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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LABORATORY STUDIES OF THE PENDVANE FLOWMETER

Hydraulic Laboratory Report No. R-HYD-10

DIVISION OF ENGINEERING LABORATORIES

OFFICE OF ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

July 30, 1962

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Hydraulic Laboratory
Report No. R-HYD-10
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LABORATORY STUDIES OF THE PENDVANE FLOWMETER

SUMMARY

Laboratory tests were performed to determine the accuracy, operating characteristics, limitations, and usefulness of the Pendvane Flowmeter. One Model 6A24 meter, and prefabricated ditch liner sold with the meter, was tested in two laboratory flumes, each with different approach conditions. This particular meter was designed for use in a trapezoidal ditch having a capacity of 6 cfs (cubic feet per second).

Under laboratory conditions, the Pendvane Flowmeter's mean deviation from the flow indicated by calibrated venturi meters was 1.6 percent when operated in the "recommended" range and 2.9 percent when operated in the "usable" range. These ranges are defined by the manufacturer and are shown on the calibration curves supplied with each meter.

The meter produced no measurable head loss, was independent of depth and approach velocity over a wide range of ditch flows, was read directly without the use of tables or curves, was found to be portable, and was simple to adjust. On the other hand, accurate readings were difficult on the high end of the designed usable range because of meter oscillation; slow response and low sensitivity were encountered at extremely low-flow rates, and wind had an effect on the accuracy of the meter. The error caused by wind was found to be a function of the depth and velocity of the water, and under certain conditions could be as high as 100 percent. However, wind errors were reduced to a negligible amount by proper selection and positioning of a windbreak.

It was determined from the tests that the flow entering the liner should be free of surface disturbances and local high-velocity currents which might be produced by a poor transition from ditch to liner. A satisfactory transition in the field could probably be obtained by shaping the ditch sides with a shovel to produce smooth flow.

The meter maintained its initial factory calibration throughout the testing period of about 3 months. It appeared to be durable and well constructed. The meter is simple in concept and easy to operate, and should provide dependable service when installed and used according to the manufacturer's specifications.

DESCRIPTION OF METER

The Pendvane Flowmeter is a vane-type instrument in which the deflection or movement of the vane from a zero position is used to measure the volume flow rate of water in an open channel, Figure 1. The vane is shaped for use in a particular channel cross section, and may be obtained for either trapezoidal or rectangular shapes. Within reasonably wide limits, the meter indicates discharge irrespective of the depth or velocity of flow in the measuring section. Backwater or changing flow depths do not affect the meter's accuracy when they are within these limits. This has been accomplished by shaping the vane so that the integration of forces produced by the flowing water on the submerged area of the vane is essentially constant for a given discharge.

The meter head, Figure 2, contains a level-type bubble adjacent to a scale calibrated in cubic feet per second. Other scales such as miners inches, gallons per minute, etc., can be obtained from the manufacturer. The bubble size, which affects the meter's sensitivity, may be changed by the meter user following the instructions provided.

As previously stated, the vane is shaped for use in a ditch having one particular cross section. The manufacturer offers precast-concrete slabs that can be quickly bolted together to form the necessary channel shape, and also provides the necessary information for complete fabrication of the channel in the field.

The vane and meter head snap together and are held by a magnetic lock. The vane and attached indicating head are suspended into the channel from a bracket, which completes the assembly, Figure 2. No tools are required for the assembly. The bracket, which may be permanently mounted on a cross channel brace, must be positioned in accordance with the manufacturer's specifications.

The meter head is supplied with a durable carrying case. No case is provided for the vane; a sheath could be improvised to prevent damage during nonuse. The meter is constructed of nonrusting metals.

OPERATION OF THE PENDVANE FLOWMETER

After installation and adjustment of the ditch liner and bracket, the steps required to obtain a discharge reading are:

a. Place the vane bearing rod sockets, Figure 2, on the pivot points of the bracket.

b. Place the meter head on the bearing rod so that the magnet engages the vane at the prescribed position.

c. Allow time, usually a few seconds, for the resisting forces of the meter to equal the forces of the water impinging on the vane.

d. Read the scale.

TEST INSTALLATION

Pendvane Flowmeter (6A24A60), designed for use in a trapezoidal channel for discharges up to 6 cfs, was loaned to the Bureau of Reclamation by the manufacturer. Precast-concrete ditch-liner slabs and a mounting bracket were also supplied. A test channel to contain the meter and liner, Figure 1A, was fabricated according to the details given below.

A 6- by 4- by 3-1/2-foot-deep head box was placed at the upstream end of the installation. To provide uniform flow patterns in the test channel, the head box was fitted with a 4-inch-thick graded gravel baffle. An 8-inch pipe located behind the baffle was used to supply water.

The entrance to the channel from the head box was equipped with a 5-inch radius on either side to provide a smooth transition to the rectangular channel. The nominal channel dimensions were 3.4 feet wide by 2.5 feet deep. A 7.7-foot plywood transition starting 4.3 feet downstream from the head box, provided a change in channel shape from rectangular to trapezoidal. An 8-foot-long plywood trapezoidal channel with the same cross section as the manufacturer's precast-concrete ditch liner was placed between the transition and the liner to provide additional length to minimize undesirable flow patterns. Thus, the start of the precast ditch liner was located 20 feet from the head box exit.

A second 5.8-foot-long transition was placed immediately downstream from the ditch liner to change the cross section back to rectangular. A tailwater control gate consisting of removable vertical slats, was constructed 2.6 feet downstream from the latter transition. All joints in the construction were sealed to prevent loss of water. The transitions from rectangular to trapezoidal and vice versa used in the laboratory tests, represents the most difficult condition expected to be encountered in the field.

The precast-concrete ditch liner was installed according to the manufacturer's instructions. The vane bracket was leveled and adjusted to provide the specified height of 30-9/16 inches from the bottom of the channel to the top of the bearing rod.

Test discharges, supplied by an 8- or 12-inch centrifugal pump, were measured by a 4-, 6-, 8-, or 12-inch calibrated venturi meter. A point gage, readable to the nearest thousandth of a foot, was used to measure the depth of the water in the ditch liner adjacent to the meter. The point gage appears as the vertical rod extending above the water surface in the photographs of Figure 1, and should not be confused with the meter itself.

To simulate wind conditions, a 36-inch-diameter, 5-hp, 3-bladed fan was directed toward the Pendvane meter from positions both 20 feet upstream and downstream from the meter location, Figures 1A and 5A. The fan was located laterally 4 feet from the centerline of the channel with the blade center 4.8 feet above the channel floor. Wind speeds produced by the fan were measured with a propeller-type Taylor anemometer and stopwatch.

TEST PROCEDURE

The manufacturer supplied a graph which indicated the recommended and the usable ranges of the flowmeter tested. The overall range included depths of from 0.6 to 2.0 feet, and discharges of from 0.2 to 6.0 cfs. The corresponding mean water velocities were approximately 0.07 feet per second to approximately 3.3 feet per second.

The meter was checked throughout its entire range by varying the flow depths in the test channel by means of the tailgate, and by varying the discharge through the venturi meters. Readings were taken for depth intervals of 0.25 feet while holding the discharge constant. This procedure was repeated for discharge increments of 0.5 cfs. Additional measurements were chosen later to fill in the calibration curve and to provide more complete information on the accuracy of the instrument, Table 1 and Figure 3.

The effect of upstream and downstream winds on the meter was determined for flow depths of 1.25, 1.50, and 1.75 feet and discharges of from 1 to 5 cfs. After the desired flow rate and depth had been attained, the meter was read. The fan was then turned on and the altered meter reading, due to wind, was recorded. The wind velocities at the meter were measured with an anemometer, and recorded.

Additional tests were performed utilizing as a windbreak a 1- by 12-inch board with the ends cut to fit the side slopes of the liner. The board was placed with the 12-inch dimension vertical and with the bottom 1.77 feet above the top of the center slab of the precast-concrete channel. For the upstream wind, the windbreak was placed 2 feet downstream from the meter bracket. For the downstream wind, the windbreak was placed 1.2 feet upstream from the meter bracket. Evaluation of the windbreak was based on meter readings taken with no wind, with wind, and with wind and windbreak. Readings were taken for several representative depths and discharges within the recommended range.

The meter was also installed in a second rectangular flume with a 5-foot-long upstream transition connected directly to the ditch-liner section. The angle formed at the intersection of the transition and liner was sharp and produced flow disturbances in the liner section for all but the lowest flows. Flow surface irregularities consisting of diamond-shaped patterns and steep drawdown curves several inches deep were observed. It was immediately apparent that the meter could not cope with flow conditions as poor as these, and testing was discontinued in this flume.

DISCUSSION OF RESULTS

Meter Readability

The calibrated meter head used in these tests was graduated in tenths of a cubic foot per second. Thus, the readability of the meter, using one-half the least scale marking, was equal to 0.05 cfs. The spacing of the scale markings increased from 1/8 inch at the low-flow end to 5/32 inch at the high-flow end of the scale.

