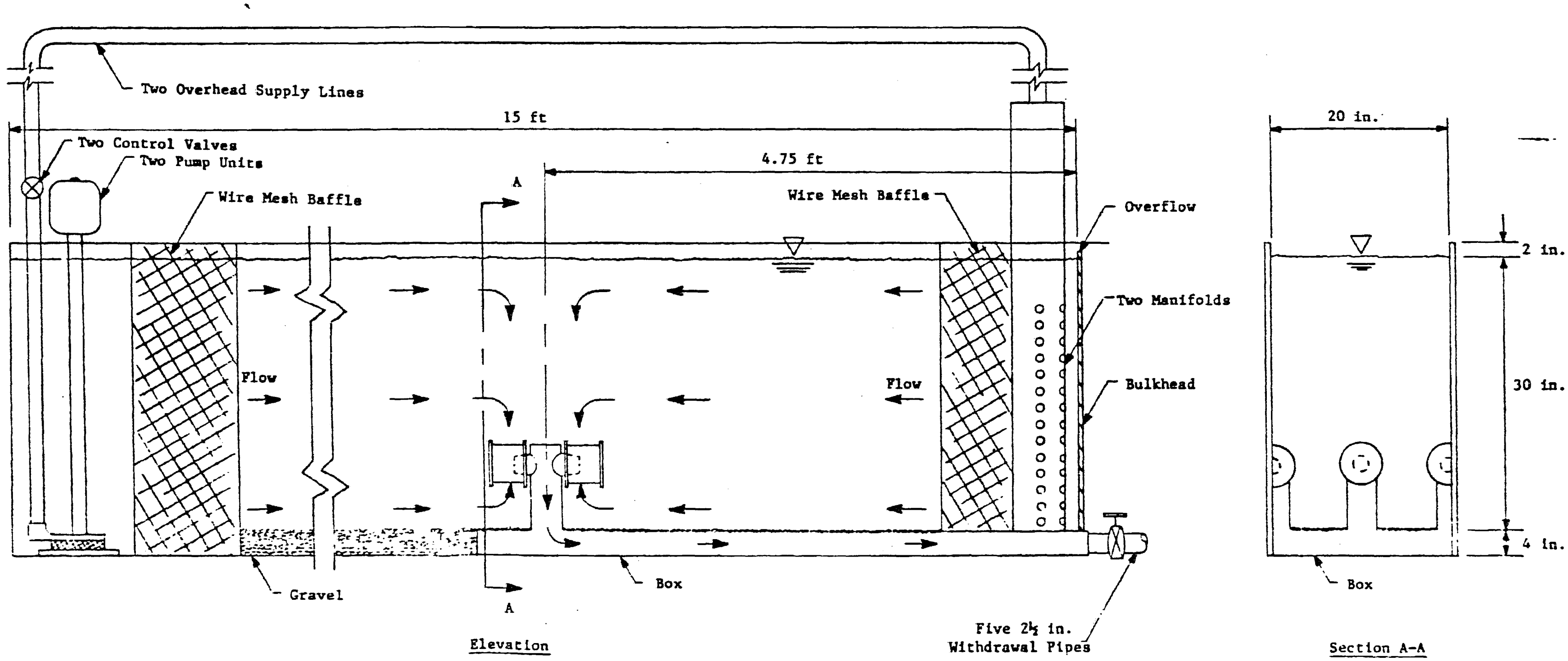
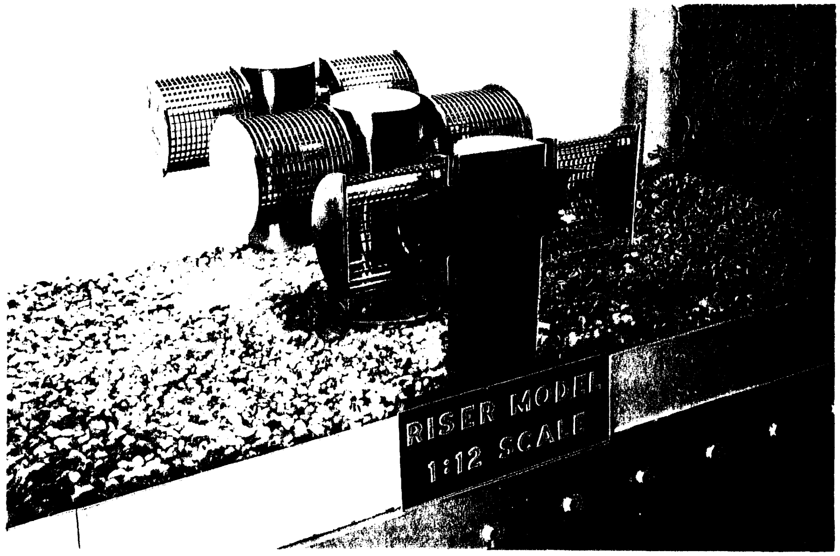
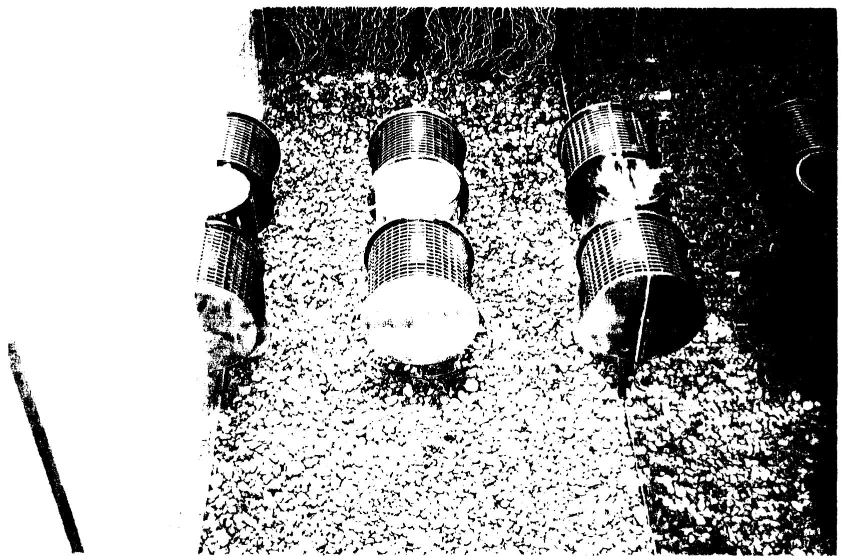


Fig. V-1 - Test Section for the 1:12 Scale Riser Model Installed in the 20 in. Glass-Walled Channel for Flow Visualization Experiments.

Fig. V-2. The 1:12 Scale Riser Model Installed in the 20 in. Channel.


RISER MODEL
1:12 SCALE



asymmetrical flow, the two pumps were turned off and flow entered the test section from the left only; this would represent the situations when lake currents would be present. Wire mesh baffles were provided at both ends of the test section to reduce the turbulence in the inflow. The area to the left of the false floor was filled in with gravel. A layer of stones was placed over the false floor also to provide a level lake bed of uniform material.

