A TWO-DIMENSIONAL MANIFOLD STUDY

by

HAROLD DUANE PRITCHETT

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APPROVED:

[redacted]

Associate Professor of Civil Engineering

In Charge of Major

[redacted]

Chairman of Department of Civil Engineering

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

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LIST OF ILLUSTRATIONS

NOTATION

a	Slot width
A	Cross sectional area of flow
b	Manifold width
V	Average velocity of fluid in manifold. Subscripts denote location in manifold.
v	Local velocity
n	Slot number. Number one begins at downstream end.
P	Pressure in manifold
Q	Manifold flow rate
q	Slot discharge
α	Angle of discharge measured from manifold center-line downstream. Subscript denotes slot number.
γ	Specific weight of fluid
ρ	Mass density
H_L	Energy losses
g	Gravitational acceleration
K_e	Kinetic energy correction coefficient
C_L	Energy loss coefficient

A TWO-DIMENSIONAL MANIFOLD STUDY

INTRODUCTION

A two-dimensional analysis for frictionless flow divisions has been analyzed mathematically by McNown and Hsu (5).

This study involves a laboratory investigation to gather experimental data. For this study an approximate two-dimensional test apparatus was constructed of clear plexiglas to allow visual observations to be made.

Present three-dimensional flow division analysis has proven to be quite accurate for single flow divisions. As more laterals are placed closer together the analysis becomes quite complicated and, due to frictional effects, less realistic. This test apparatus had six slots from which the manifold flow discharged. The width of the slots was varied. Pressure readings were recorded along the centerline at 0.2-foot intervals throughout the test section. The individual lateral discharges and discharge angles were also recorded.

The apparatus used in most of the previous investigations was circular in cross section, with circular lateral openings. This allows a comparison to be made between two-dimensional and three-dimensional flow.

A previous investigation (5) analyzed a two-dimensional manifold system. A comparison is made between experimental data and that analysis (Figure 7).

The lateral discharge angle is of much concern as it is directly related to the entrance loss of the lateral, thus affecting the flow rate. A comparison was made of the actual discharge angle with a value computed by means of a momentum analysis applied to a section across the slot.

Purpose and Scope

The purpose of this thesis is to compare the experimental data obtained from the two-dimensional manifold with that obtained by previous investigators for three-dimensional flow and to compare actual two-dimensional flow with a two-dimensional analysis of other investigators. The test manifold was limited to two-dimensional flow, with a fixed slot spacing.

JET ANGLE ANALYSIS

The momentum equation, $\Sigma F = \Delta(Q\rho V)$, may be written for a section along the manifold across the lateral slot opening. When written across the slot opening it takes the following form.

$$[(P_n - P_{(n-1)})]A = (Q\rho V)_{n-1} + (Q\rho V)_{jet} \cos\alpha - (Q\rho V)_n$$

The slots are numbered from the downstream end, as are the flow rates and discharge angles. The flow rate Q_6 is the manifold flow rate approaching slot number six where q_6 (lateral number six discharge) is removed. Then $Q_5 = Q_6 - q_6$ and is the flow rate between slots six and five.

In the laboratory the lateral discharge rates were measured, thus enabling the manifold flow rates to be computed. The manifold pressures were measured across the slots. With this data and the lateral discharge, angle α may be computed from the momentum equation. These values were computed for one of the test runs and compared with the experimental values measured (Figure 9). Average velocities were used, and the momentum correction coefficient was assumed to be unity. The computed angles were generally smaller than the measured values.

If a momentum correction coefficient were used in order to equal the experimental values, it would have to increase in magnitude in the downstream direction across each slot. After the first slot (slot number six) the flow is still highly turbulent with probably a more uniform velocity distribution because the boundary layer does not have a chance to fully establish on the slot side of the manifold. This is also the apparent reason for the discontinuity in the angle α for slot number six for the low velocity boundary layer flow, but the succeeding slots are fed by flow with a higher velocity because the boundary layer does not have space to become re-established between slots. In the higher velocity tests (Figure 5) this was not the finding, since the boundary layer thickness was quite small.

ENERGY LOSS ANALYSIS

When the energy equation is used in the form

$$\left(Ke\frac{V^2}{2g} + \frac{P}{\gamma} + Z\right)n = \left(Ke\frac{V^2}{2g} + \frac{P}{\gamma} + Z + H_L\right)n-1$$

it may be applied across each slot to compute the energy loss. This is the method used in the analysis to solve for the losses in the two-dimensional manifold. In the analysis average velocities are used, and the kinetic energy correction coefficient is assumed to be unity. The average velocities were computed by the continuity equation Q = AV.

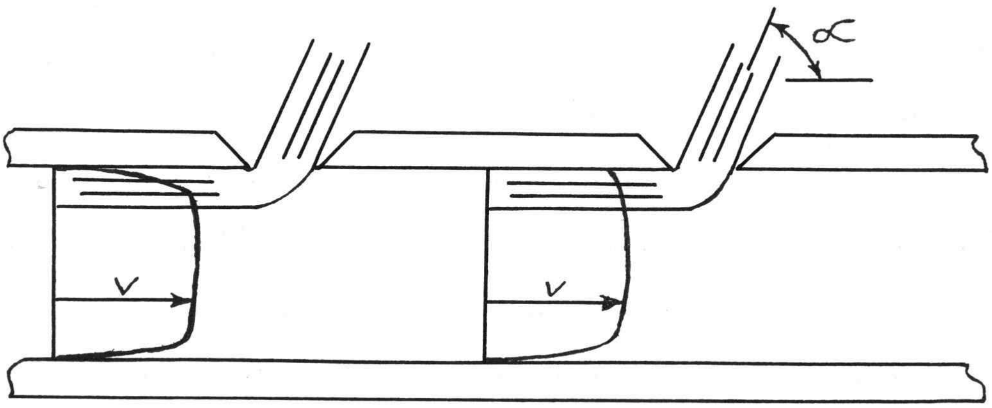

Figure 1. Velocity Distribution Diagram

Since the area of manifold flow is constant and the flow rate decreases across each slot in the downstream direction, the velocity must also decrease across each slot.