Meter Sensitivity

The sensitivity of the instrument varied throughout the range of the tests. At extremely low-flow rates in the manufacturer's usable range (greater than 0.2 cfs, but less than 0.4 cfs), the instrument had low sensitivity to small changes in flow rate. At higher flow rates within the recommended and usable ranges, the instrument had much greater sensitivity. In the high-flow range (greater than 5 cfs), oscillations occurred which required reading the meter at the maximum and minimum point of oscillation and obtaining the average.

If turbulent flow conditions prevail in a particular channel, the viscosity of the fluid in the indicating tube may be increased by the manufacturer to dampen the bubble oscillations and provide less sensitivity to surges. This was not done, nor was it necessary, in the laboratory tests.

Meter Response

The response of the instrument varied throughout the range of the tests. At low-flow rates, the time necessary for a change in the rate to be shown on the meter was much greater than at the higher flow rates, for a given percentage of total flow change. This characteristic was evidently due to the very slight curvature in the glass bubble tube at the low-flow-rate end of the meter indicating device. The more rapid response at higher flow occurred because of the increased curvature in the indicating device. Under field operating conditions, the 1 minute or so required to be sure that the meter was indicating a change in discharge would not ordinarily be of concern.

Meter Repeatability

The repeatability of the instrument appeared to be good. During laboratory tests, an attempt was made to read the instrument to the nearest 0.01 cfs. The maximum error resulting from repeated readings was 0.03 cfs, which was 0.02 cfs better than the recommended field readability.

Meter Accuracy

The laboratory tests performed on the Pendvane meter showed the meter to be dependable and accurate when operated within the manufacturer's recommended and usable ranges of operation. The meter was found to give erroneous readings when used to measure flows below the limit depicted on the manufacturer's curve. These latter points are designated as Zone C in Table 1. Table 1 also contains test data for the recommended range, Zone A, and for the usable range, Zone B. Figures 4, 5, and 6 show operation in the recommended usable and unusable ranges, respectively.

The meter's mean deviation from that indicated by a calibrated venturi meter, based on 43 different combinations of depth and discharge in the manufacturer's recommended range, was 1.6 percent. The maximum error of 4.7 percent occurred for a flow rate of 0.493 cfs at a 1.1-foot depth. The mean deviation for the usable range, computed from 24 variations of depth and discharge, was 2.9 percent. The maximum error noted was 8.0 percent at a flow rate of 0.213 cfs at a 1.7-foot depth. Figure 8 summarizes the meter's accuracy as tested in the laboratory and indicates that the meter has an overall tendency to read low. The exceptions to this are at discharges near 1 and 5 cfs of the recommended range where no consistent variation exists, and at discharges less than 2 cfs in the usable range where the tendency is to read high.

Effect of Approach Flow on Accuracy

Tests in two test flumes indicated that the flow in the ditch-liner section must be smooth and uniform to insure accurate discharge measurements. A poor transition from the ditch cross section to the liner cross section can produce flow conditions which seriously affect the meter's accuracy.

In the field it should be readily apparent to a careful observer that more extensive shaping of the earth transition would be necessary to eliminate flow surface disturbances. It could be concluded that a sufficient transition existed when the flow at the meter had a flat water surface free of waves or other visible disturbances.

Effect of Wind on Accuracy

The fan used to study the effects of wind on meter readings produced an average wind speed at the meter head of approximately 10 miles per hour. Air speeds, measured by standard practices, would necessarily be much greater to attain this speed in a protected channel in the field.

The wind had a varying effect on the meter readings. Larger deviations from actual flow were found when the fan was located downstream than when located upstream. This was probably caused by asymmetry between the upstream and downstream channels and a larger projected area of the vane exposed to the downstream fan.

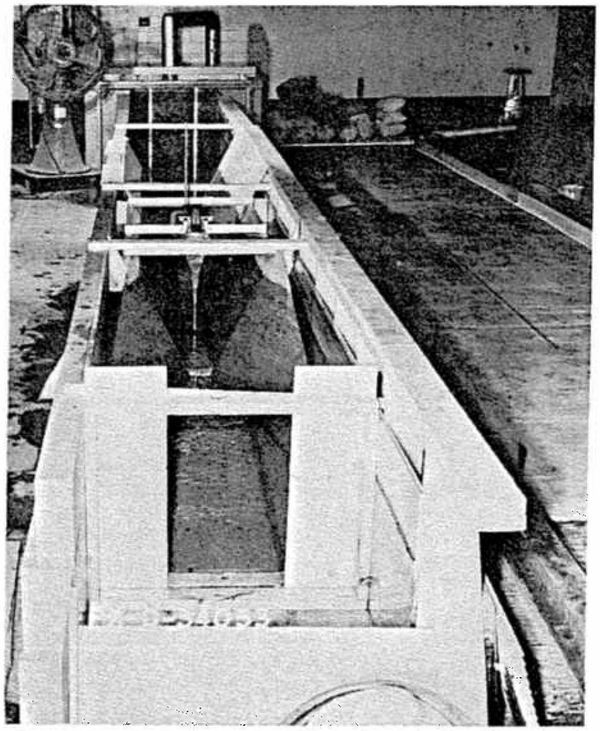
The maximum recorded errors created by an upstream wind were 100 percent for water depths of 1.25 and 1.50 feet, and 57.1 percent for a depth of 1.75 feet. The maximum errors under identical depth and flow conditions for a downstream wind were 41.5, 34.6, and 24 percent, respectively.

Data for these tests are presented in Tables 2 and 3. The percent error was computed by dividing the change in reading due to the wind by the initial Pendvane reading, and multiplying by 100. A plot of percent error versus mean water velocity, Figures 8 and 9, indicates that as depth and/or water velocity increase, the percent error decreases.

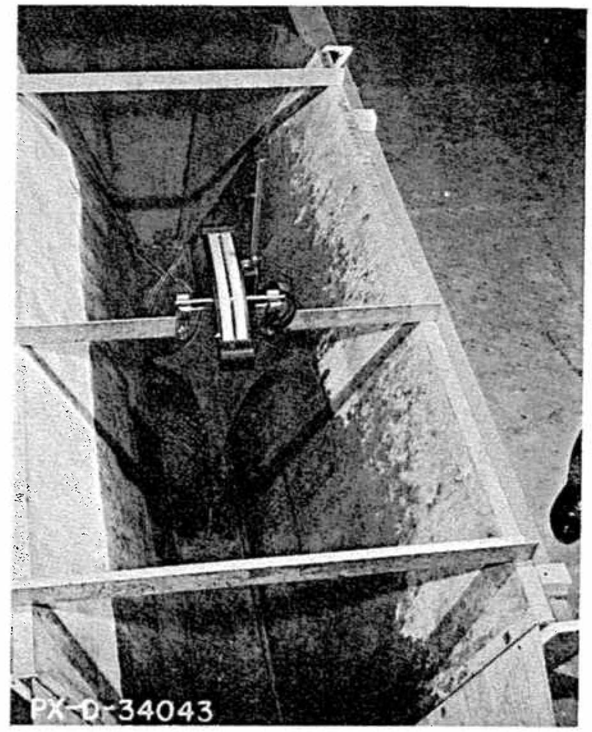
Effect of Windbreak

An attempt was made to decrease the wind effect by placing a windbreak upwind of the meter. A variety of results was obtained by this method. It was found that the error could be minimized by placing a 1- by 12-inch board immediately above the water surface and reasonably close to the meter. It was also found that the direction of the error (plus or minus) could be reversed by moving the board too close to the meter; however, the magnitude of the reverse error was not as great as the initial wind error. Representative data for the effect of a windbreak on the meter readings are shown in Tables 4 and 5. Values in these tables were read from the meter scale after the windbreak was placed in a single position for each direction of wind, as described under "Test Procedure."

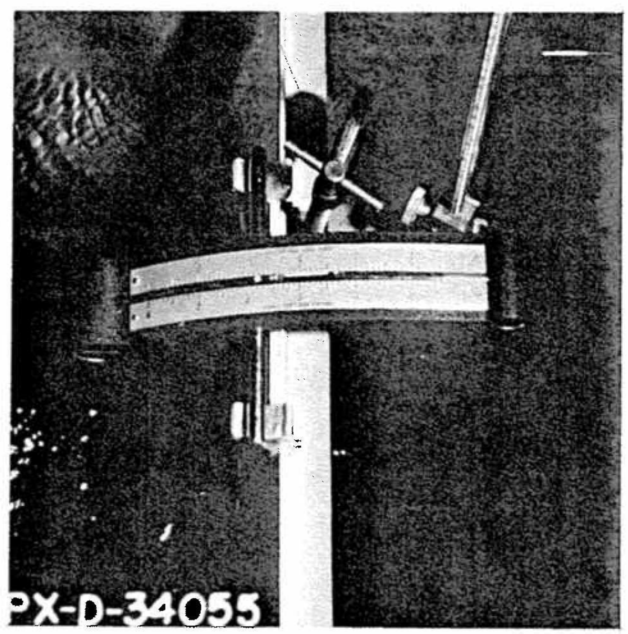
A comprehensive study of the wind flow patterns would undoubtedly yield the ideal position of windbreak for minimizing the wind error under the specific conditions used in the tests. However, under a different magnitude and direction of wind, the position would probably not be optimum and of doubtful benefit to the meter user. Therefore, the conclusions are general in nature: (1) wind can cause an error in the meter reading, (2) the error can be minimized by proper use of a windbreak, however, the optimum position is dependent on the magnitude and direction of the wind and should be determined by inspection in each individual case.