3. Procedures

To operate the facility for the visualization studies the control valve in the supply line was opened and the desired discharge set, the flow then passed over the calibrated weir filling the test section. To maintain the predetermined constant level during the tests, the withdrawal control valves were adjusted. For the configuration shown in Fig. V-2 with three risers which consists of one full riser and two one-half risers, the model discharge was 0.408 cfs. For tests with configurations using only the one-half riser or one full riser, the model discharges were 0.102 cfs and 0.204 cfs, respectively.

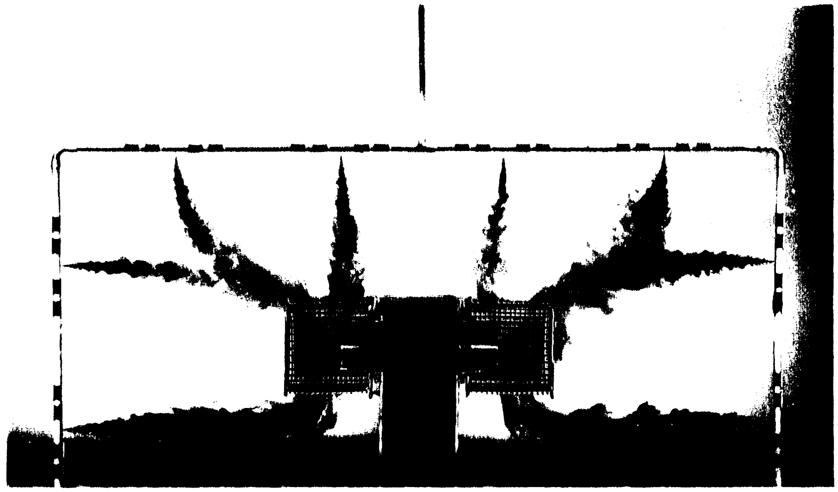
Observations were then made on four model configurations: (a) the three risers as shown in Figs. V-1 and V-2, (b) the one-half riser next to the front glass panel, (c) one full riser located centrally in the channel with the long axis parallel to the channel sides, and (d) one full riser located centrally in the channel but turned 90° so that the long axis was perpendicular to the channel sides. To visibly show the flow patterns to the intakes and make it possible to photograph them, various agents were used including red dye, unity oil, and confetti. To effectively show the overall pattern with dye, a multiple source dye system as shown in Fig. V-3 was made. It consisted of 3/8 in. copper tubes assembled in the form of an upside down U over the model with a central tube vertical to an overhead dye container. Eight 1/32 in. diameter holes were drilled at selected locations to release the dye around the intake. The dye was injected by gravity and the dye flow rate controlled with a valve. The dye system was movable so it could be placed near the glass wall as in Fig. V-3 or at various locations away from the glass. For observations at specific locations a single dye source was used. It consisted of a small diameter tube connected to an overhead dye supply. The red rhodamine dye was supplied as a water soluble powder and for these tests mixed with water to provide a solution with a specific gravity of

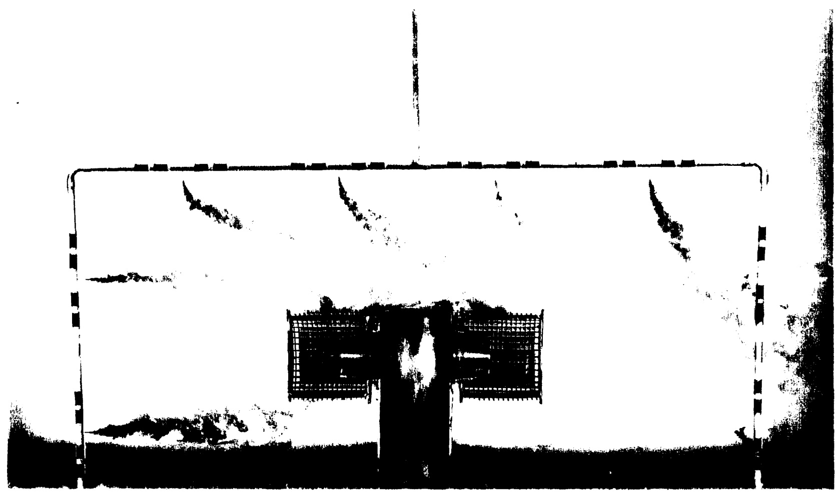
Symmetrical Flow (S)

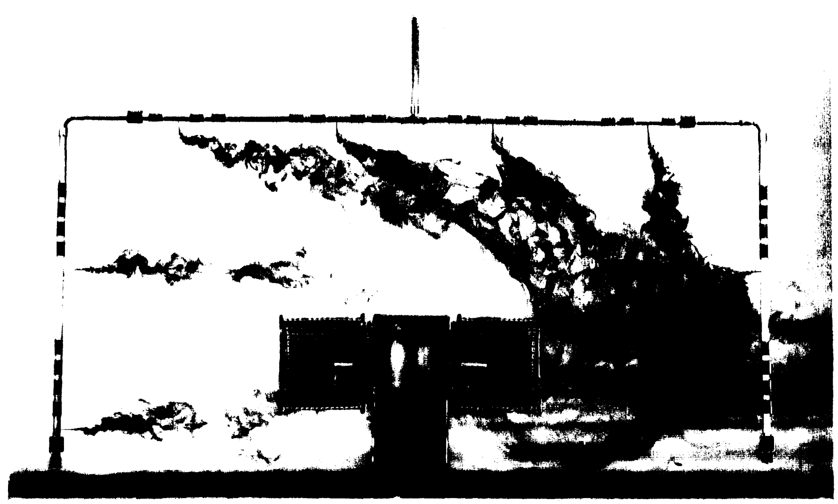
Asymmetrical Flow (AS1)

Asymmetrical Flow (AS2)

Fig. V-3. Three Risers, Multiple Dye Injected at Glass, Flow Patterns.







about 1.0 or the same as water; thus, the dye would not have any influence on the flow lines observed.

Another agent used was Meriam red unity oil, unity indicating it had a specific gravity of 1.0. Unity oil when injected into water through a small diameter tube forms small red spheres, the size of which depends on the tube diameter and the injection pressure. In the model tests the unity oil was injected just below the water surface in the test section and drawn to the intakes indicating the flow pattern. This technique was quite effective because the unity oil droplets are neutrally buoyant. The only force on the bubbles was due to the motion of the flowing water. The droplets not only indicated streamlines visually, but photographs of proper time exposure showed streaks which can be transposed to flow velocities. The droplets even if they are relatively large, will not clog the screen but deform and pass through. Nevertheless, the use of unity oil also presents some problems. It is difficult to get enough droplets simultaneously and uniformly in the test section. It also has a very potent smell.

Another agent which photographs very well is confetti and observations were made using this material. Confetti is simply paper punchings which is available in various sizes. For our tests confetti with a diameter of about 1/16 in. was selected so that it would pass through the screens and not clog them. The confetti was fed in by hand just below the water surface in the test section. It is convenient to use and much easier to distribute uniformly than unity oil. It does have the disadvantage that sometimes the particles are either lighter or heavier than water depending on the wetting characteristics. Because of the fall velocity of the particles one observes wrong flow patterns. This effect showed up along the edges of some confetti pictures.