The energy loss involved is primarily due to deceleration loss for the expanding flow (Figure 1). The sudden expansion loss analysis $h_L = C_L \dfrac{(V_1 - V_2)^2}{2g}$ (6) does not appear to be analogous to the two-dimensional manifold. If this equation were to be used, C_L would have to become a variable function in order to correlate with the experimental data.

APPARATUS

The laboratory test apparatus was constructed of clear acrylic plexiglas. The test apparatus, hereafter called the manifold, had an inside area of 0.2 square feet, the cross section being 1.0 foot in height and 0.2 of a foot in width. The overall length of the test section, excluding the transition, was 16.4 feet.

The manifold was cemented on three sides to form a permanent connection. The fourth side (front) was connected to the others with screws on 0.1 foot centers along the top and bottom of the plexiglas plate. This feature provides for changeable slot widths.

Six equally spaced vertical slots were placed along the front of the manifold (Figures 2 and 10).

The slot exits were bevelled at a 45 degree angle to facilitate a free and unobstructed discharge.

A 4 by 9 foot rectangular tank with sides varying from 1 to 3 feet in height was used to collect the discharge. From this tank a 1 foot wide channel conveyed the discharge flow to a weigh tank which was used to measure total flow. The individual flows from the laterals were collected and weighed. A stop watch was used to time the period of flow.

A series of piezometer openings were tapped into the manifold along the centerline on the rear side. These openings were placed on a 0.2 foot spacing to facilitate the measurement of the hydraulic grade line along the manifold.

Two 36-inch manometers were used to measure pressures. A calibrated orifice was used to measure flow rates.

The flow was provided to the manifold by the recirculatory pumping system in the Civil Engineering Hydraulics Laboratory at Oregon State University.

RESULTS AND CONCLUSIONS

The experimental results indicate that the lateral discharge rate increases in the downstream direction. This can be explained by considering the energy level down the manifold in the direction of flow. This energy level falls only slightly and on a few tests was found to rise across the first lateral. The discharge angles increased in the direction of flow, causing the lateral jet to become almost perpendicular to the manifold. As this angle increases the lateral jet contracts less. Since the energy level is decreasing only slightly while the jet area is increasing relatively faster, it is reasonable to assume that the lateral discharge rates increase in the downstream direction.

In the comparison of the experimental data to that of McNown and Hsu (5) the $\propto$ values were found to be consistently smaller in magnitude experimentally (Figure 7). The range of values compared was for slot width to manifold width ratios from 0.05 to 0.3. This range covers only a limited portion of the theoretical curves of McNown and Hsu (5). The experimental curves tend to flatten for larger values of a/b. This would tend to indicate closer agreement for values of a/b greater than those covered by these experiments.

The gain in piezometric head in the direction of flow for this two-dimensional manifold is compared to the data found in the Iowa Experiments (Figure 8). The Iowa Experiments (6) were conducted using circular conduits with circular laterals presenting a three-dimensional flow problem. A small gain in unit energy was found to exist across lateral number six for high manifold flow rates. This was also found to be true in the Iowa Experiments for small lateral to manifold flow ratios and large ratios of lateral area to manifold area.

The energy loss due to wall friction in the two-dimensional manifold was negligible. The loss of energy, due to expansion across the lateral, does not appear to follow the sudden expansion analysis as suggested in the Iowa Experiments. As may be seen in Figure 8, the losses computed by this analysis are greater at both ends and less in the center part of the test section than those found experimentally.

When the sum of the area openings are 2.54 times the manifold cross sectional area, a situation of reverse flow arises according to Keller (4). At a ratio of 2.75 the writer was unable to produce full flow in the manifold. When the ratio was dropped to 2.2 full flow was established in the manifold, but near-zero pressures were found to exist at lateral number six.

A small vortex was found to exist downstream from slot number one (last downstream slot). This unsteady flow condition produced considerable instability for the flow discharging from slot number one. This flow condition has been found to exist in previous three-dimensional studies (2).

TESTING

The two-dimensional manifold was arranged with six vertical slots with a 0.99 foot spacer between slot openings. The slot width was varied from a minimum of 0.01 foot to a maximum of 0.11 foot.

The first tests were conducted with a slot width of 0.01 foot. The individual slot discharges were measured, and the total discharge was also measured as a check.

The slot width was then widened to 0.11 foot, making the area ratio approximately one to two. With six slots at this spacing, the total slot area was more than three times the area of the manifold cross section.

With this large area ratio an unsteady flow condition arose with air being sucked in at lateral number six. This situation bears out the analysis by Keller (4) that air inflow occurs when the sum of the lateral openings is greater than 2.54 times the cross sectional area of the manifold.

The slots were next set at 0.06 foot spacing, giving a 1.8 area ratio. The flow rates were varied for each slot width spacing so that a wide range of data could be collected.

Two sets of the data are presented graphically in Figures 3 and 5. The piezometric head was measured at

0.2 foot intervals throughout the test section and at 1 foot intervals for 5 feet directly upstream from the test section.

The individual lateral discharges were collected and timed and then weighed. The sum of these individual discharges was checked by use of a large weighing tank below the floor level which weighs the total flow discharging from the system over a period of time.

The discharge angles were measured and are compared in Figure 7 to the theoretical values for the angles presented by McNown and Hsu.