A. Headbox, Channel, Tailgate, Fan Upstream

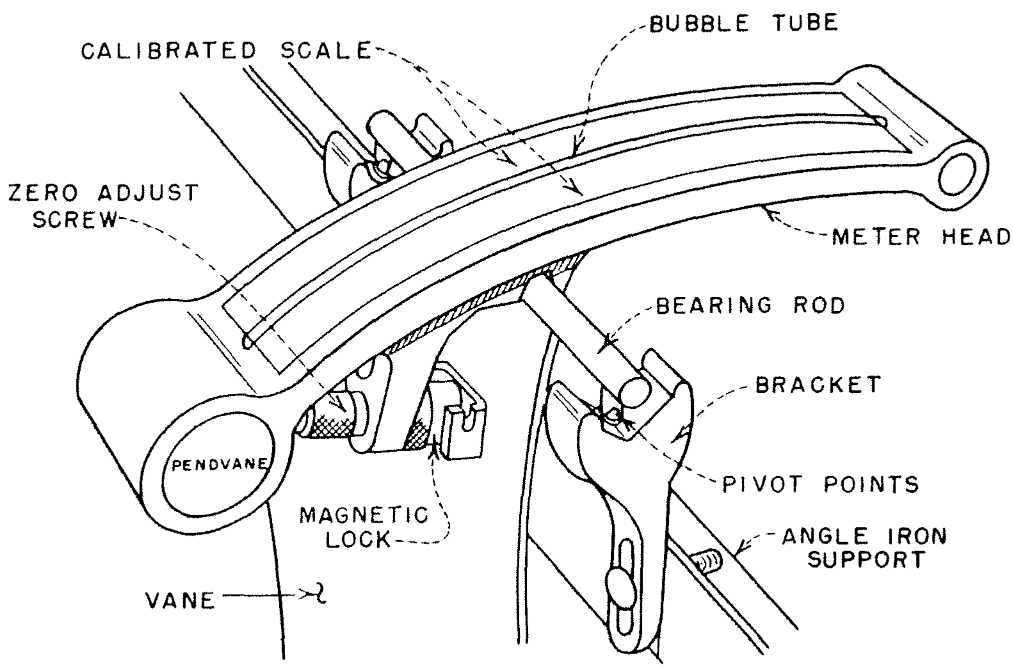


B. Pendvane Flowmeter, Mounting Bracket, and Precast Channel



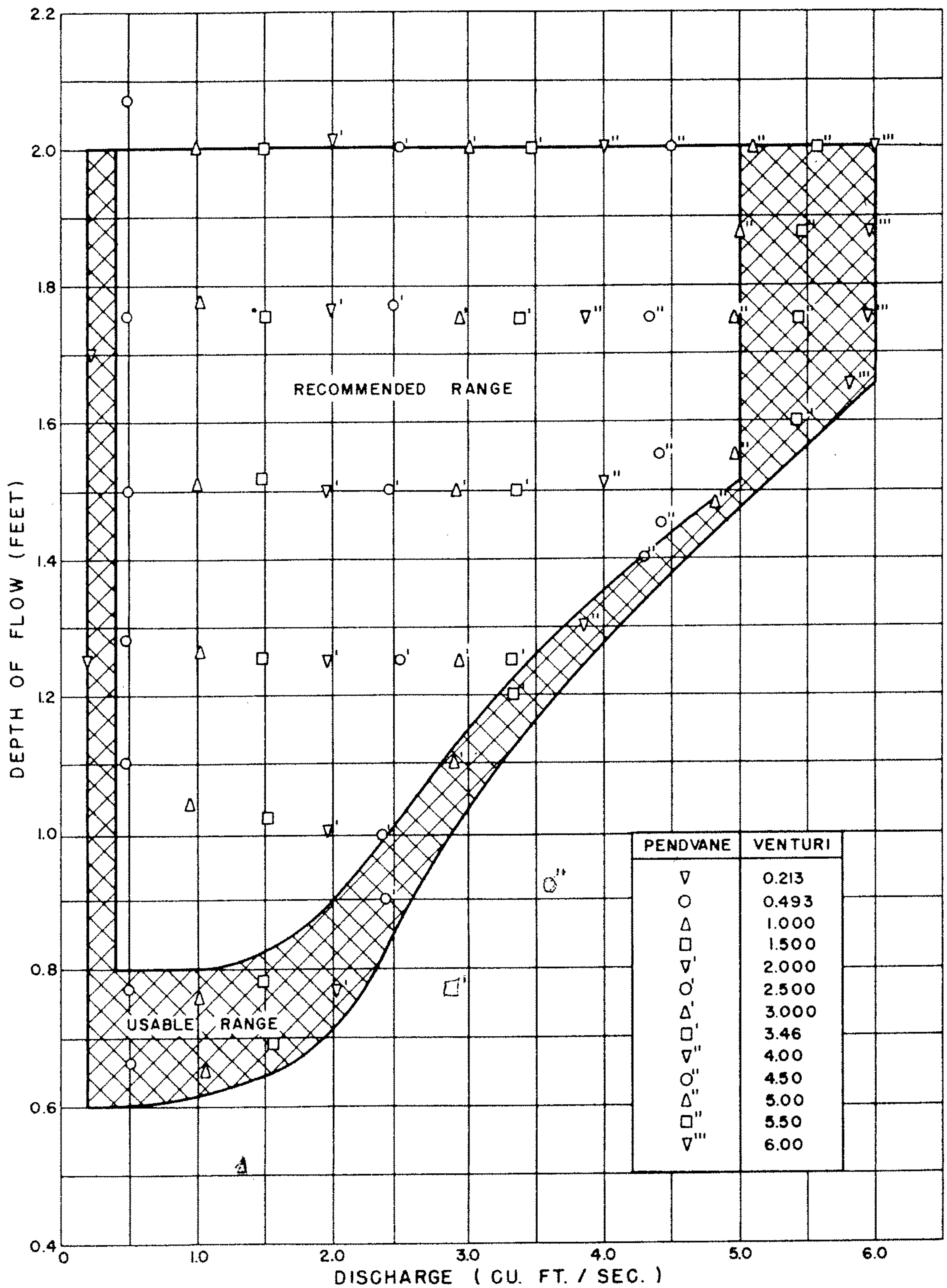
C. Meter Indicating Head and Point Gage
Q = 1.75 cfs, depth = 1.6 feet

