

A STUDY OF THE DISCHARGE COEFFICIENT OF A TRIANGULAR
WEIR AS AFFECTED BY WEIR-PLATE CONDITIONS.

A THESIS

SUBMITTED BY

CHARLES EDWARD GIBSON

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AND

THOMAS WILLIAM PETTUS

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I.

INTRODUCTION

The two problems submitted to analysis in this thesis were: first, the changes in the value of the discharge coefficient of a triangular weir, as affected by the degree of roughness of the weir-plate; and second, the variations in the mean value of the coefficient with a rising head and with a falling head on the weir.

The value of the results obtained from many scientific investigations is dependent upon the accuracy with which measurements have been made. Any conditions which affect the measurements are, therefore, of vital importance, and consequently merit the careful consideration of the engineer.

Among the many problems to which the above statement applies, is the specific one of measuring the flow of water by means of the triangular weir. This thesis deals with several phases of this particular problem. The increasing use of the triangular weir as a device for measuring flow of liquids gives importance to the problem.

In so far as the writers have been able to ascertain, the amount of experimental work which has been done on this problem is small. Consequently the quantity of literature available for reference was meager, and hence the work for this thesis was performed with but few suggestions from outside sources. The writers are indebted to Professor J. A. Switzer for suggestions concerning the arrangement of the apparatus used in the experimental work, and for supervision of the work.

In the work preceding the actual experiments, invaluable aid was rendered by Dr. J. T. Porter in calibrating certain portions of the apparatus which later will be described. The authors acknowledge their indebtedness to him for his gracious assistance.

II.

GENERAL SURVEY OF THE FIELD.

To the best knowledge of the authors, very little attention has been devoted to research work concerning the triangular weir and the conditions under which it functions. "The properties of the V-notch weir were first investigated by Prof. James Thomson, brother of Lord Kelvin, and recently more exhaustively by Mr. James Barr, of Glasgow University."* The experiments of Dr. Barr covered an extensive range of conditions. He varied the width and the depth of the channel of approach, the angle of the V-notch, and the size of the notch-plate. The weir-plates which he used were of non-corrodible material.

At present the triangular, or V-notch, weir is incorporated into several commercial metering devices. In such installations the notch-plate is of non-corrodible material, and the measurements obtained are of a sufficient degree of accuracy. For instance, one well known manufacturing company # guarantees for all its V-notch meters "an accuracy within $1\frac{1}{2}$ per cent of actual weight, temperature variations not to exceed 25° F. either way."

* Engineering Leaflet No. 18, Cochrane Corporation.

The Cochrane Corporation.

III.

STATEMENT OF PURPOSE

The condition of the upstream surface of the weir-plate has a marked effect on the rate of discharge over the weir. The object in undertaking this work was to determine the effects produced on the discharge over a triangular weir, by changing the conditions (as regards roughness) of the surface of the plate. Primarily, it was desired to discover to what extent confidence could be placed in the triangular weir as a device for measuring the flow of liquids.

The facts as disclosed by the experiment are presented with no attempt to apply them to the support of any existing theory.

IV.

GENERAL THEORY

The formula for computing the discharge over a 90-degree triangular weir is

$$Q = C H^{5/2}, \quad (1)$$

in which Q represents the discharge in cubic feet per second, C is an empirical coefficient, and H represents the head on the weir in feet.

This formula is derived as follows: The general equation for discharge is

$$Q = C a v, \quad (2)$$

in which Q is the discharge in cubic feet per second, C is the coefficient of discharge, a is the area, in square feet, of the opening through which the discharge takes place, and v is the velocity of the liquid in feet per second. In dealing with discharges through a triangular weir, a is always the area of a triangle. The base of this triangle varies directly as H varies. The altitude of this triangle also varies directly as H . Hence the area a (equals one-half the product of the base by the altitude) is proportional to H^2 . The velocity v (equals $\sqrt{2 g H}$) varies as $H^{1/2}$. Then a times v is proportional to H^2 times $H^{1/2}$, or to $H^{5/2}$, and $Q = C H^{5/2}$.