TYPICAL VIEWS

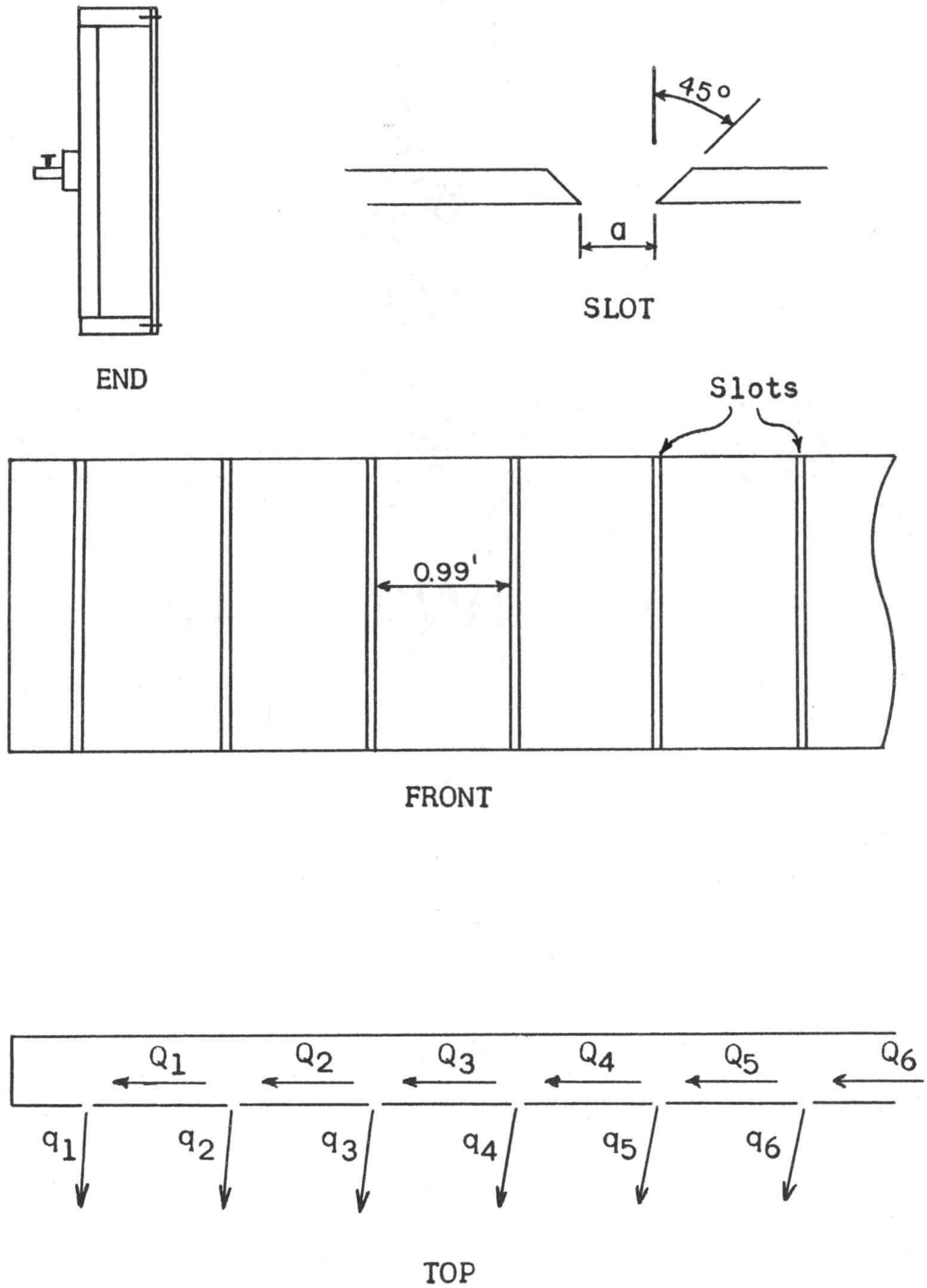

Figure 2

EXPERIMENTAL RESULTS

$Q_6 = 0.534$ cfs   Slot Width = 0.01'