The complete testing program is outlined in Table V-1. The flow rates and cross flow velocities are identified in Table V-2. Tests were documented with black and white still photographs, colored slides, and 16 mm colored movies. In photographs using unity oil and confetti to show streak lines, a timer with a disk rotating one revolution per second was located in the picture. The timer disk was marked with a white line which would sweep out a white sector of a circle, the size depending on the camera shutter speed. The exact exposure time can be determined by measuring the sector angle and dividing

TABLE V-1. Model Testing Program

Symmetrical flow (S) = water supplied equally from left and right

Asymmetrical flow (AS1) = water supplied from left only.

Asymmetrical flow (AS2) = water supplied from left and increased by 50% above withdrawal rate

Configuration	Visual Technique	Flow Conditions
three risers	multiple dye at glass	S, AS1, AS2
three risers	multiple dye between risers	S, AS1, AS2
three risers	multiple dye over center riser	S, AS1, AS2
three risers	single dye at glass	S
one-half riser	multiple dye at glass	S, AS1
one full riser axis parallel to channel	multiple dye over centerline	S, AS1, AS2
one full riser axis perpendicular to channel	multiple dye over centerline	S, AS1, AS2
one full riser axis perpendicular to channel	multiple dye over screen	S, AS1, AS2
three risers	unity oil	S, AS1
one-half riser	unity oil	S, AS1
three risers	confetti	S, AS1
one-half riser	confetti	S, AS1

TABLE V-2

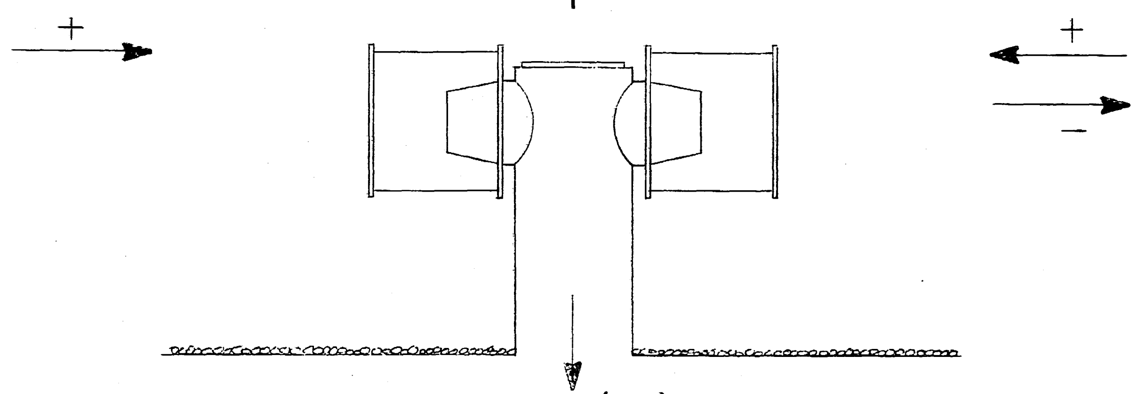
Cross Flow Velocities

FROM LEFT

Flow Condition	3 Risers		1 Riser		1/2 Riser	
	Q cfs	V fps	Q cfs	V fps	Q cfs	V fps
S	.204	.049	.102	.024	.051	.012
AS1	.408	.098	.204	.049	.102	.024
AS2	.600	.144	.300	.072	--	--

FROM RIGHT

Flow Condition	3 Risers		1 Riser		1/2 Riser	
	Q cfs	V fps	Q cfs	V fps	Q cfs	V fps
S	.204	.049	.102	.024	.051	.012
AS1	0	0	0	0	0	0
AS2	-.192	-.046	-.096	-.023	--	--



	Q(cfs)
3 Risers	.408
1 Riser	.204
1/2 Riser	.102

Note: Discharges given are for model and in cfs; velocities are for both model and prototype and in fps.

by 360°. Experience shows that the camera shutter speed will vary; the timer gives an accurate time for determining velocity values from streak lines.

4. Results

The initial observations on the 1:12 riser model were conducted using the multiple source red dye system to show the overall flow patterns to the screen riser. The first configuration investigated was with the three risers as shown in Fig. V-2. Fig. V-3 shows typical flow patterns to the riser with the dye injected at the front glass panel. The top photo shows the pattern with a symmetrical (S) prototype flow of 29.44 cfs per riser being simulated. The model discharge (Q_m) is 0.408 cfs. The streamlines are fairly symmetrical and give the pattern at one instant of time. Observations over a longer period of time show that the flow patterns will vary somewhat. The top photo of Fig. V-4 shows a close-up view of the same flow condition at a later time with a slightly different pattern.

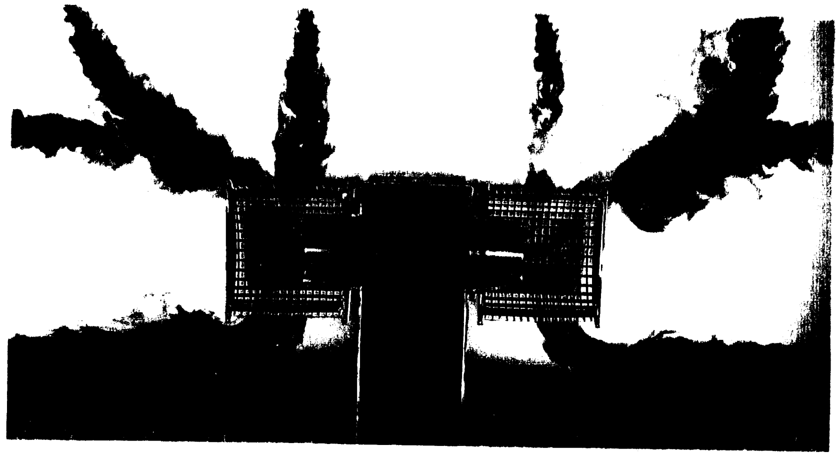
In the middle photo the pumps have been turned off so that the flow (Q_m = 0.408 cfs) is coming from the left or asymmetrical (AS1) with the resulting pattern shifted to the right. This photo was taken just after the dye injection was started. Eventually the dye from the 3 sources on the right would necessarily drift back toward the risers and cloud the picture. This is shown in the close-up view taken at a later time in the bottom photo of Fig. V-4.