V.

DISCUSSION OF AVAILABLE METHODS.

Several methods of measuring the head were considered: namely, by means of a hook-gage, by means of a float connected to a system of levers, and by means of a cathetometer.

Of these three methods of measuring the head on a weir, the hook-gage method is, perhaps, most widely used. By means of it, the head may be measured to the nearest one-thousandth foot. It was desired in this work, however, to secure readings within even more restricted limits. For this reason, this first method was deemed unsuitable.

The principle of the next method considered is , in brief: The water in the channel of approach to the weir supports a float to which is connected a system of counter-balanced levers. Any movement of the float is transmitted in magnified form to the end of the last lever (a pointer), which moves along a graduated scale. This scale is so calibrated that the position of the pointer serves to indicate the value of the head at any given time. Among the factors which caused this method to be rejected were the probable difficulties of securing joints which were sufficiently free from either friction or lost motion.

The cathetometer method gave promise of being most suitable for the work at hand, and was selected.

The most outstanding advantage to be gained by the use of the cathetometer for measuring the head is the accuracy with which observations can be made. With the instrument employed in this work, readings to the nearest $5/100$ millimeter (equivalent, approximately, to $1/6100$ foot) can be secured. The zero reading of the cathetometer was obtained by sighting upon the apex of the weir. Therefore the difficulty of adjusting the water surface to the level of the weir crest, in order to obtain the zero reading, was eliminated. Subsequent readings were obtained by bringing the horizontal

cross-hair of the telescope tangent to the meniscus within a gage-glass attached to the weir-tank. Such direct measurements could not be had with either of the other methods considered. In fact, this method had greater advantages and fewer faults than any of the other possible ones.

The first method considered for the measurement of the discharge was by means of a deflector in connection with a weighing tank. The deflector would allow the discharge to enter the tank for a given length of time.

The discharge over a weir may be measured by noting the rate of rise of water in a tank. This method was used by Dr. Barr in his experiments, but was not available for this work.

The method adopted was to obtain the time required for a given weight of water to flow into the weighing tank. This method was the best of those available.

VI.

DESCRIPTION OF APPARATUS

The experimental work was conducted in the Hydraulic Laboratory of the University. The apparatus was so arranged as to form a complete circuit for the water, which was kept circulating by means of a centrifugal pump. The discharge line of the pump was connected to a closed overhead tank, which, in turn, was connected by a pipe-line (about 30 feet long) to the weir-tank. The next link in the circuit was the weighing tank. The outlet valve from the weighing tank was arranged to discharge into a concrete pit, into which the suction pipe from the pump projected. Thus the circuit was completed.