PENDVANE FLOWMETER STUDIES
TEST FACILITY



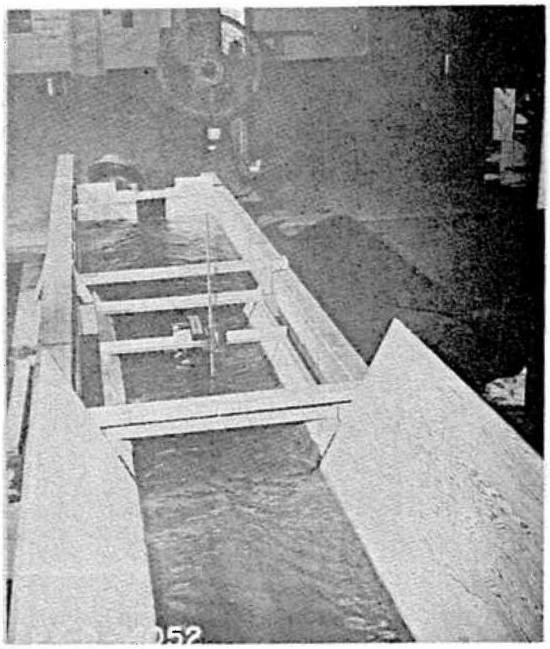
PENDVANE FLOWMETER STUDIES

METER ASSEMBLY

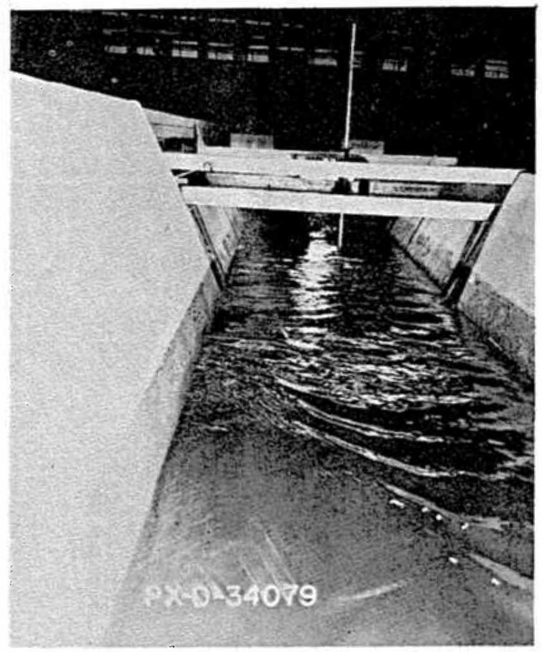


PENDVANE FLOWMETER STUDIES

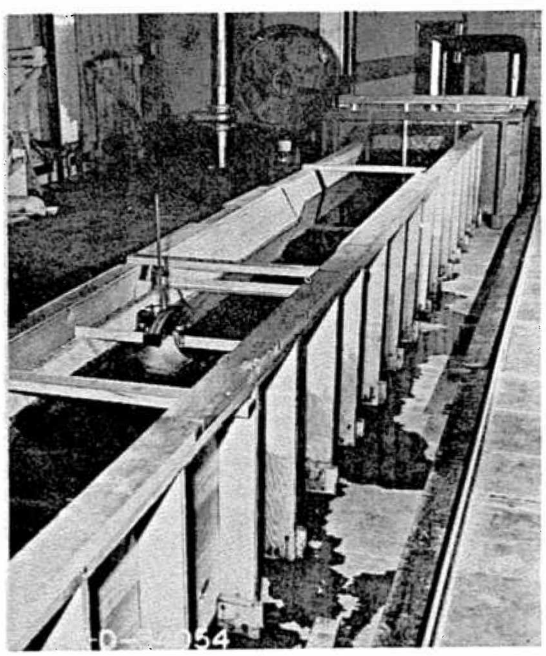
DEPTH OF FLOW VERSUS DISCHARGE



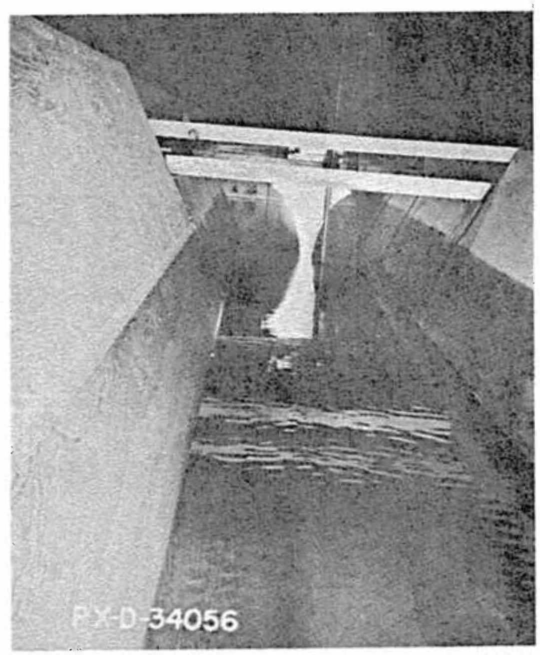
A. Q = 3.5 cfs, depth = 1.75 feet



B. Q = 3.0 cfs, depth = 1.5 feet

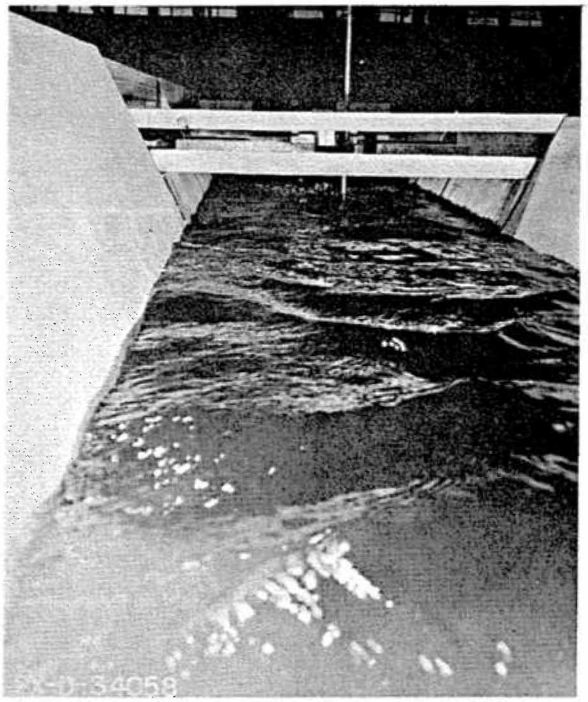


C. Q = 1.5 cfs, depth = 1.75 feet

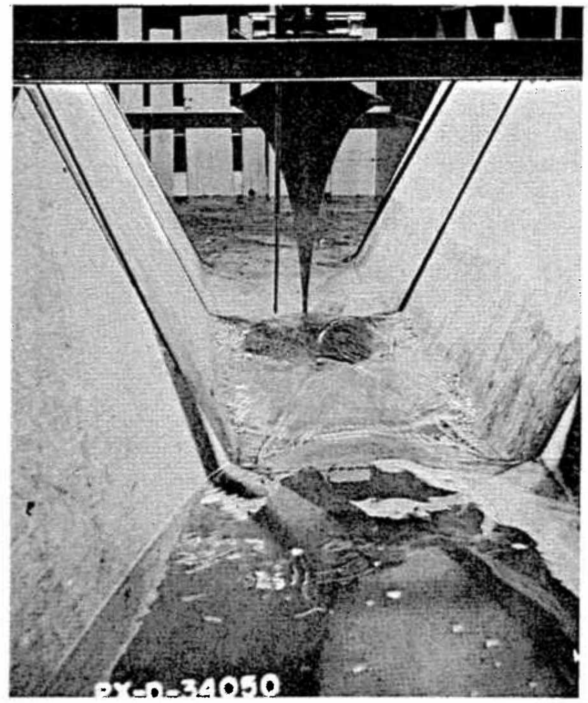


D. Q = 1 cfs, depth = 1.25 feet

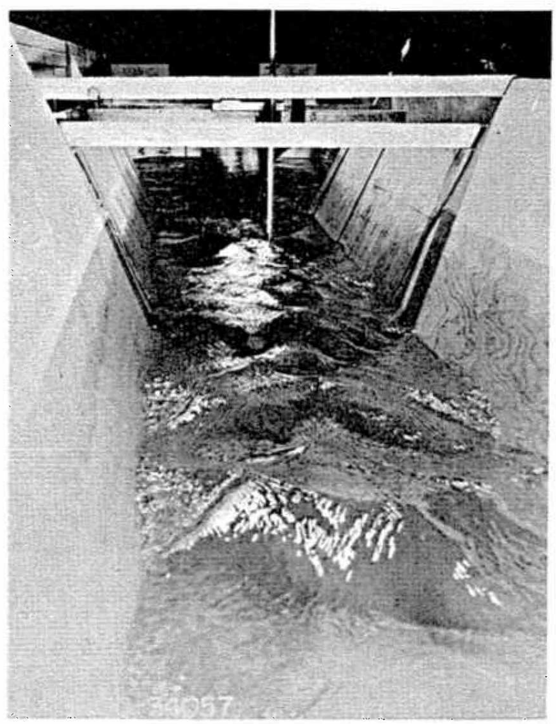
PENDVANE FLOWMETER STUDIES
FLOWS IN RECOMMENDED RANGE (ZONE A)