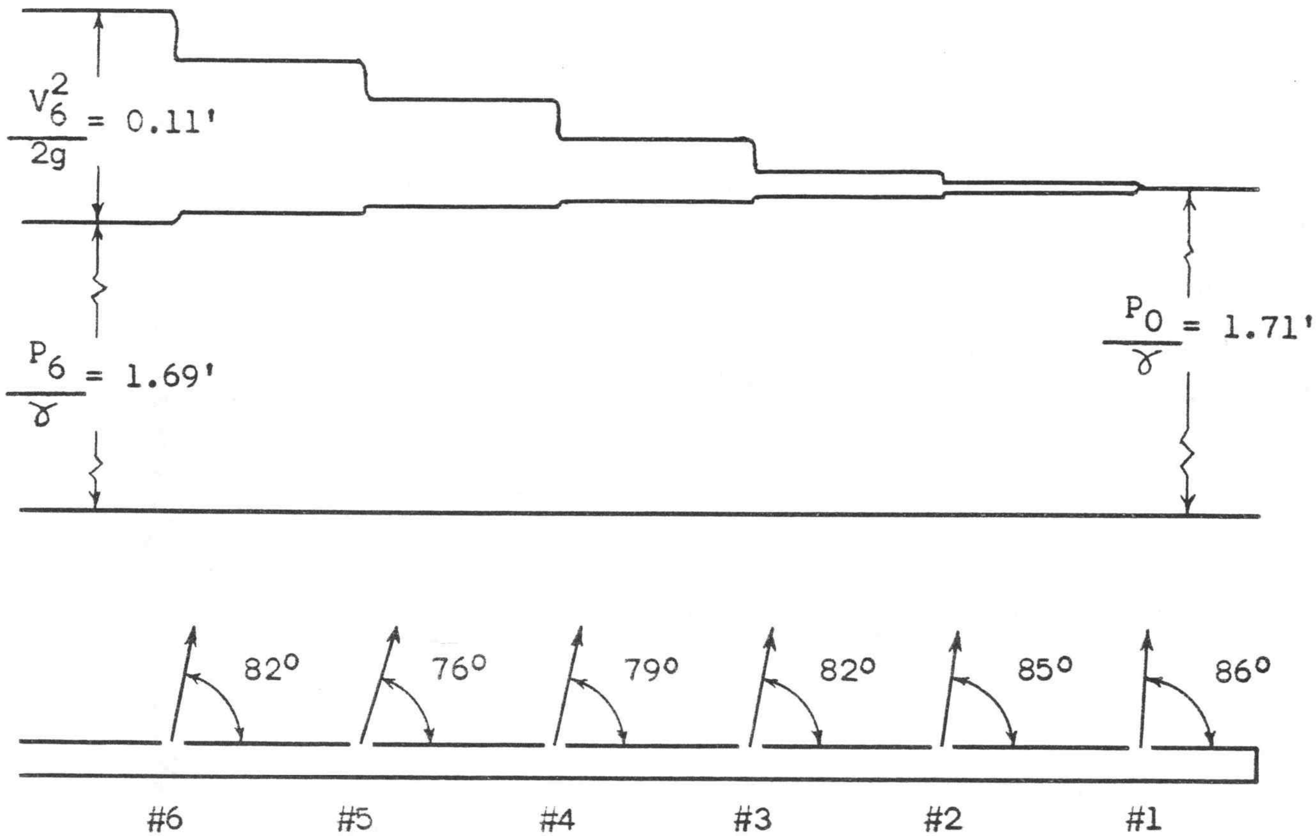

Figure 3

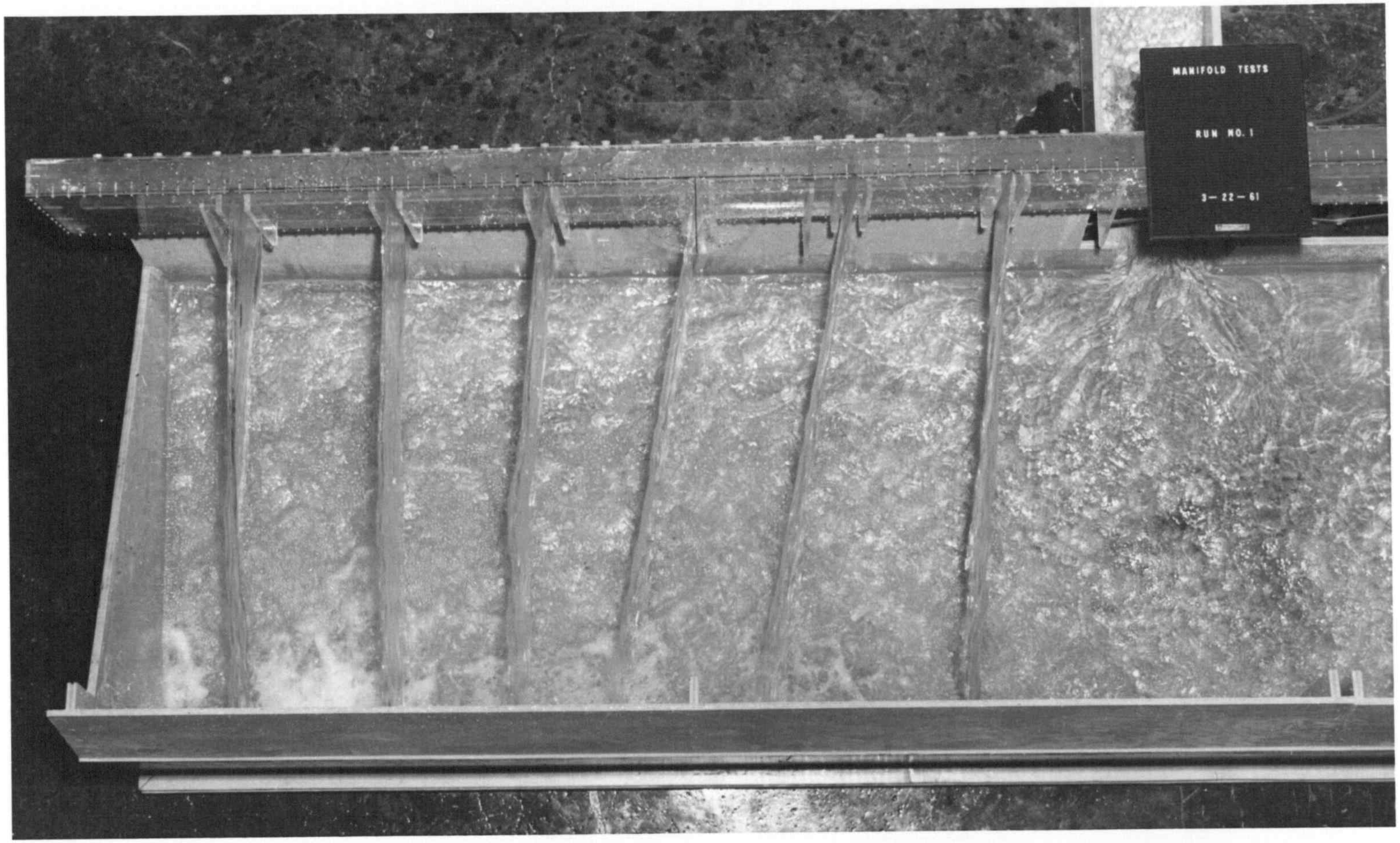

Figure 4. Photograph of Discharge.