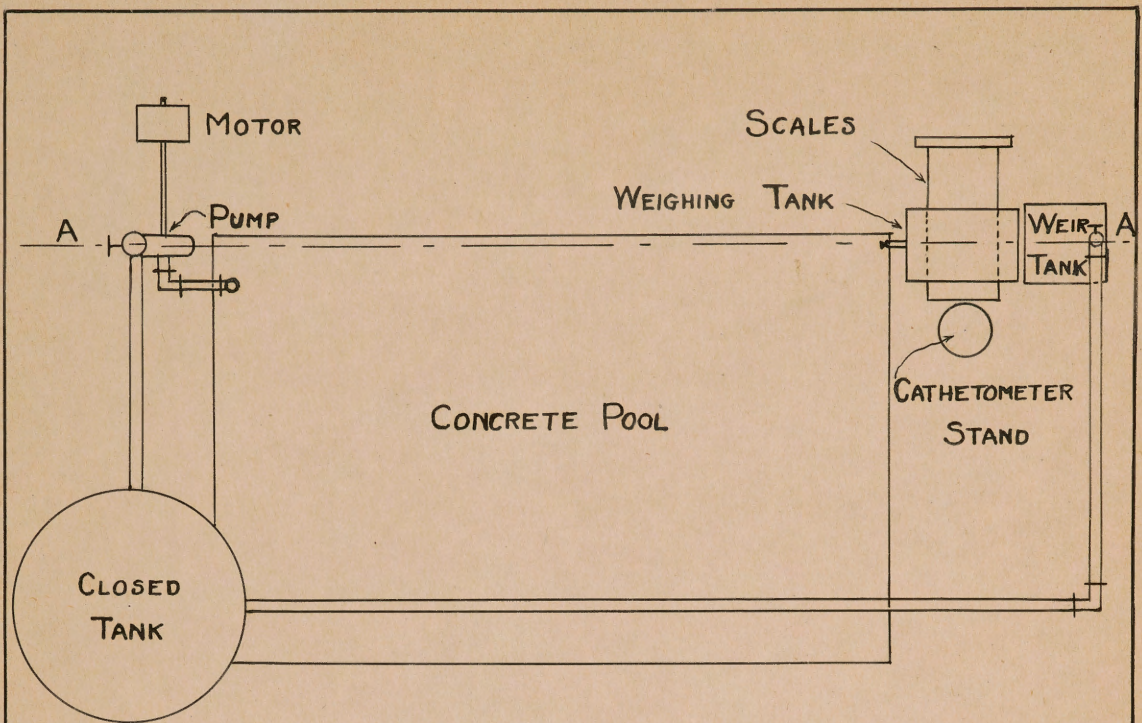
The centrifugal pump used (Serial No. 117) was manufactured by the I.P.Morris Company. Its rated capacity is 1250 gallons per minute against 48 feet total head at 1000 revolutions per minute.

The closed steel tank to which the discharge pipe from the pump was connected, had a capacity of approximately 7500 gallons. Attached to the tank were two auxiliaries which proved of great value in regulating the head on the weir. The first of these was a mercury manometer; the second, an air valve.

The weir-plate (made of iron) was connected to a tank 35 inches long, 30 inches wide and 30 inches deep. This tank was equipped with two means of stilling the water in the channel of approach. The turbulence of the water was lessened by means of a burlap bag inclosing the end of the inlet pipe. The turbulence was further checked by a baffle which stood in a vertical position within the tank. This baffle consisted of a wooden framework, the sides of which were covered by coarse-mesh wire screen. Within this framework a filler of coarse gravel was placed. It served its purpose satisfactorily.

The metal weighing tank had a capacity of 60 cubic feet.

The platform scales were manufactured by the Fairbanks Company, and were designed for hydraulic laboratory use. More accurate timing of periods of discharge was made possible by the use of an electric signal. The scale-beam was made a portion of the electric circuit. One end of this beam was connected through a buzzer to a storage battery. As the other end of the beam moved upward, a contact was made which closed the circuit, thereby energizing the buzzer.



PLAN



SECTION AT A-A

ARRANGEMENT OF APPARATUS



A GENERAL VIEW OF THE APPARATUS SHOWING
THE RELATIVE SIZE AND LOCATION OF
THE VARIOUS PARTS.



A FRONT VIEW OF THE WEIR-TANK
SHOWING THE LOCATION AND ARRANGEMENT
OF THE RELATED APPARATUS

VII.

DESCRIPTION OF METHODS USED

In this thesis, the preliminary work involved the calibration of a set of weights, the setting up of the apparatus, and the testing of the scales for sensitiveness.

The set of weights used in connection with the platform scales were calibrated by Dr. J. T. Porter, who is the custodian of the standard weights and measures of the State of Tennessee. The weights employed in this work were calibrated by comparison with these standards.

The weighing tank was centered on the platform of the scales. The platform was leveled with the aid of a spirit level. A firm stand was used as a base for the cathetometer.

A sensitiveness test was conducted as follows: the scales were brought into equilibrium with the tank empty. Then a given mass was placed on the platform and the scales were balanced, the value of the balancing weight being observed. After the mass was removed from the platform, the tank was filled with water and the scales balanced. The same mass and the same counterweight used at first were then applied in their proper places. The scales came to a balance, indicating that they possessed sufficient sensitiveness.