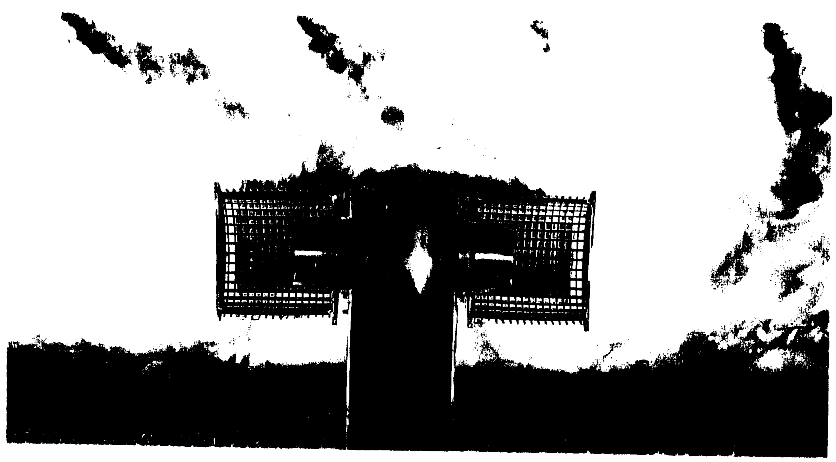
The bottom photo of Fig. V-3 shows a more distorted pattern when the asymmetrical flow (AS2) from the left is increased by about 50% (Q_m = 0.60 cfs). In this test the flow through the risers was kept the same (Q_m = 0.408 cfs) with the excess flow going over the downstream bulkhead. The photos of Fig. V-5 show flow patterns for the same 3 flow conditions from top to bottom, that is symmetrical (S), asymmetrical (AS1), and asymmetrical (AS2), but with the dye distribution line moved to a plane between the front and center risers. The photos in Fig. V-6 show the flow patterns for the same flow conditions with the dye injected along the centerline of the center riser. One can, for example, compare the top photos, middle photos, and bottom photos of Figs. V-3, V-5, and V-6 and see that the flow patterns at

Symmetrical Flow (S)

Asymmetrical Flow (AS1)

Fig. V-4. Three Risers, Multiple Dye Injected at Glass, Flow Patterns.



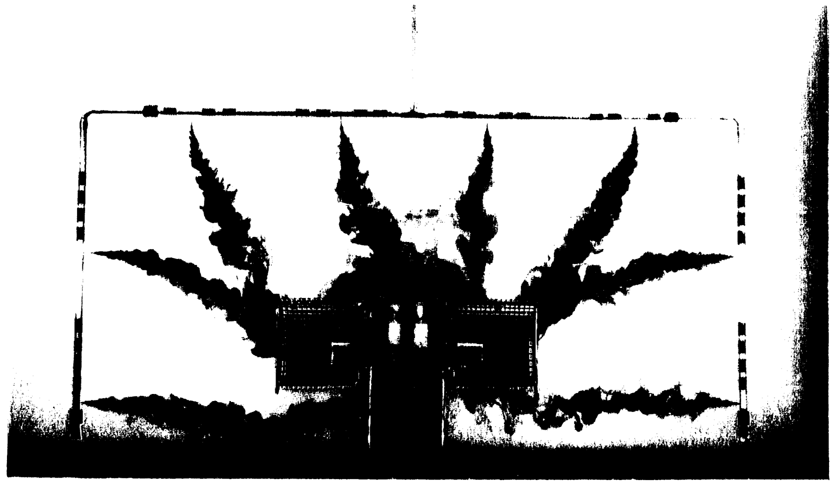


Symmetrical Flow (S)

Asymmetrical Flow (AS1)

Asymmetrical Flow (AS2)

Fig. V-5. Three Risers, Multiple Dye Injected Between Front and Center Risers, Flow Patterns.

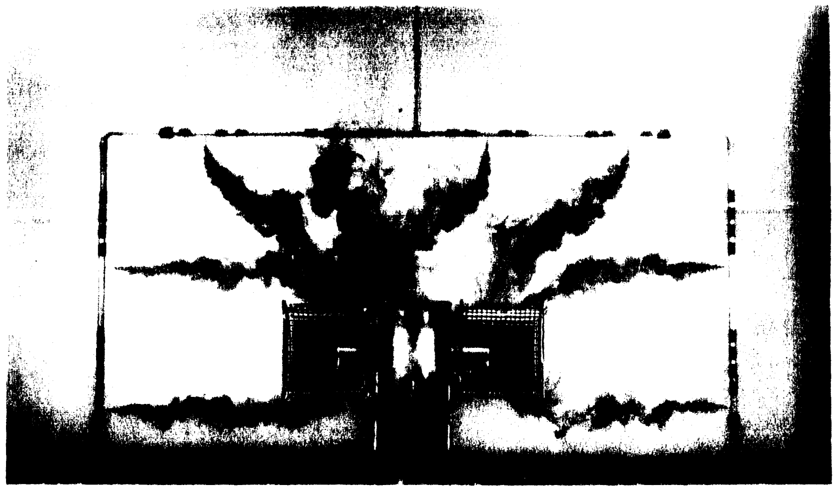


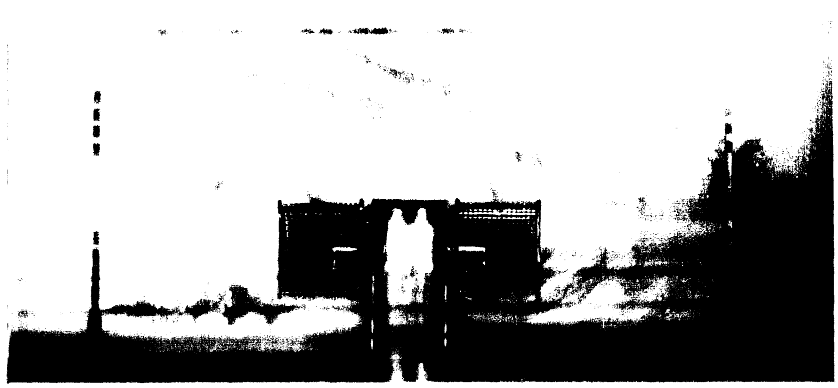
Symmetrical Flow (S)

Asymmetrical Flow (AS1)

Asymmetrical Flow (AS2)

Fig. V-6. Three Risers, Multiple Dye Injected Over Center Riser, Flow Patterns.





the three locations are quite similar, indicating minimal interference between the risers. Some variations are more noticeable. For example, comparing the three top photos, the top photo of Fig. V-6 shows the dye from the two top central dye sources drifting more to the left than the others. As stated before these patterns are shifting with time, and the patterns over the center riser tend to vary more than at the other two locations.

To increase the depth perception of the flow patterns photos were taken obliquely from the left. They are presented in Fig. V-7. In this figure the flow is symmetrical with dye injected along the glass (top), between the risers (middle), and over the center riser (bottom). Again the similarity is remarkable.

Figs. V-8 through V-11 show the flow patterns with symmetrical flow when a single dye source at selected locations is used. The resulting flow patterns in Figs. V-8 and V-9 are similar to those obtained with the multiple dye system, although the turbulence in the flow is more noticeable with the single source. This is probably due to the lower dye injection rate used in the single source. In Fig. V-10 the dye is injected close to the screen and delineates the flow conditions near the screen. The bottom photo clearly shows the flow streamline through the screen and nozzle. In Fig. V-11 the dye is injected inside the screen and delineates the flow streamlines through the nozzle. The flow through the nozzle does not follow the nozzle boundary everywhere but shoots more or less straight through from the leading edge, creating a zone of separation. This zone extends from about the leading edge of the nozzle into the dome of the riser pipe. Dye injected near the leading edge is drawn into the separation or lower pressure zone of both nozzles, illustrating the separation phenomenon. Because the dye is drawn into this separation area and diffused so rapidly,no good black and white photos could be obtained to illustrate this. The colored slides and movies demonstrate this more clearly.