EXPERIMENTAL RESULTS

$Q_6 = 1.43$ cfs Slot Width = 0.06'

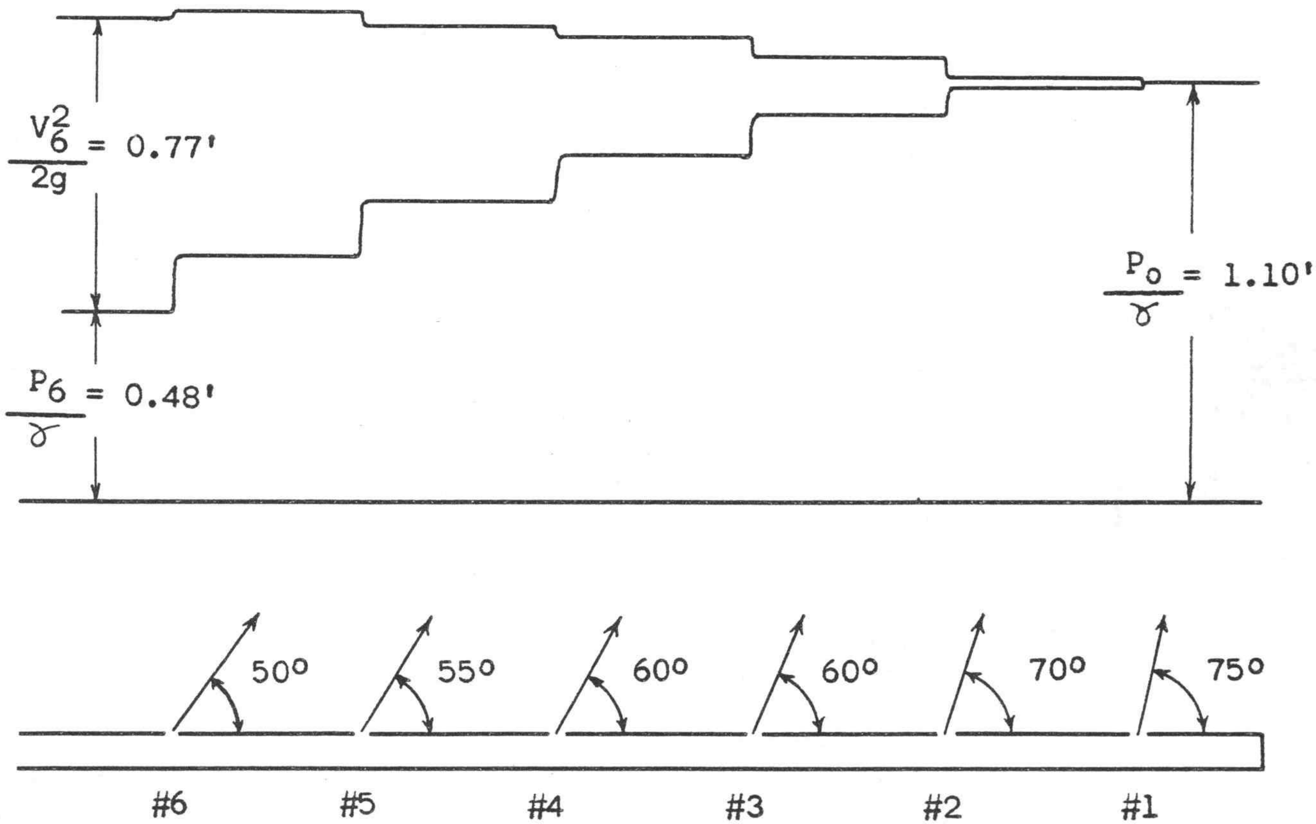

Figure 5

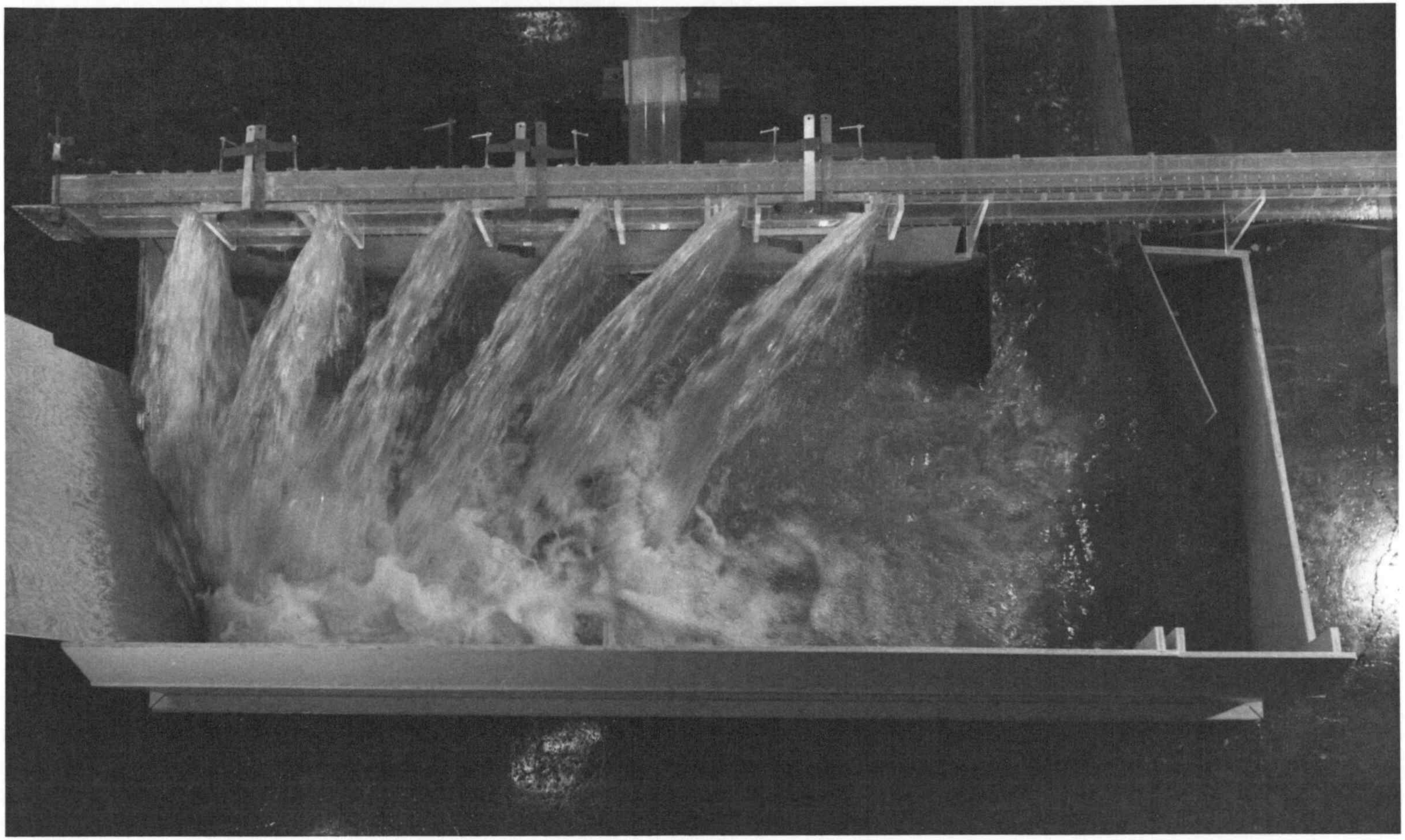

Figure 6. Photograph of discharge.