Another test was performed to determine the lever arm ratio of the scales. The scales were brought to a balance, and a mass of known weight was placed upon the platform. A mass sufficient to balance the scales was applied to the hanger, and afterwards accurately weighed on chemical balances. The ratio of the weight upon the platform to the balancing counterweight gave the ratio of the lever arms.

The method employed in the experimental work may be illustrated by describing the procedure followed in a typical run. The cathetometer was

set upon the base provided for it and leveled. The zero reading was obtained by bringing the horizontal cross-hair of the telescope into line with the vertex of the weir crest. With the zero reading secured, the pump was started, and water was admitted into the weir-tank, its rate of flow being controlled by the adjustment of the pump discharge valve, and of the weir-tank inlet valve. The maintenance of a constant head was facilitated by keeping an air cushion above the water in the closed intermediate tank. When the level of the mercury in the manometer ceased to fluctuate, it indicated that conditions prerequisite to maintaining a constant head on the weir prevailed. The cross-hair of the telescope was brought tangent to the meniscus of the water in the gage-glass.

A run quickly followed the establishment of a constant head. The outlet valve of the weighing tank was closed after it was ascertained that the counterweights slightly more than balanced the weight of the tank and its contents. After the accumulation of a sufficient quantity of water in the tank, the scale-beam rose, completing the electric circuit. The time of occurrence of this initial contact was observed. It was endeavored to read the time to the nearest one-fifth second. A sufficient number of counterweights to insure a run of more than 200 seconds (in most cases) was added. The numbers stamped upon these counterweights were recorded as the weights were added on the hanger. During the process of the run, check observations were made on the manometer and the cathetometer. After an amount of water sufficient to balance the counterweights accumulated in the tank, a second contact was made by the rising beam. The time of occurrence of this contact was likewise noted. From the two observations, the time length of the run was found.

The first of six series of runs was made with the iron weir-plate in

its original rusty condition. The coating of rust made the up-stream surface decidedly rough, although it was not pitted. Twenty-four runs were made with the head on the weir increasing, and eighteen with the head decreasing. The results are plotted on Curve Sheet No. 1.

The rust was removed from the plate, and it was polished with emery cloth before the second series of runs was begun. Fourteen runs were made with the head increasing, and eighteen with it decreasing. The results of this run are shown graphically on Curve Sheet No. 2.

The third and fourth series of runs were made after greasing the smooth plate with vaseline. The third series comprised seventeen runs with the head increasing, and twenty-four with it decreasing. The results are plotted on Curve Sheet No. 3. The fourth series comprised fifteen runs with the head increasing, and fifteen with it decreasing. Graphic results are shown on Curve Sheet No. 5.

Carbon tetrachloride was used to clean the vaseline from the plate before the fifth series of runs was begun. This series had seventeen runs with the head increasing, and sixteen with it decreasing. The results are plotted on Curve Sheet No. 4.

The plate was rusted by the application of solutions of ammonium chloride and sodium chloride. The coating of rust so obtained was not as heavy as the original one. The sixth and last series of runs was made with the weir-plate in this last described condition. Fifteen runs were made with the head increasing, and sixteen with it decreasing. Curve Sheet No. 6 shows the results of this run.

The principal difficulty encountered was that of maintaining a constant head on the weir. Fluctuations in head were due mainly to variations in the voltage at the pump motor terminals. These tendencies of

the head to vary were counteracted by adjustments of the pump discharge valve and of the air valve.

Independent cathetometer observations were made at frequent intervals, to lessen personal errors.

Time observations were taken at the break of the electrical contact. The initial sound of the buzzer served as a warning signal. Two observers took time readings for each run. The mean of these two readings was used in the subsequent computations. The difference between the two readings was rarely more than one second, and usually was only a fraction of a second.