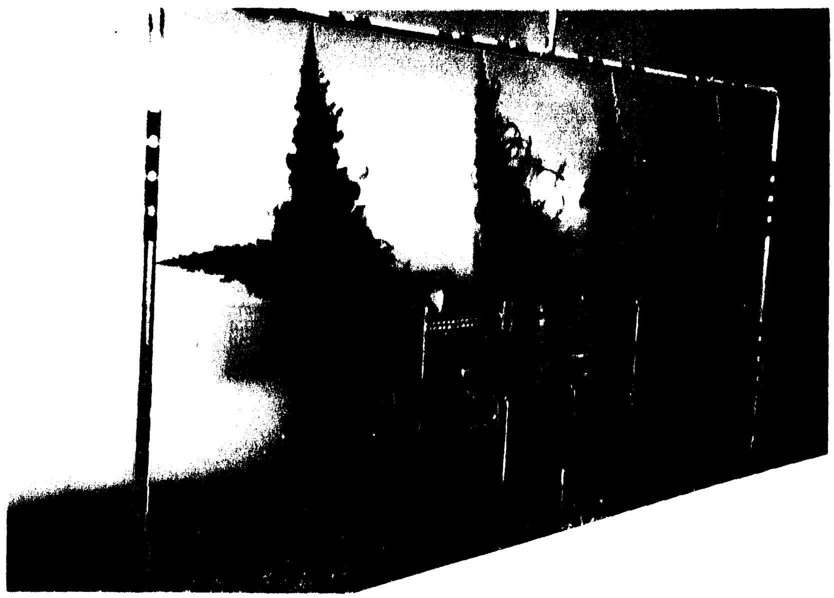
During the course of the model studies, it was observed that a swirl or vortex would occasionally occur on the water surface over the intakes. Dye fed in this swirl at the surface would be drawn down to the riser intakes as illustrated in Fig. V-12. This phenomenon occurs rather infrequently and is characterized by the swirling motion on the water surface with very little

Multiple Dye Injected at Glass

Multiple Dye Injected Between Front
and Center Risers

Multiple Dye Injected Over Center Riser

Fig. V-7. Three Risers, Symmetrical Flow (S), Flow Patterns.



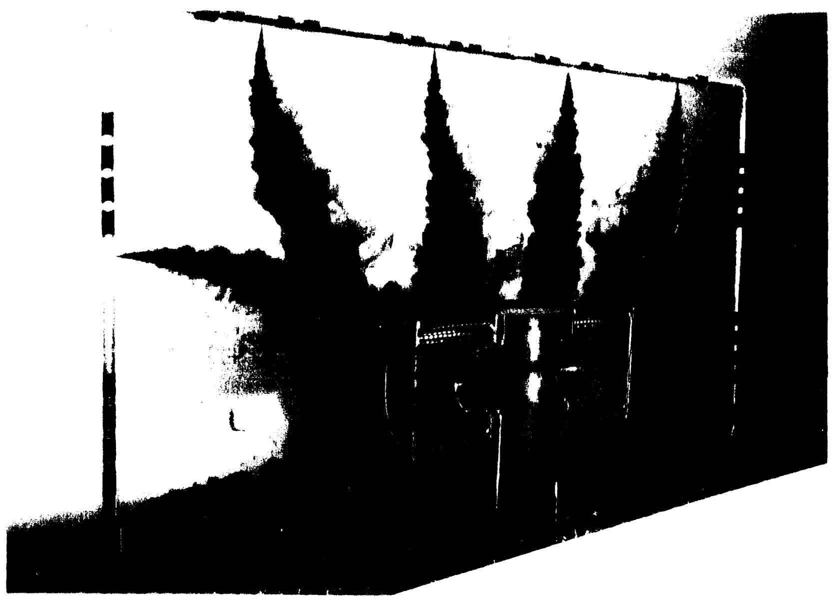
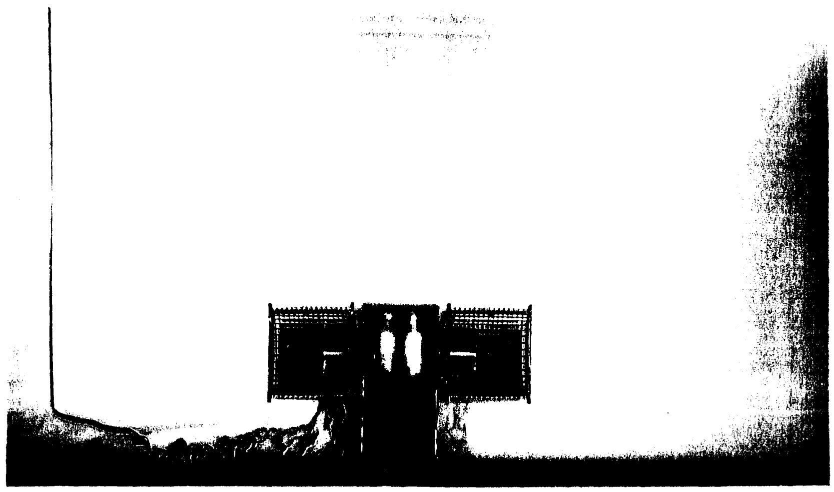


Fig. V-8. Three Risers, Symmetrical Flow (S), Flow Patterns with Single Dye Injected at Glass and on Left Side.