CHARACTERISTICS OF FREE EFFLUX

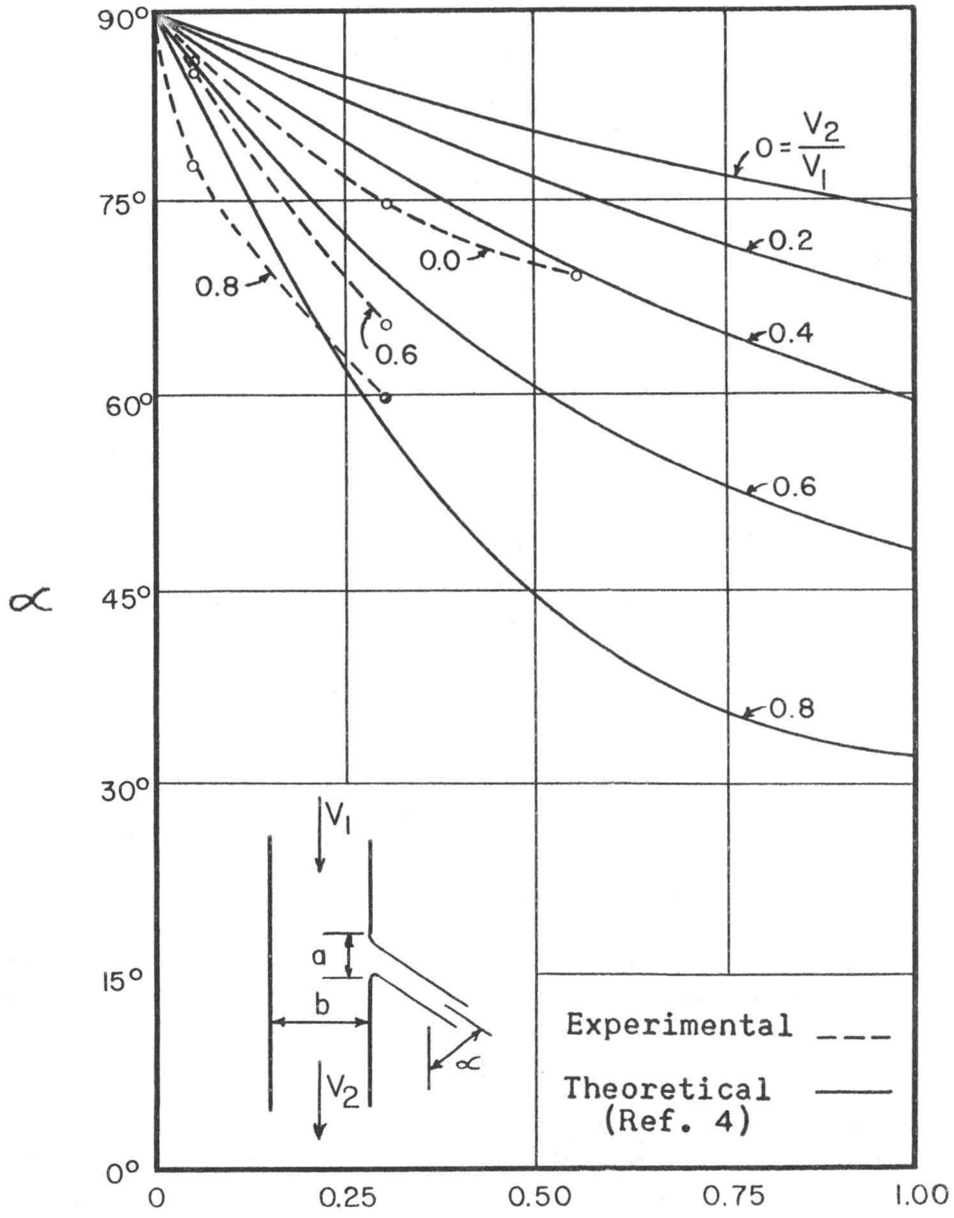

Figure 7

CHANGE IN PIEZOMETRIC HEAD IN THE CONDUIT