A. Q = 6.0 cfs, depth = 1.75 feet

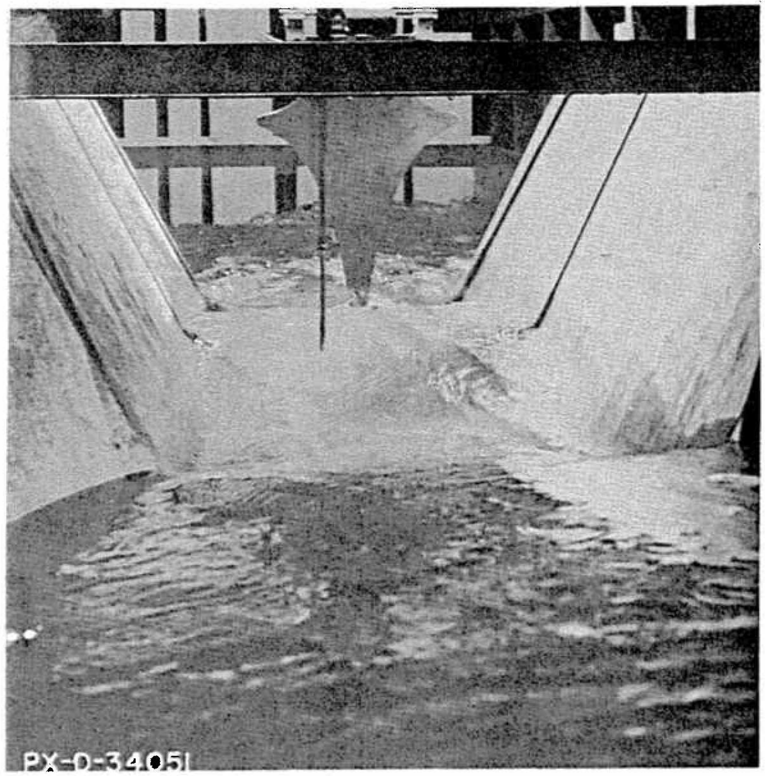


B. Q = 3.5 cfs, depth = 1.20 feet

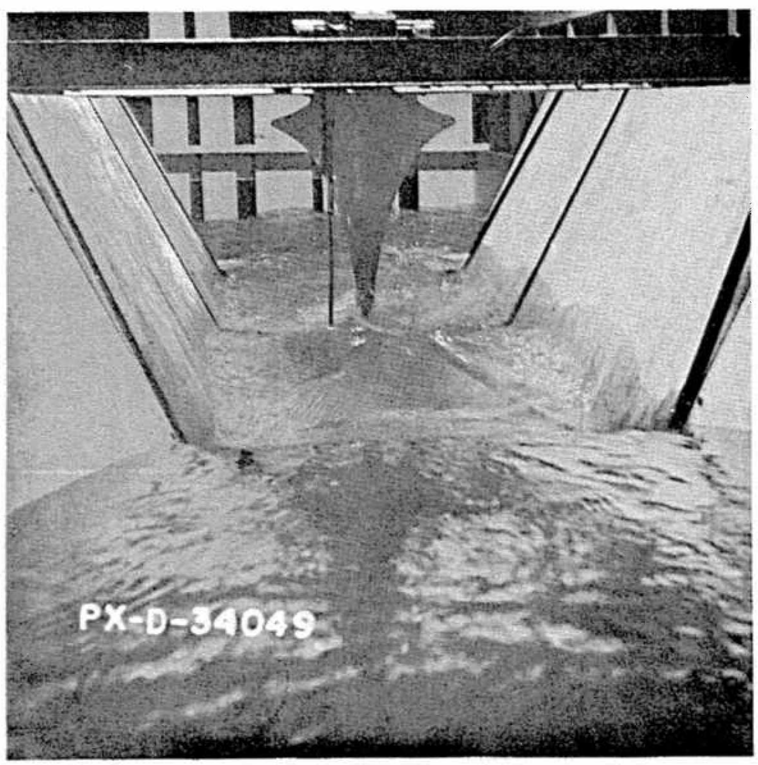


C. Q = 1.5 cfs, depth = 0.73 feet

PENDVANE FLOWMETER STUDIES
FLOWS IN USABLE RANGE (ZONE B)

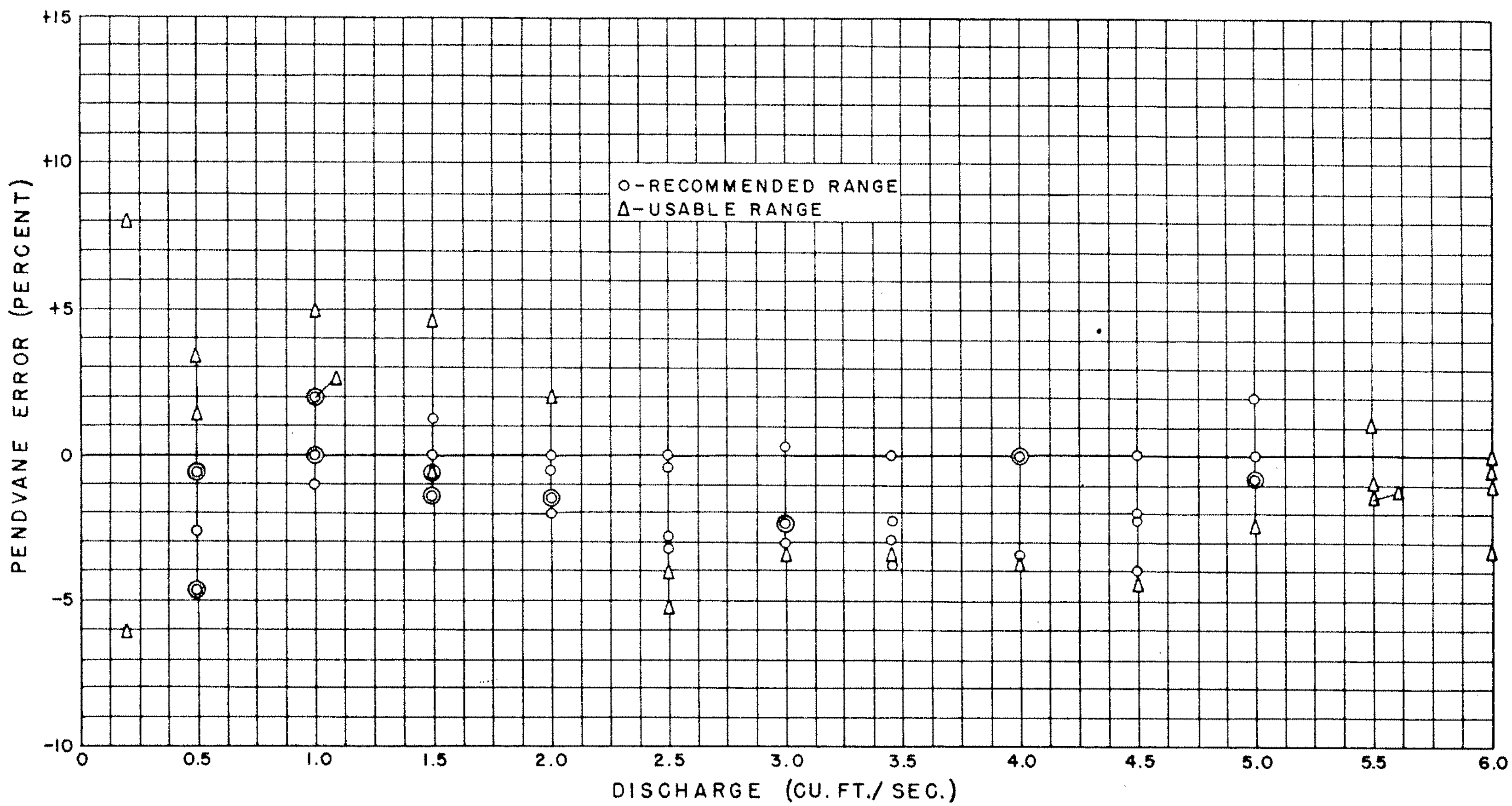


A. Q = 3 cfs, depth = 0.98 feet



B. Q = 3.2 cfs, depth = 1.00 feet

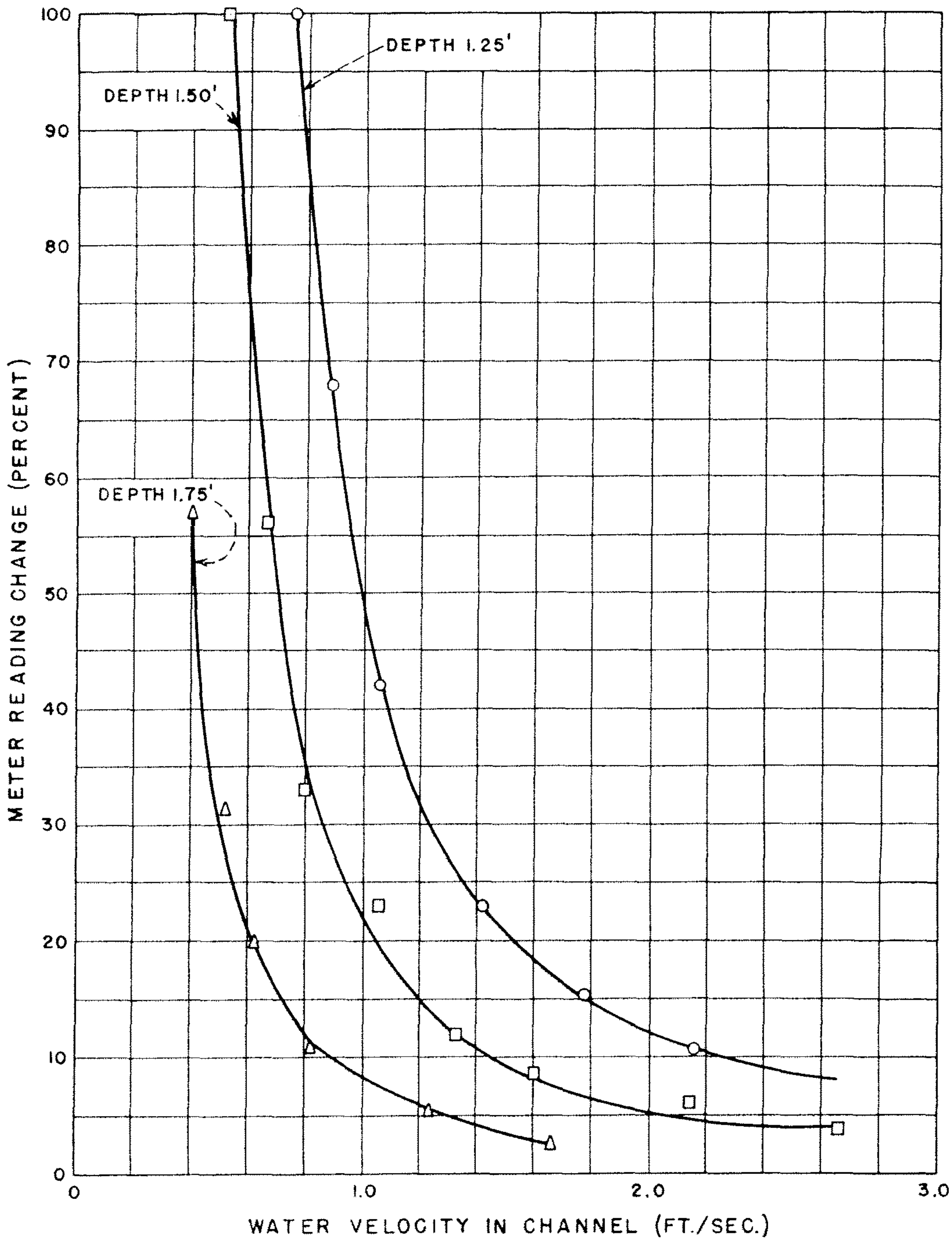
PENDVANE FLOWMETER STUDIES
FLOW IN UNUSABLE RANGE (ZONE C)