In this work, the volume of the discharge was obtained from its weight. Any marked changes in temperature would, therefore, be a source of error unless duly compensated for in the calculations. The mean temperature of the water during the experimentation was approximately 65 degrees F. No single reading varied more than 5 degrees from this mean. The weight of a cubic foot of water at 65 degrees F. (62.344 pounds) was used in the calculations. The error due to temperature variations did not exceed $1/20$ %.

VIII.

CALCULATIONS

The volume of water corresponding to each weight was calculated as follows: The product of the lever arm ratio and the value of the weight under consideration determined the balancing weight on the platform. The balancing weight, divided by the weight of one cubic foot of water at 65 degrees F. gave the volumetric equivalent of the weight.

The discharge in second feet was obtained by dividing the mean time of the run (in seconds) into the total discharge (in cubic feet). The head on the weir (in centimeters) was found by subtracting the zero cathetometer reading from the reading taken during the run. A transfer of the head from centimeters to feet was made. The quotient of the discharge in second feet by the five-halves power of the head (in feet), was recorded as the coefficient of discharge ($C = \frac{Q}{H^{5/2}}$).

In calculating the values of the five-halves power of the heads, five-place logarithm tables were used. No slide-rule calculations were made in any instance. Each calculation was checked.

IX.

RESULTS AND CONCLUSIONS

Although every reasonable care was exercised in conducting the experimental work, the values of the coefficient varied irregularly and throughout a wide range.

For the first series of runs the lowest value of the coefficient of discharge, C , was 2.3463, obtained at a head of 0.2369 foot. The highest value of C was 2.5360, at a head of 0.2410 foot. The difference between these extreme values is 0.1897, which is a variation of 8.1 % from the lowest value.

For the second series, the lowest value of C was 2.3436, at a head of 0.1740; the highest value was 2.7248, at a head of 0.1859. The variation is 0.3812, which is 16.3 % of the lowest value of C found during the run.

For the third series, the lowest value of C was 2.4980, at a head of 0.1750 foot; the highest value was 2.7197, at a head of 0.1708 foot. The difference is 0.2217, which is 8.9 % of the lowest value.

For the fourth series, the lowest value of C was 2.4048, at a head of 0.1478 foot; the highest value was 2.6952, at a head of 0.1445 foot. The difference is 0.2904, which is 12.1 % of the lowest value.

For the fifth series, the lowest value of C was 2.1888, at a head of 0.1373 foot; the highest value was 2.4933, at a head of 0.3389 foot. The difference is 0.3045, which is 13.9 % of the lowest value.

For the sixth series, the lowest value of C was 2.2238, at a head of 0.1365 foot; the highest value was 2.5579, at a head of 0.3425 foot. The difference is 0.3341, which is 15.0 % of the lowest value.

The greatest variation of the coefficient is 16.3 %. The least variation is 8.1 %. The average variation is 12.4 %. Such variations warrant

the conclusion that the triangular weir is not a reliable device for the measurement of water when the surface condition of the weir-plate is subject to change.

The collected data indicate a lower mean value of the coefficient with a decreasing than with an increasing head. This indication is confirmed by the results of five of the six series of runs.

For the first series, the mean value of C with the head increasing was 2.4353; with the head decreasing, 2.4674. The difference is 0.0321, which is 1.3 % of the mean value with the head increasing.

For the second series, the mean value of C with the head increasing was 2.6161; with the head decreasing, 2.4392. The difference is 0.1769, which is 6.8 % of the mean value with the head increasing.

For the third series, the mean value of C with the head increasing was 2.5842; with the head decreasing, 2.5208. The difference is 0.0634, which is 2.5 % of the mean value with the head increasing.

For the fourth series, the mean value of C with the head increasing was 2.5131; with the head decreasing, 2.4728. The difference is 0.0403, which is 1.6 % of the mean value with the head increasing.

For the fifth series, the mean value of C with the head increasing was 2.3801; with the head decreasing, 2.3518. The difference is 0.0283, which is 1.2 % of the mean value with the head increasing.

For the sixth and last series, the mean value of C with the head increasing was 2.4909; with the head decreasing, 2.4015. The difference is 0.0894, which is 3.6 % of the mean value with the head increasing.