FOR DIVIDING FLOW

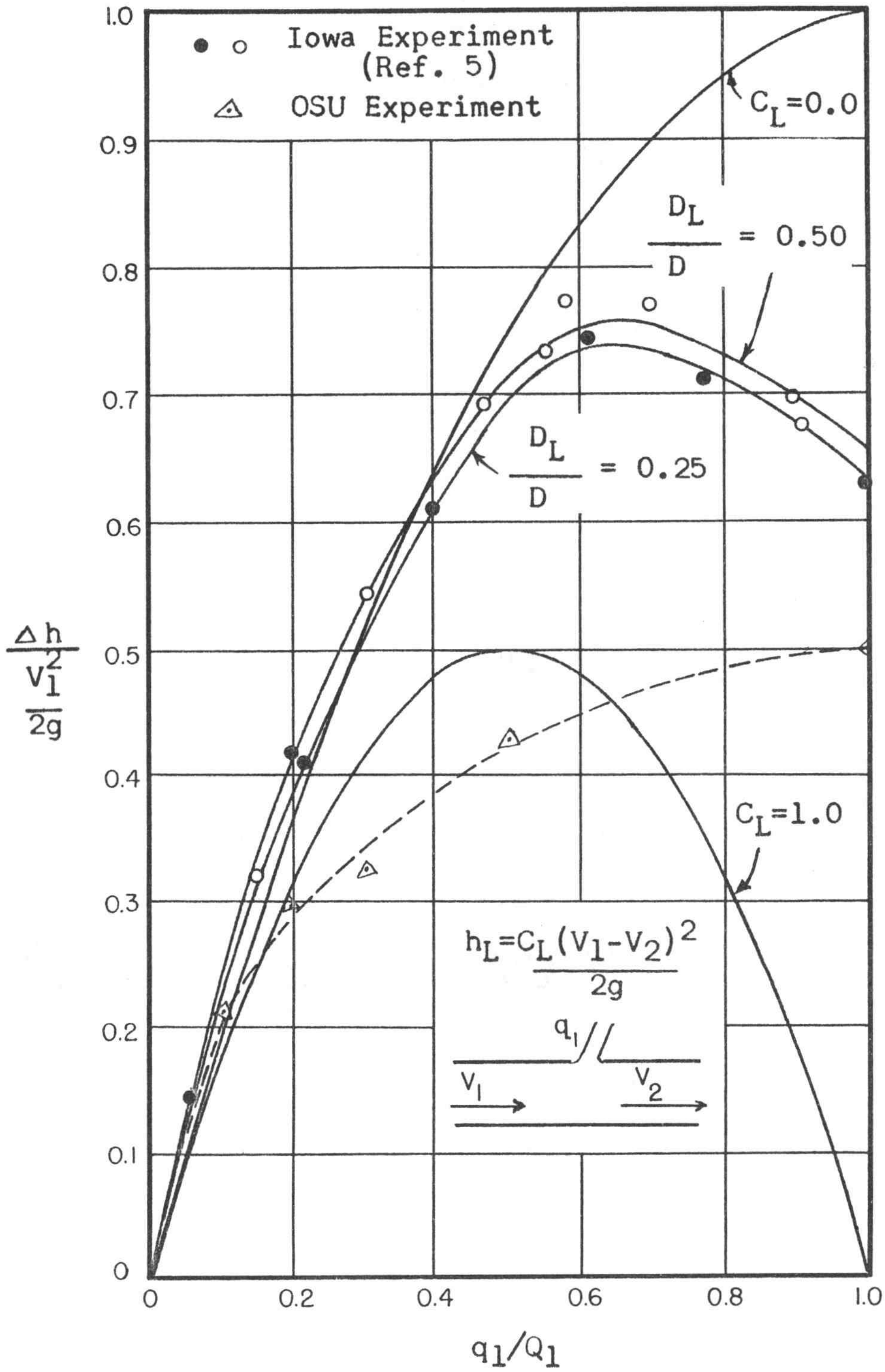

Figure 8

EXPERIMENTAL RESULTS

Q_6 = 1.43 cfs Slot Width = 0.06'