PENDVANE FLOWMETER STUDIES

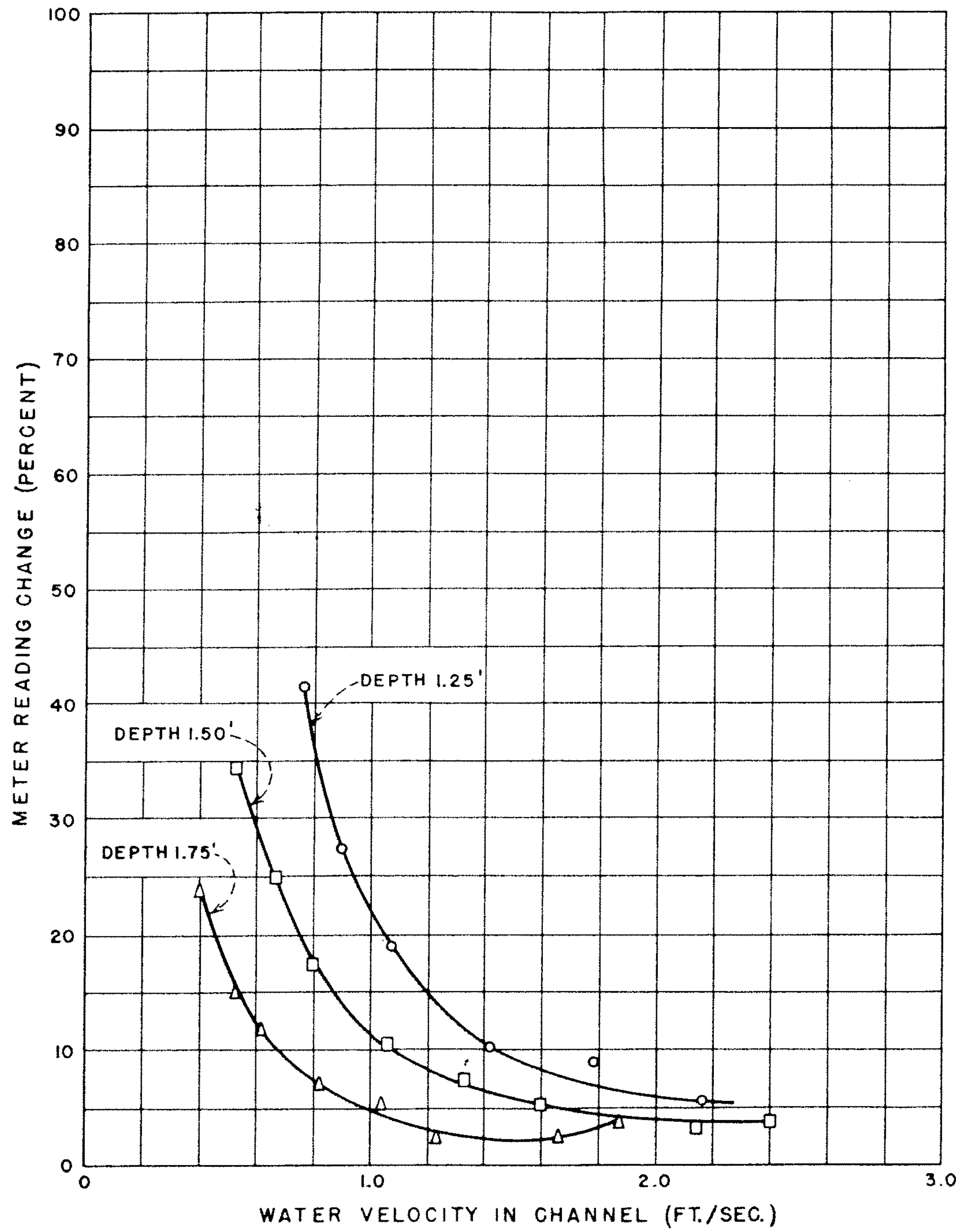
ERROR VERSUS DISCHARGE

FIGURE 7
REPORT R-HYD. 10



PENDVANE FLOWMETER STUDIES

METER READING CHANGE FOR
10 M.P.H. UPSTREAM WIND



PENDVANE FLOWMETER STUDIES

METER READING CHANGE FOR 10 M.P.H. DOWNSTREAM WIND

Table 1

COMPARISON OF PENDVANE READINGS TO CALIBRATED FLOW

Flow (cfs)	Depth (ft)	*Zone	Pendvane reading (cfs)	Error (%)
0.213	1.695	B	0.23	+8.0
0.213	1.250	B	0.20	-6.1
0.493	0.527	C	0.66	+33.9
0.493	0.663	B	0.51	+3.4
0.493	0.775	B	0.50	+1.4
0.493	1.100	A	0.47	-4.7
0.493	1.282	A	0.47	-4.7
0.493	1.500	A	0.49	-0.6
0.493	1.755	A	0.48	-2.6
0.493	2.070	A	0.49	-0.6
1.00	0.526	C	1.30	+30.0
1.00	0.650	B	1.05	+5.0
1.00	0.759	B	1.02	+2.0
1.00	1.040	A	0.99	-1.0
1.00	1.267	A	1.02	+2.0
1.00	1.510	A	1.00	0
1.00	1.775	A	1.02	+2.0
1.00	2.000	A	1.00	0
1.50	0.500	C	1.75	+16.7
1.50	0.690	B	1.57	+4.7
1.50	0.782	B	1.49	-.7
1.50	1.020	A	1.52	+1.3
1.50	1.255	A	1.48	-1.3
1.50	1.520	A	1.48	-1.3
1.50	1.754	A	1.49	-.7
1.50	2.000	A	1.50	0
2.00	0.586	C	2.08	+4.0
2.00	0.768	B	2.04	+2.0
2.00	1.000	A	1.96	-2.0
2.00	1.250	A	1.97	-1.5
2.00	1.500	A	1.97	-1.5
2.00	1.750	A	1.99	-0.5
2.00	2.000	A	2.00	0
2.50	0.661	C	2.35	-6.0
2.50	0.820	C	2.68	+7.2
2.50	0.900	B	2.40	-4.0
2.50	0.996	B	2.37	-5.2
2.50	1.250	A	2.50	0
2.50	1.500	A	2.42	-3.2
2.50	1.769	A	2.43	-2.8
2.50	2.000	A	2.49	-0.4
3.00	0.719	C	2.63	-12.3

Table 1--Continued

Flow (cfs)	Depth (ft)	*Zone	Pendvane reading (cfs)	Error (%)
3.00	0.999	C	2.82	-6.0
3.00	1.100	B	2.90	-3.3
3.00	1.250	A	2.93	-2.3
3.00	1.500	A	2.91	-3.0
3.00	1.750	A	2.93	-2.3
3.00	2.000	A	3.01	+0.3
3.46	0.787	C	2.89	-16.6
3.46	1.000	C	3.23	-6.7
3.46	1.200	B	3.34	-3.5
3.46	1.250	A	3.33	-3.8
3.46	1.500	A	3.36	-2.9
3.46	1.750	A	3.38	-2.3
3.46	2.000	A	3.46	0
4.00	0.869	C	3.25	-18.7
4.00	1.103	C	3.62	-9.5
4.00	1.250	C	3.80	-5.0
4.00	1.300	B	3.85	-3.7
4.00	1.511	A	4.00	0
4.00	1.750	A	3.86	-3.5
4.00	2.000	A	4.00	0
4.50	0.913	C	3.55	-21.0
4.50	0.942	C	3.65	-18.9
4.50	1.226	C	4.05	-10.0
4.50	1.400	B	4.30	-4.4
4.50	1.450	A	4.41	-2.0
4.50	1.550	A	4.40	-2.2
4.50	1.750	A	4.32	-4.0
4.50	2.000	A	4.50	0
5.00	1.480	B	4.88	-2.4
5.00	1.550	A	4.96	-0.8
5.00	1.750	A	4.96	-0.8
5.00	1.875	A	5.00	0
5.00	2.000	A	5.10	+2.0
5.50	1.600	B	5.42	-1.4
5.50	1.750	B	5.42	-1.4
5.50	1.875	B	5.45	-0.9
5.50	2.000	B	5.56	+1.1
6.00	1.650	B	5.80	-3.3
6.00	1.750	B	5.94	-1.0
6.00	1.875	B	5.97	-0.5
6.00	2.000	B	6.00	0

*A zone is recommended.
B zone is usable.
C zone is unusable.