Considering the five series in which the coefficient was less for decreasing than for increasing values of head, an average difference of 3.1 % is found in the mean values of C .

The differences in the mean values of the coefficient as discussed above are attributed to capillarity effects. The surface of the weir-plate above the level of the water was dry as the head was increased, but wet as the head was decreased. The diminished discharge under decreasing heads is chargeable to the clinging of the surface film to the wet surface of the weir-plate.

Inasmuch as wide and somewhat irregular variations in the discharge coefficient accompanied the use of a weir-plate of iron, it would seem that the highest degree of accuracy is unattainable with a weir-plate of such material.

BIBLIOGRAPHY.

Engineering, LXXXIX, pp. 435 - 37, 470 - 73.

Engineering News, LXXIII, p. 636.

Lowell's Hydraulic Experiments, pp. 143 - 44.

Cochrane Engineering Leaflet No. 18.

APPENDIX

APPENDIX

Data

Lever Arm Ratio of Scales:

Weight on Platform = 50.0197 lbs.

Balancing Counterweight = 0.2502 lbs.

$$\text{Ratio} = \frac{50.0197}{0.2502} = 199.889$$

Calibration of Weights:

Large Weights:

No.	Wt. in lbs.	Corresponding Cu.Ft.
1	3.1248	10.017
2	3.1250	10.018
3	3.1250	10.018
4	3.1249	10.017

Small Weights:

No.	Wt. in lbs.	Corresponding Cu.Ft.
1	0.6244	2.002
2	0.6249	2.003
3	0.6239	2.000

Wt. of one cu. ft. of water at 65° F. = 62.344

DATA FOR SERIES NO. 1.

Plate in Original Rusty Condition

Note: Time observations mean of 2 readings marked by asterisk.*
All others mean of 4 readings.

No.	Mean Time in Seconds	Cubic Feet of Water	Discharge in Second Feet
1	417.6	10.017	0.0240
2	348.1	10.017	0.0288
3	273.1	10.017	0.0367
4	227.7	10.017	0.0440
5*	226.1	10.017	0.0443
6	194.8	10.017	0.0514
7	218.6	14.022	0.0641
8*	212.2	14.022	0.0661
9	255.0	20.035	0.0786
10*	190.1	22.037	0.1159
11	206.4	24.040	0.1165
12	222.5	30.053	0.1351
13	234.0	40.070	0.1712
14*	175.7	42.072	0.2395
15	181.8	42.072	0.2314
16	223.0	40.070	0.1797
17	213.0	30.053	0.1411
18	204.7	22.039	0.1077
19*	248.2	20.035	0.0807
20	193.9	14.022	0.0723
21*	203.2	10.017	0.0493
22	225.9	10.017	0.0443
23	387.0	10.017	0.0259
24	398.9	10.017	0.0251

DATA FOR SERIES NO. 1 CON.

No.	Cathetometer Reading	Zero Cathetometer Reading	Head in Centimeters
1	57.150	52.405	4.745
2	57.550	52.405	5.145
3	58.085	52.405	5.680
4	58.485	52.405	6.080
5*	58.510	52.405	6.105
6	58.915	52.405	6.510
7	59.530	52.310	7.220
8*	59.600	52.310	7.290
9	60.080	52.310	7.770
10*	61.365	52.310	9.055
11	61.395	52.310	9.085
12	61.890	52.310	9.580
13	62.980	52.455	10.525
14*	64.400	52.455	11.945
15	64.265	52.455	11.810
16	63.155	52.455	10.700
17	62.170	52.455	9.715
18	61.225	52.455	8.770
19*	60.285	52.455	7.830
20	59.865	52.520	7.345
21*	58.900	52.520	6.380
22	58.630	52.520	6.110
23	57.420	52.520	4.900
24	57.385	52.520	4.865

DATA FOR SERIES NO. 1 CON.