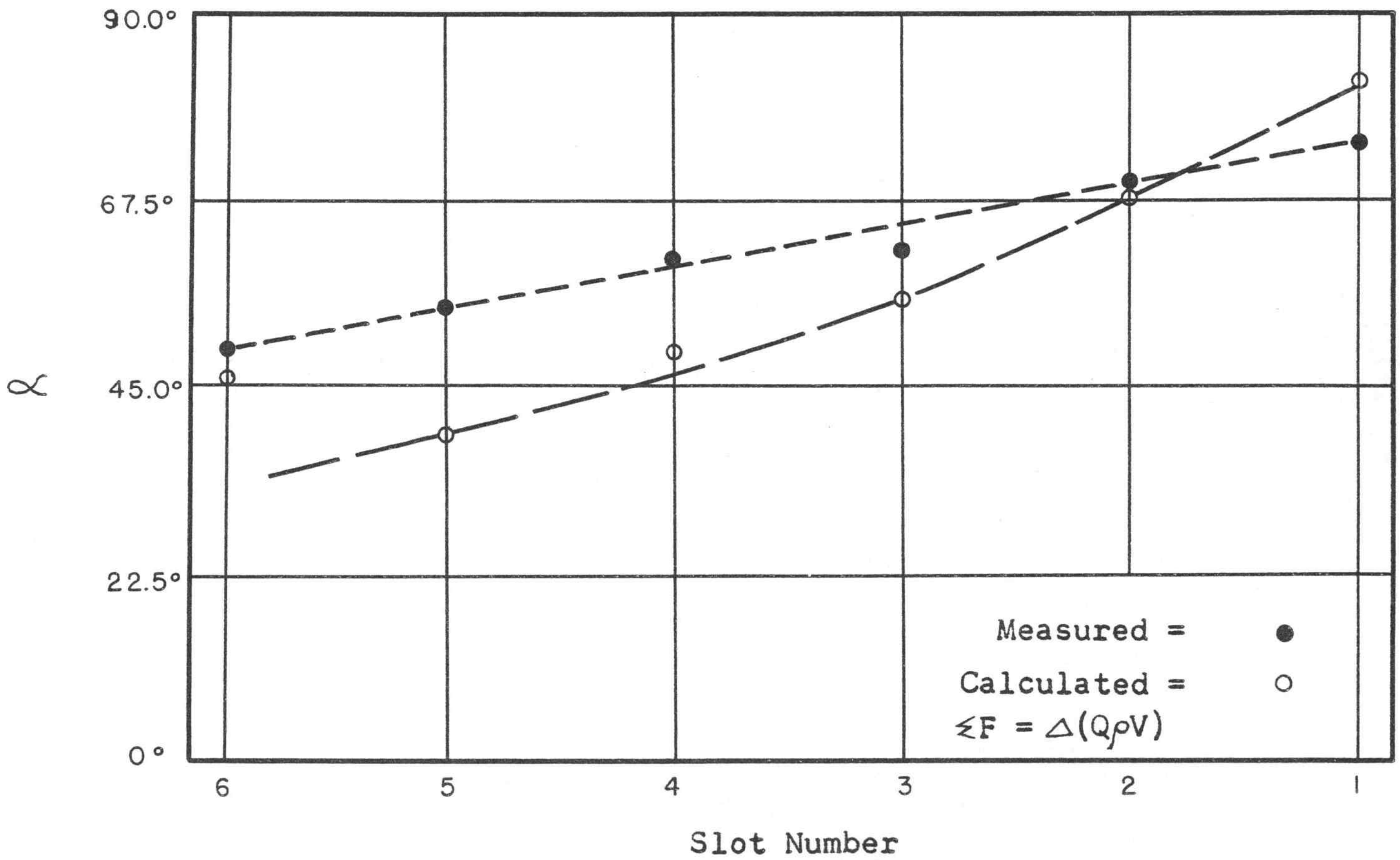

Figure 9

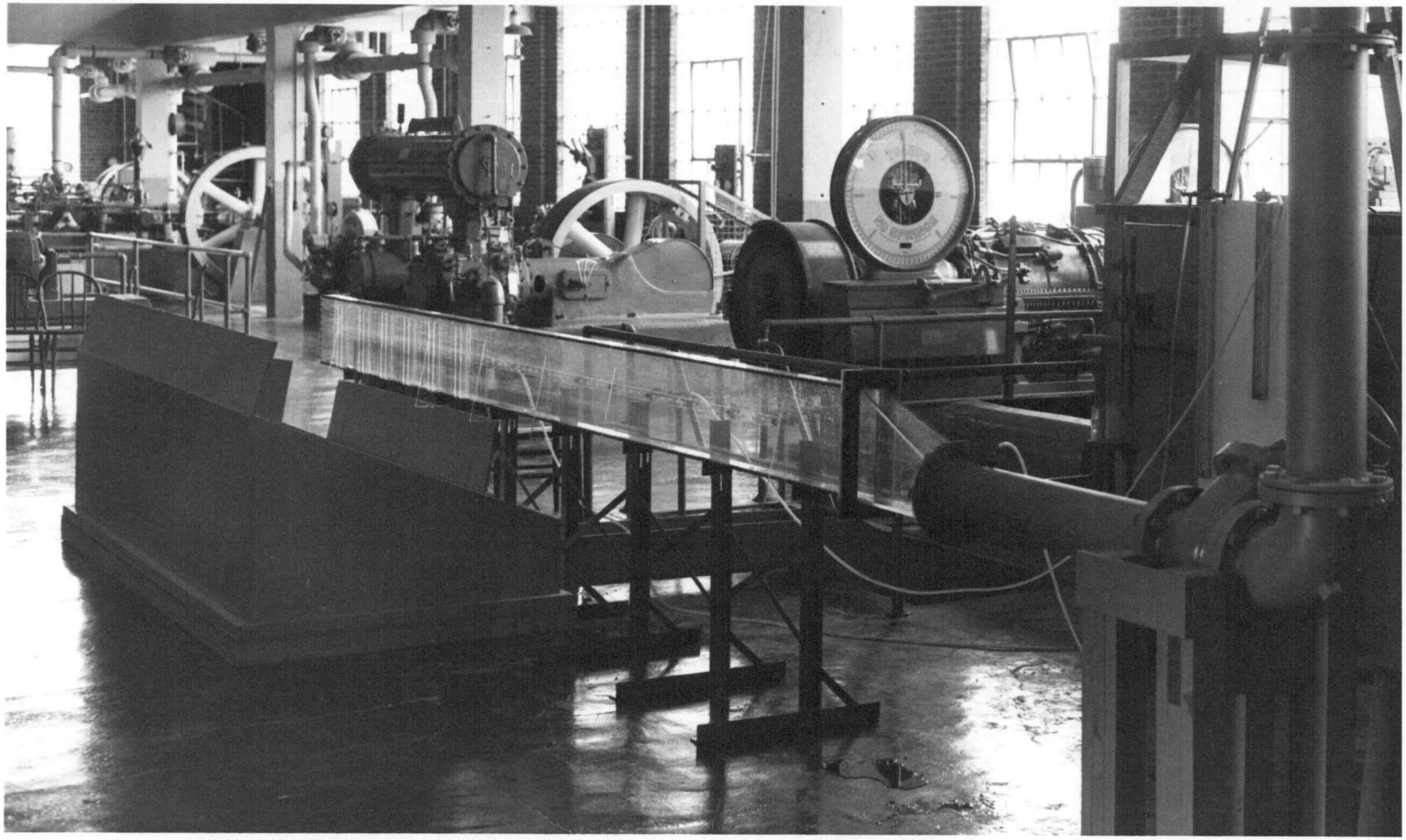

Figure 10. Overall view of test apparatus.

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