Table 2

UPSTREAM WIND EFFECT ON PENDVANE READING*

Depth (ft)	Flow rate (cfs)	Pendvane reading (cfs)	Altered reading (cfs)	Velocity (ft/sec)	Error (%)
1.25	1.00	0.98	-0	0.76	100.0
1.25	1.25	1.24	0.40	0.89	67.7
1.25	1.50	1.47	0.85	1.07	42.2
1.25	2.00	1.95	1.50	1.42	23.1
1.25	2.50	2.42	2.05	1.78	15.3
1.25	3.00	3.00	2.72	2.16	10.7
1.50	1.00	1.00	0	0.53	100.0
1.50	1.25	1.23	0.54	0.67	56.0
1.50	1.50	1.47	0.98	0.80	33.3
1.50	2.00	1.95	1.50	1.06	23.1
1.50	2.50	2.42	2.13	1.33	12.0
1.50	3.00	2.90	2.65	1.60	8.6
1.50	4.00	3.83	3.60	2.14	6.2
1.50	5.00	4.72	4.55	2.66	3.6
1.75	1.00	1.05	0.45	0.40	57.1
1.75	1.25	1.24	0.85	0.52	31.4
1.75	1.50	1.50	1.20	0.62	20.0
1.75	2.00	1.99	1.77	0.82	11.0
1.75	2.50	2.47	2.25	1.04	7.0
1.75	3.00	2.94	2.78	1.23	5.5
1.75	4.00	3.85	3.75	1.66	2.6

*Wind velocity is approximately 10 mph immediately above the water surface.

Table 3

DOWNSTREAM WIND EFFECT ON PENDVANE READING*

Depth (ft)	Flow rate (cfs)	Pendvane reading (cfs)	Altered reading (cfs)	Velocity (ft/sec)	Error (%)
1.25	1.00	0.99	1.40	0.76	41.5
1.25	1.25	1.24	1.58	0.89	27.4
1.25	1.50	1.48	1.76	1.07	18.9
1.25	2.00	1.96	2.16	1.42	10.2
1.25	2.50	2.52	2.75	1.78	9.1
1.25	3.00	3.08	3.26	2.16	5.9
1.50	1.00	1.04	1.40	0.53	34.6
1.50	1.25	1.23	1.54	0.67	25.2
1.50	1.50	1.48	1.74	0.80	17.6
1.50	2.00	1.94	2.15	1.06	10.8
1.50	2.50	2.47	2.66	1.33	7.7
1.50	3.00	3.00	3.16	1.60	5.3
1.50	4.00	3.90	4.04	2.14	3.6
1.50	4.50	4.38	4.55	2.40	3.9
1.75	1.00	1.00	1.24	0.40	24.0
1.75	1.25	1.25	1.44	0.52	15.2
1.75	1.50	1.48	1.66	0.62	12.2
1.75	2.00	1.97	2.11	0.82	7.1
1.75	2.50	2.49	2.63	1.04	5.6
1.75	3.00	3.04	3.12	1.23	2.6
1.75	4.00	3.86	3.97	1.66	2.8
1.75	4.50	4.25	4.41	1.87	3.8

*Wind velocity is approximately 10 mph immediately above the water surface.

Table 4

EFFECT OF WINDBREAK ON PENDVANE READING UNDER DOWNSTREAM WIND CONDITIONS

Depth (ft)	Pendvane reading (cfs)	Pendvane reading with wind (cfs)	Pendvane reading windbreak installed (cfs)
1.25	0.99	1.40	1.28
1.25	1.24	1.58	1.48
1.25	1.48	1.76	1.65
1.25	1.96	2.16	2.07
1.25	2.52	2.75	2.64
1.25	3.08	3.26	3.16
1.50	1.04	1.40	1.22
1.50	1.23	1.54	1.42
1.50	1.48	1.74	1.59
1.50	1.94	2.15	2.05
1.50	2.47	2.66	2.55
1.50	3.00	3.16	3.05
1.50	3.90	4.04	3.97
1.50	4.38	4.55	4.46
1.75	1.00	1.24	1.04
1.75	1.25	1.44	1.28
1.75	1.48	1.66	1.55
1.75	1.97	2.11	2.00
1.75	2.49	2.63	2.52
1.75	3.04	3.12	3.06
1.75	3.86	3.97	3.90
1.75	4.25	4.41	4.27

Table 5

EFFECT OF WINDBREAK ON PENDVANE READING UNDER UPSTREAM WIND CONDITIONS

Depth (ft)	Pendvane reading (cfs)	Pendvane reading with wind (cfs)	Pendvane reading windbreak installed (cfs)
1.25	2.42	2.07	2.30
1.25	3.42	3.15	3.30
1.50	2.42	2.15	2.38
1.50	3.34	3.15	3.30
1.75	2.46	2.30	2.46
1.75	3.41	3.30	3.39

Evaluation of the Vane-Type FLOW METER

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THE vane-type flow meter was calibrated for a range of operating conditions both in the hydraulics laboratory at Colorado State University and through a field trial. Three meters were tested, all of which were made for a 2-ft rectangular section. Each of the meters was a production model furnished by the manufacturer*.

The early development of the vane meter was made by Ralph L. Parshall starting about 1948. The development was inspired by need for a simple, direct-reading device which would give reasonable accuracy and would operate at practically no loss of head. Disadvantages of most devices in present use are that a considerable loss of head is usually required for correct operation and that, for most, a reading of depth must be converted to flow by use of tables or charts. In many cases it has been found that these two items limit the use of the devices. Another great need exists for a device that will work under conditions of very low velocities and submerged conditions. Most of the existing devices will not operate at all under these conditions. It has been advanced that the vane-type meter operates very successfully for this condition and that its action is not affected by variation of approach velocity or by any downstream condition.

The flow meter has been developed so that vanes of different shapes are available for measurement of flow in different cross sections. The vane shape was so determined that, for a constant flow, the meter should indicate the same flow for high velocities and shallow depths as for slower velocities and greater depths. The shape of the vane integrates the force due to the flowing water for a range of velocities and depths under constant discharge conditions.

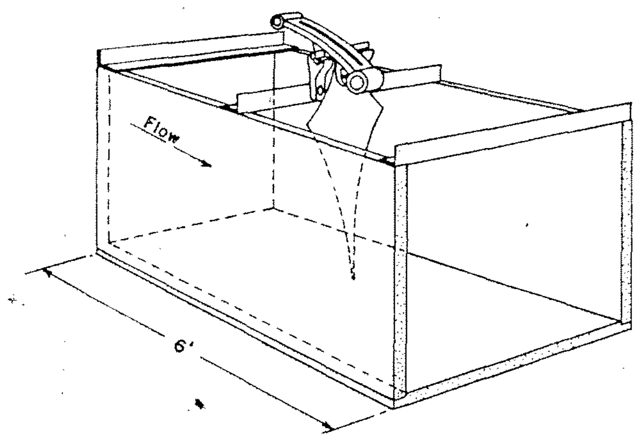

Fig. 1 Vane meter in a rectangular section

The vane must be suspended in a specified section of defined shape and size. Sections being recommended are 6 ft in length with the meter mounted approximately at the halfway point. These measuring sections may be either trapezozidal or rectangular, but must conform to the shape for which the meter was developed and calibrated.

The indicating device in the head of the meter consists of a liquid-filled tube mounted opposite a calibrated scale. This curvature of the head was predetermined in the laboratory. In the liquid-filled tube is a small air bubble which moves along the curved tube depending on the deflection of the vane. The amount of flow is then indicated on the scale opposite the bubble in the tube. This scale can be marked in cubic feet per second, gallons per minute, or any prescribed unit of discharge. A meter being used in a rectangular section is shown as Fig. 1.

Description of Tests

Most of the tests were made in a 2-ft-wide, glass wall, testing flume which is part of the permanent equipment in the hydraulics laboratory. This flume was used by Parshall for much of the early development work of the vane meter. For these tests the flowmeter was installed at a point which gave approximately a 15-ft length of unobstructed channel immediately upstream. The meters were installed very carefully in the manner prescribed by the developers. This included proper clearance of the tip from the floor and the meter being level and exactly at right angles to the direction of flow.

To determine the effect of the approach velocity profile on the operation of the meter, a lattice baffle was installed 8 ft upstream from the measuring section for some of the tests. This baffle consisted of 1 x 1-in. strips of lumber having openings 1⅜ in. square. In effect the baffles changed the velocity distribution at the measuring section so that this variation in velocity profile, as it affected meter operation, could be studied. The baffle is not a recommended feature of the field installation.

The discharge was determined using precalibrated

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*Meters for the tests reported were furnished by the Applied Research Co. Trade and company names are included for the benefit of the reader and do not infer endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.

orifice plates in the discharge line from the pump. Flows up to about 5 cfs were used, with the depth of flow for a given discharge being varied with an adjustable tailgate. Usually, for a constant discharge, five depths of flow and the corresponding velocities were used.

For the field tests an existing concrete box on a farm lateral which was 2 ft wide and 2 ft deep was used with the meter installed 3 ft from the upstream end. The box was located approximately 150 ft downstream from the headgate on the lateral.

A 1-ft Parshall measuring flume was installed immediately downstream from the meter section. To insure that the flume was not under submergence during the test periods, depths of flow at the point for determining submergence effect were measured. With these measurements it was determined that submergence was not a factor during the flume operation so that the free-flow discharge relationship was used throughout the testing. An adjustable tailgate was used in the ditch downstream from the meter section to vary the depth of flow through the section for a given discharge.

Presentation and Evaluation of Data

For the operation of the meter, zones A and B have been specified by the manufacturer. Zone A is the recommended range of operation for greater accuracy, but zone B also covers a usable range of operation. Actually these zones limit the range of velocities with those in zone B being higher than those in zone A. Depths shallower than specified for zone B would necessarily mean much higher velocities, and therefore are not in a recommended zone of operation. These operation zones are shown in Figs. 2 and 3.