No.	Head in Feet	Head to $5/2$ Power	Coefficient of Discharge
1	0.1557	0.00957	2.5078
2	0.1688	0.01171	2.4594
3	0.1864	0.01500	2.4467
4	0.1995	0.01778	2.4747
5*	0.2003	0.01796	2.4666
6	0.2136	0.02109	2.4371
7	0.2369	0.02732	2.3463
8*	0.2392	0.02798	2.3743
9	0.2549	0.03280	2.3963
10*	0.2971	0.04811	2.4091
11	0.2981	0.04852	2.4011
12	0.3143	0.05538	2.4397
13	0.3453	0.07006	2.4436
14*	0.3919	0.09615	2.4909
15	0.3875	0.09347	2.4757
16	0.3510	0.07299	2.4620
17	0.3187	0.05734	2.4608
18	0.2877	0.04440	2.4257
19*	0.2569	0.03345	2.4126
20	0.2410	0.02851	2.5360
21*	0.2093	0.02009	2.4539
22	0.2005	0.01800	2.4611
23	0.1608	0.01037	2.4976
24	0.1596	0.01018	2.4656

DATA FOR SERIES NO. 2.

Plate Smooth after Removal of Rust

Note: All time observations mean of 4 readings.

No.	Mean Time in Seconds	Cubic Feet of Water	Discharge in Second Feet
1	246.6	10.017	0.0406
2	184.9	10.017	0.0542
3	188.9	14.022	0.0742
4	209.6	22.037	0.1051
5	224.2	30.053	0.1340
6	231.7	40.070	0.1729
7	183.8	40.070	0.2180
8	184.0	40.070	0.2178
9	229.4	40.070	0.1747
10	222.8	30.053	0.1358
11	212.4	22.037	0.1038
12	260.8	20.035	0.0768
13	238.4	12.019	0.0504
14	279.0	10.017	0.0359
15	203.2	6.005	0.0296
16	205.7	4.005	0.0195

DATA FOR SERIES NO. 2, CON.

No.	Cathetometer Reading	Zero Cathetometer Reading	Head in Centimeters
1	58.355	52.690	5.665
2	59.125	52.690	6.435
3	60.015	52.690	7.325
4	61.150	52.690	8.460
5	62.035	52.690	9.345
6	63.035	52.690	10.345
7	64.035	52.690	11.345
8	64.035	52.690	11.345
9	63.065	52.690	10.375
10	61.955	52.410	9.545
11	61.025	52.410	8.615
12	60.065	52.410	7.655
13	58.925	52.410	6.515
14	58.135	52.410	5.725
15	57.715	52.410	5.305
16	56.885	52.410	4.475

DATA FOR SERIES NO. 2, CON.

No.	Head in Feet	Head to $5/2$ Power	Coefficient of Discharge
1	0.1859	0.01490	2.7248
2	0.2111	0.02047	2.6478
3	0.2403	0.02831	2.6210
4	0.2776	0.04060	2.5887
5	0.3066	0.05205	2.5744
6	0.3394	0.06711	2.5764
7	0.3722	0.08452	2.5793
8	0.3722	0.08452	2.5769
9	0.3404	0.06760	2.5843
10	0.3131	0.05485	2.4758
11	0.2826	0.04245	2.4452
12	0.2511	0.03160	2.4304
13	0.2137	0.02111	2.3875
14	0.1878	0.01528	2.3495
15	0.1740	0.01263	2.3436
16	0.1468	0.00826	2.3596

DATA FOR SERIES NO. 3.

Smooth Plate Greased.

Note: Time observations mean of 2 readings marked by asterisk.*
 All others mean of 4 readings.