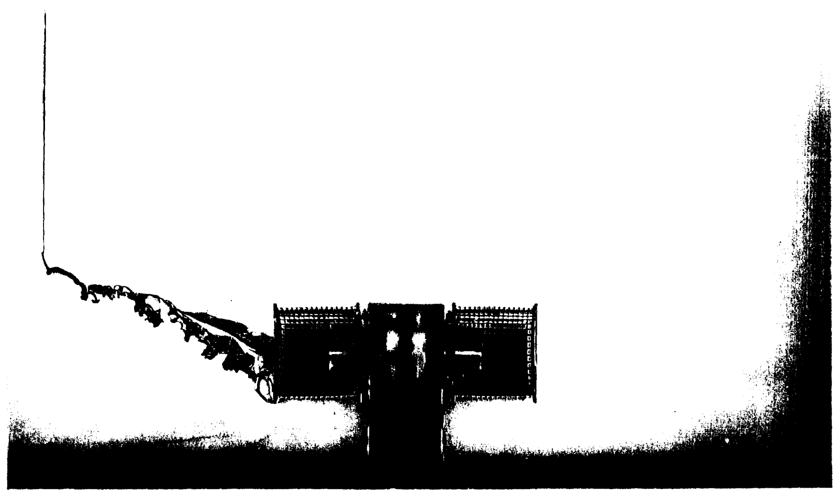
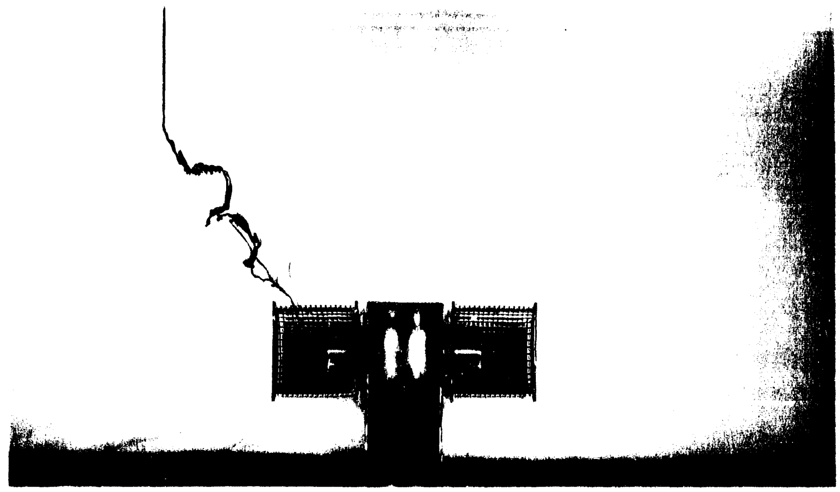


Fig. V-9. Three Risers, Symmetrical Flow (S), Flow Patterns with Single Dye Injected at Glass and Over the Riser.



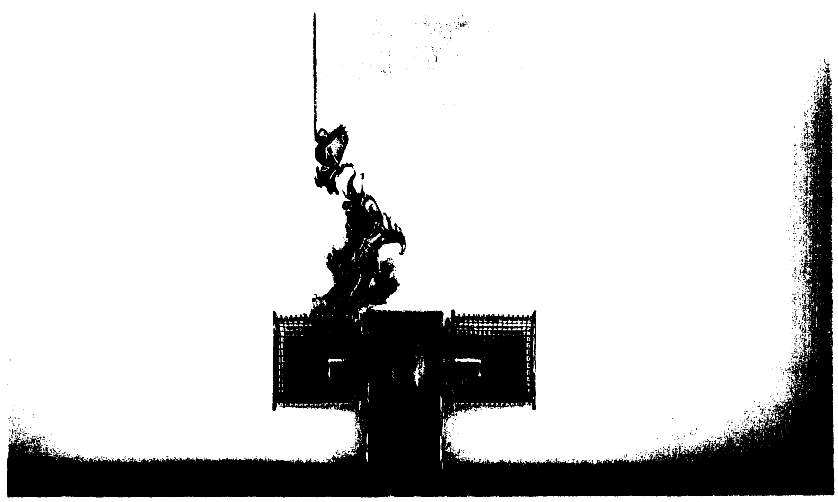
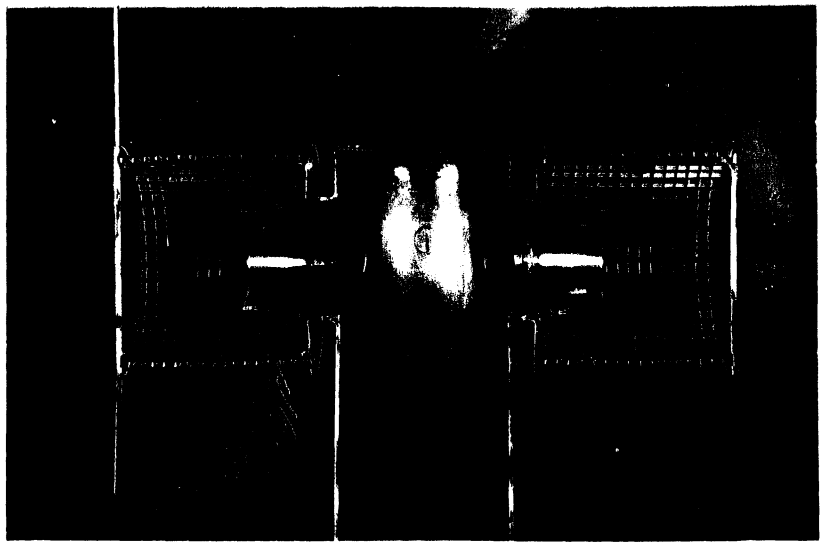


Fig. V-10. Three Risers, Symmetrical Flow (S), Flow Patterns with Single Dye Injected at Glass and Below the Left Screen.



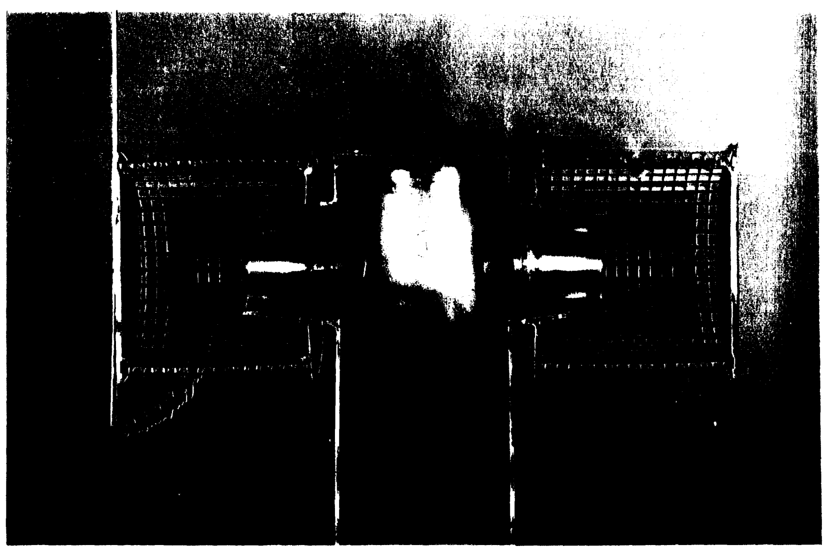


Fig. V-11. Three Risers, Symmetrical Flow (S), Flow Patterns with Single Dye Injected at Glass and Inside the Screen.