For the laboratory tests shown in Fig. 2, relatively constant discharges of 1, 2, 3, 4, and 5 cfs were used. For each discharge the depth was varied in the 2-ft-wide section so that both the A and B zones of operation were included. For this comparison a ratio of the discharge as indicated by the vane meter to that determined from the orifice in the pump-discharge line was used. A ratio of 1.0 would indicate that the two determinations were the same. If the ratio were 0.9, then the vane discharge would be 10 percent lower than that from the orifice meter. Conversely, for a ratio of 1.10 the vane discharge determination would be 10 percent higher than that from the orifice meter. The normal section indicated in Fig. 2 was the 2-ft-wide glass wall flume with 15 ft of unobstructed approach. The second condition was with the baffle installed 8 ft upstream from the vane meter section.

Considering first those tests in the laboratory channel for the A zone and the normal flume section, it is noted that, for flows of 1 to 3 cfs, the vane meter indicated discharges that were always equal to or higher than those from the orifice meters. For the higher flows the vane meter gave discharges that were both lower and greater than by the orifice method. Almost identical trends were noted for each of three meters tested. For the three lower flows with the so-called normal section, the vane meter overregistered the flow by as much as 9 percent at the intermediate depths. However, the average range of this variation was in the order of 5 percent. As an example, for a flow of 3 cfs the ratio varied from 1.025 to 1.068

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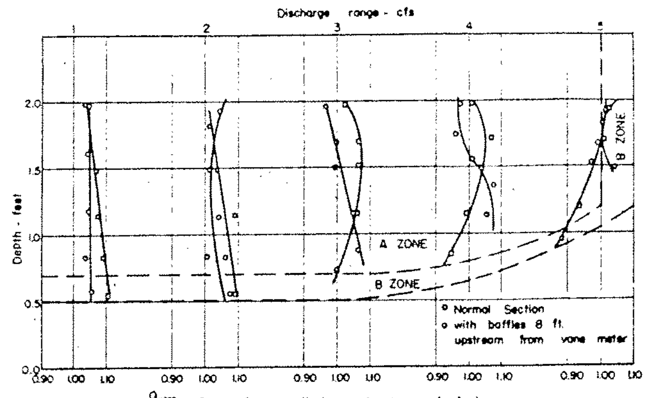

Fig. 2 Laboratory tests of the vane meter

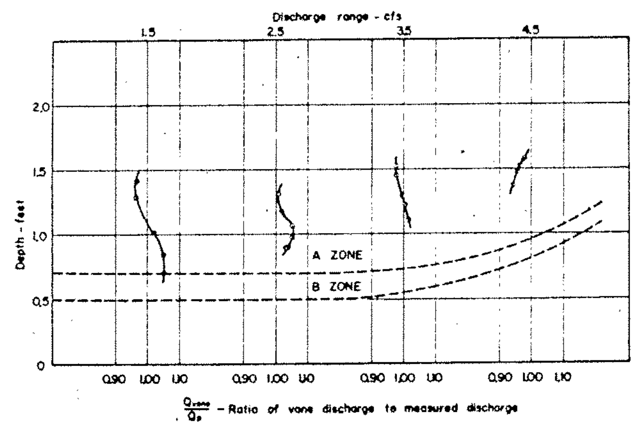

Fig. 3 Field tests of the vane meter

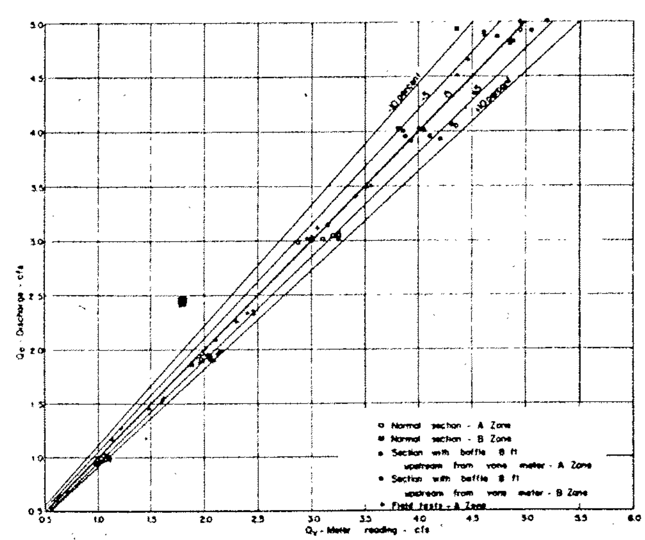

Fig. 4 Laboratory and field tests of the vane meter

. . . Vane-Type Flow Meter

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for the A zone. Considering the two higher flows under this condition, there was a much wider variation in the determined discharges. Here again the trends were identical for the three meters and the ratios varied. For 4 cfs at the shallower depth this ratio was about 0.94, whereas at depths nearer 1.7 feet it was 1.07.

To introduce a different approach condition baffles were installed 8 feet upstream from the measuring point as previously discussed. This situation introduced turbulence and resulted in a shorter length for establishment of the velocity profile. More uniform velocities throughout the section would exist for this condition. The effect of this situation on the operation of the meters is illustrated in Fig. 2. In general, an entirely different relationship was found than with the previous condition, illustrating that the approach-velocity profile does exert a considerable influence on the operation of the meter as would be expected.

In general, the laboratory tests made in the B zone of operation show a wider range in deviation of vane discharge from the independent method. Differences up to plus 11 percent for the lower flows and minus 12 percent at the higher flows were observed.

The results of observations on the meter operation under field conditions are shown in Fig. 3. The effect of a range of depths for each of four different discharge ranges are shown. For flows of 1.5 and 3.5 cfs the vane meter gave discharges that were both less and greater than those determined by the Parshall flume. At an intermediate flow of 2.5 cfs the vane meter gave flows that were always larger, and at 4.5 cfs always smaller, than those from the Parshall flume determination. This amounted to a total variation of about 8 percent for the lowest flow and 4 percent for the others. All these tests were within the A zone of operation. Considering only the lowest and highest ratios results in an overall expected accuracy of about ±5 percent for a total possible range of 10 percent.

Another method of presenting the results of the vane meter tests is shown in Fig. 4. The comparison of the discharge as determined by the vane meter and that of the independent method of orifice or Parshall flume is given. If the two determinations are the same, then a 1-to-1 relationship given by the heavier line applies. For flows in the A zone of operation for the laboratory tests, the deviations are generally within ±5 percent, although there are several points which fall outside these zones. In general, for the B zone of operation the points show a wider deviation.

Field tests comparing the discharge of the vane meter with that of an accurately installed Parshall flume also are given in Fig. 4. Here the maximum deviations are near ±5 percent with most of the points falling within ±4 percent accuracy. These points represent carefully observed data where, in most cases, duplicate observations were made.

Discussion of Results

From the results of these tests it is evident that approach conditions and the resulting approach-velocity profiles do affect the accuracy of the flow meter. With the long, smooth-walled section, somewhat greater deviations were noted than under the other conditions. With this condition the velocities in the vertical section might range from twice the average velocity near the surface to one-half near the bottom.

For the case of the lattice baffle installed upstream from the measuring point in the laboratory flume, the velocities in a center-line profile would be more nearly the same. This would also be true for the field-measuring section, primarily because the measurements are made immediately downstream from a section of converging flow which results in a more uniform velocity profile.

An accuracy of about ±5 percent could be expected from the vane meters used in these tests. At intermediate depths the accuracy is best, usually being in the range of 0 to ±5 percent. The largest deviations in the A zone were usually at the lower depths and corresponding higher velocities.

Other items not investigated in this study may affect the accuracy of the meter. One of these is magnitude and direction of the wind at the time the discharge measurement is being made. Another is the presence of debris in the flow. The latter should not be important if care is taken to clean the vane before each reading.

. . . Elected Fellow

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Research Division; vice-chairman of the Farm Structures Division; a member of the Curriculum and Course Content Committee of the Education and Research Division, and the Electric Utilization Research Conference Committee. At present he is serving as chairman of the Public Relations and Publicity Committee.

Other Publications

OF PARTICULAR interest to libraries and research workers are the TRANSACTIONS OF THE ASAE and AGRICULTURAL ENGINEERS YEARBOOK, companion publications to AGRICULTURAL ENGINEERING.

Under the Society's new editorial program, introduced in 1963, the TRANSACTIONS of the ASAE shall serve as the Society's principal repository for detailed technical manuscripts. Articles are reviewed by reader committees and accepted for publication on their value as contributions to the published literature of the agricultural engineering profession and their ability to present new, original and competent material. Introduction of a page charge to sponsors of research reported for articles published in the TRANSACTIONS will make it possible to increase its size to at least 350 pages of full-length, technical papers in the 1963 edition. Beginning this year the TRANSACTIONS will be published in four numbers (all general editions). Complete volume of four editions may be ordered from ASAE, 420 Main St., St. Joseph, Mich., at $10.00 ($5.50 to ASAE members). Single copies sell for $4.00 each ($3.00 to ASAE Members).

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