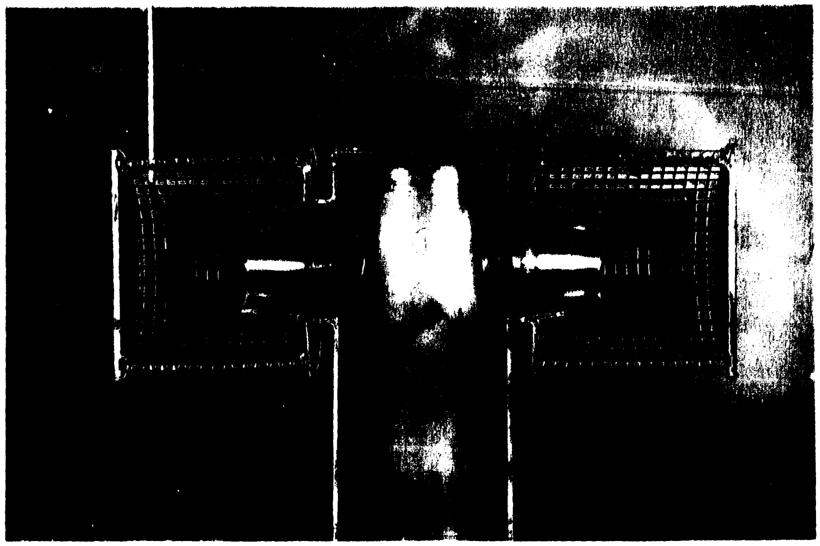
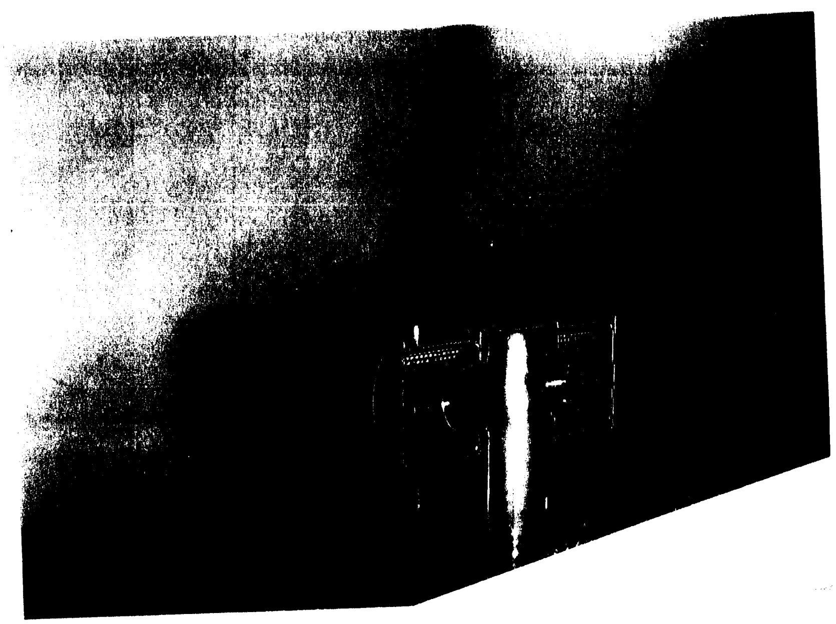


Fig. V-12. Three Risers, Symmetrical Flow (S), Single Dye Injected on Water Surface to Show Vorticity.



depression and no air drawn down. This vorticity does not appear to be a problem because of its infrequent occurrence and spatial limitation.

The second configuration investigated was with only the one-half riser next to the front glass panel in the model as shown in the top photo of Fig. V-13. The prototype flow of 29.44 cfs per riser was simulated. The model flow was 0.102 cfs. Symmetrical flow (S) is shown in the middle photo of Fig. V-13, and asymmetrical flow (AS1) is shown in the bottom photo. The middle photo of Fig. V-13 may be compared to the top photo of Fig. V-3 for symmetrical flow conditions, and the patterns appear quite similar. In comparing the asymmetrical flow (AS1) patterns, that is the bottom photo of Fig. V-13 with the middle photo of Fig. V-3, there is a noticeable difference in the dye patterns from the two center dye sources. The difference is probably due to the smaller cross flow velocity in Fig. V-13 (see Table V-2).

The third configuration investigated was with only the one full center riser installed with the long axis of the screen parallel to the channel sides. The dye supply line was placed over the center of the riser and dye injected. The resulting flow patterns are presented in Fig. V-14. For this one full riser the model discharge was adjusted accordingly to 0.204 cfs. The top photo of Fig. V-14 shows the flow pattern to the screen intake with symmetrical flow (S) and may be compared to the top photos of Figs. V-3, V-5, V-6, and the center photo of V-13. The center photo of Fig. V-14 shows the flow pattern with the asymmetrical flow (AS1) with the 0.204 cfs discharge from the left. This photo may be compared to the middle photos of Figs. V-3, V-5, V-6, and the bottom photo of V-13. The bottom photo of Fig. V-14 shows the flow pattern with the asymmetrical flow (AS2) from the left increased by about 50% to 0.30 cfs. The discharge through the riser remains at 0.204 cfs with the excess flow going over the end bulkhead. This photo can be compared with the bottom photos of Figs. V-3, V-5, and V-6.

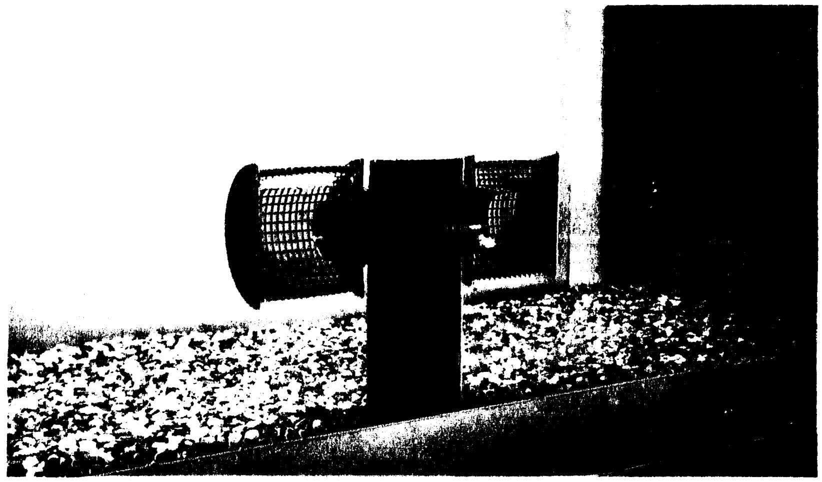
The fourth configuration investigated was again with only the one full center riser installed but with the long axis of the screen turned 90° so that it was perpendicular to the channel sides. Observations were made with the dye injected over the center of the riser (along the channel centerline (Fig. V-15), and over the center of the screen nearest the front glass panel (Fig. V-16). Figures V-15 and V-16 can be compared: flow

Model Installed in 20 in. Channel

Flow Patterns with Symmetrical Flow (S)

Flow Patterns with Asymmetrical Flow (AS1)

Fig. V-13. One-half Riser, Multiple Dye Injected at Glass.

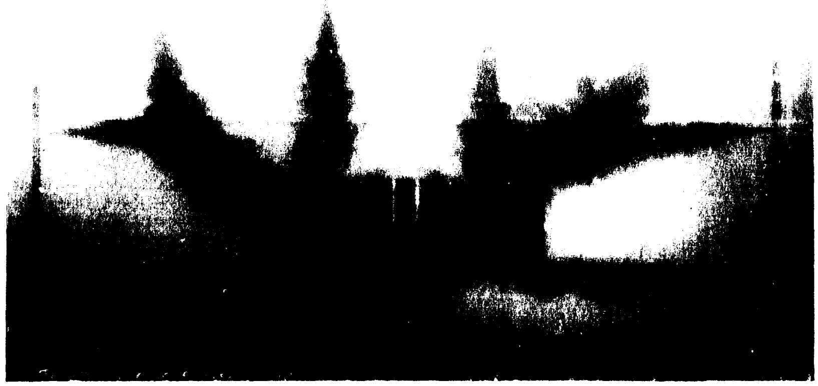


Symmetrical Flow (S)

Asymmetrical Flow (AS1)

Asymmetrical Flow (AS2)

Fig. V-14. One Full Riser Parallel to Channel, Multiple Dye Injected Over Center of Riser, Flow Patterns.



Symmetrical Flows (S)

Asymmetrical Flows (AS1)

Asymmetrical Flows (AS2)

Fig. V-15. One Full Riser Perpendicular to Channel, Multiple Dye Injected Over Center of Riser, Flow Patterns.

Symmetrical Flow (S)

Asymmetrical Flow (AS1)

Asymmetrical Flow (AS2)

Fig. V-16. One Full Riser Perpendicular to Channel, Multiple Dye Injected Over Center of Front Screen, Flow Patterns.



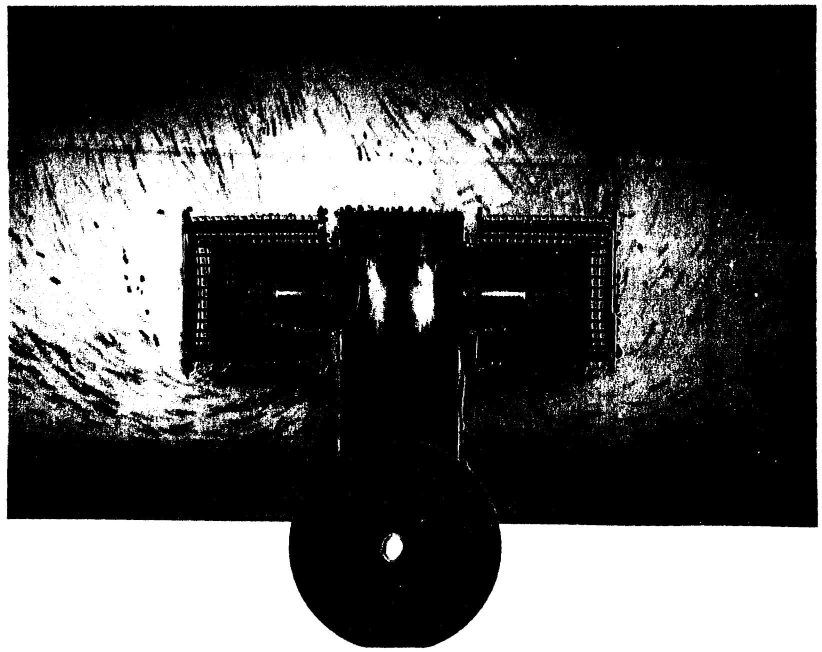
patterns in the top photos for symmetrical flow (S), the center photos for asymmetrical flow (AS1), and the bottom photos for asymmetrical flow (AS2) are quite similar; slight variations are due to residual turbulence in the tank. The reason for the lack of complete symmetry in the uppermost pictures is unknown.

The red dye injected around the risers illustrates the flow streamlines to the risers very effectively. To document intermittent streamlines or streaks for determining velocities other agents were used as discussed earlier, namely, unity oil and confetti. The unity oil was injected just below the water surface next to the front glass panel and over the entire length of the test section. Time was allowed for the unity oil spheres to spread through the model, and then a time exposure photo was taken of the resultant flow patterns. Figs. V-17 and V-18 show some typical photos taken. Fig. V-17 shows the flow patterns with the three risers and symmetrical flow (S), Fig. V-18 with the three risers and asymmetrical flow (AS1).

The same procedure was used to introduce the confetti and time exposure photos taken of the flow patterns for the same configurations and flow conditions. Sample photos are presented in Figs. V-19 and V-20. On each of the Figs. V-17 through V-20 two photos are presented to show that for the same conditions the flow patterns will vary somewhat with time. In most cases the variations are very slight, with the exception of Fig. V-19 where the streamlines are similar but the confetti streak lines are somewhat longer in the lower photo. In all these photos, the lighter area on the timer disk shows the exposure time of the picture. As the disk turns one revolution per second, the measured central angle of the white area in degrees, divided by 360, gives the exposure time in seconds. The measured angles varied from 224° to 239° or from 0.62 to 0.66 seconds.

Closer examination of the photos reveals some trends worth noting. Generally speaking, the unity oil streaks (Figs. V-17 and V-18) appear to be slightly shorter than the confetti streaks (Figs. V-19 and V-20) for the same flow condition. Also, the streaks from both the unity oil and confetti for the multiple (three) riser configurations were slightly longer than the streaks for the one-half riser configuration. Generally, both unity oil and confetti show the flow patterns fairly accurately. The confetti streaks along the sides

Fig. V-17. Three Risers, Symmetrical Flow (S), Flow Patterns with Unity Oil.



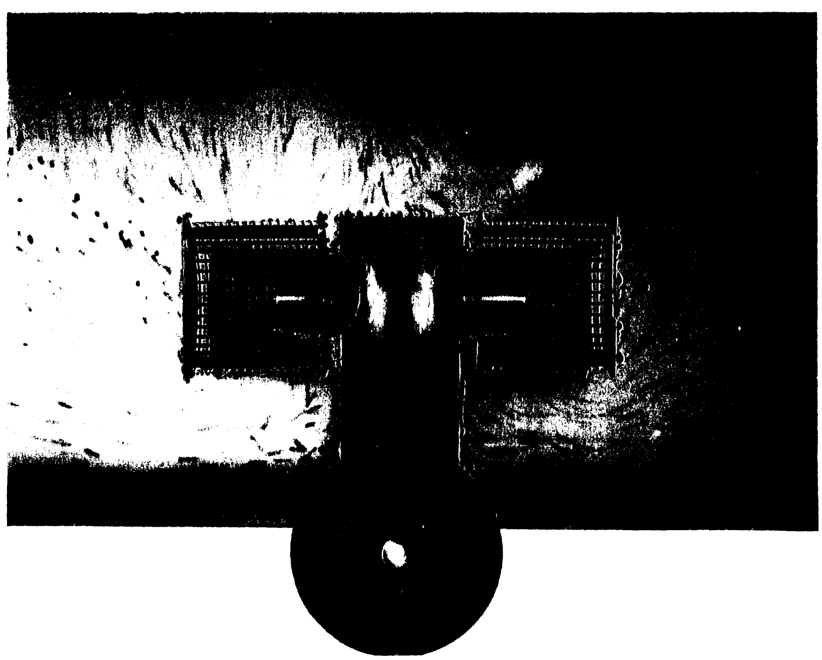


Fig. V-18. Three Risers, Asymmetrical Flow (AS1), Flow Patterns with Unity Oil.