No.	Mean Time in Seconds	Cubic Feet of Water	Discharge in Second Feet
1*	344.3	4.005	0.0116
2*	274.0	4.005	0.0146
3*	206.9	6.005	0.0290
4*	305.8	10.017	0.0327
5*	306.9	10.017	0.0326
6	261.0	10.017	0.0384
7*	257.5	10.017	0.0389
8*	203.4	12.019	0.0591
9*	241.3	20.035	0.0830
10*	238.8	20.035	0.0839
11	251.5	30.053	0.1195
12	195.8	30.053	0.1535
13	207.6	40.070	0.1930
14	205.5	40.070	0.1950
15	241.1	40.070	0.1662
16	239.0	30.053	0.1257
17	214.6	20.035	0.0934
18	220.0	16.022	0.0728
19	229.6	12.019	0.0523
20	293.9	10.017	0.0341
21*	243.1	6.005	0.0247
22	244.6	6.005	0.0246
23	209.9	4.005	0.0191
24	196.5	4.005	0.0204
25*	193.6	6.005	0.0310
26	312.7	10.017	0.0320

DATA FOR SERIES NO. 3, CON.

No.	Cathetometer Reading	Zero Cathetometer Reading	Head in Centimeters
1*	56.345	52.870	3.475
2*	56.680	52.870	3.810
3*	57.890	52.870	5.020
4*	58.075	52.870	5.205
5*	58.095	52.870	5.225
6	58.395	52.665	5.730
7*	58.425	52.665	5.760
8*	59.430	52.665	6.765
9*	60.440	52.665	7.775
10*	60.470	52.665	7.805
11	61.680	52.665	9.015
12	62.620	52.665	9.955
13	63.550	52.665	10.885
14	63.550	52.665	10.885
15	62.955	52.665	10.290
16	61.860	52.665	9.195
17	60.825	52.690	8.135
18	60.040	52.690	7.350
19	59.175	52.690	6.485
20	58.145	52.690	5.455
21*	57.485	52.690	4.795
22	57.470	52.690	4.780
23	57.005	52.690	4.315
24	57.135	52.690	4.445
25*	57.950	52.690	5.260
26	58.025	52.690	5.335

DATA FOR SERIES NO. 3, CON.

No.	Head in Feet	Head to 5/2 Power	Coefficient of Discharge
1*	0.1140	0.00438.8	2.6424
2*	0.1250	.005524	2.6430
3*	0.1647	.01101	2.6340
4*	0.1708	.01206	2.7197
5*	0.1714	.01216	2.6809
6	0.1880	.01532	2.5065
7*	0.1890	.01553	2.5048
8*	0.2219	.02320	2.5474
9*	0.2551	.02387	2.5251
10*	0.2561	.03319	2.5279
11	0.2958	.04759	2.6097
12	0.3266	.06096	2.5205
13	0.3571	.07620	2.5328
14	0.3571	.07620	2.5591
15	0.3376	.06622	2.5098
16	0.3017	.05000	2.5140
17	0.2669	.03680	2.5380
18	0.2411	.02854	2.5508
19	0.2128	.02089	2.5036
20	0.1790	.01356	2.5147
21*	0.1573	.009836	2.5102
22	0.1558	.009736	2.5257
23	0.1416	.007545	2.5298
24	0.1458	.008117	2.5123
25*	0.1726	.01238	2.5040
26	0.1750	.01281	2.4980

DATA FOR SERIES NO. 4.

Smooth Plate Greased.

Note: All time observations mean of 2 readings.

No.	Mean Time in Seconds	Cubic Feet of Water	Dis charge in Second Feet
1	280.4	6.005	0.0214
2	194.7	4.005	.0206
3	190.5	4.005	.0210
4	198.6	6.005	.0302
5	255.4	10.017	.0392
6	205.3	10.017	.0488
7	224.3	14.020	.0625
8	193.6	14.022	.0724
9	232.8	20.035	.0861
10	201.1	20.035	.0996
11	206.9	24.040	.1162
12	222.7	30.053	.1349
13	207.5	32.055	.1545
14	202.1	36.058	.1784
15	192.9	42.072	.2181
16	193.1	42.072	.2179
17	214.2	40.070	.1871
18	211.1	36.058	.1708
19	198.7	30.053	.1512
20	225.1	30.053	.1335
21	210.4	24.040	.1143
22	200.4	20.030	.1000
23	235.0	20.030	.0852
24	222.9	16.022	.0719
25	227.3	14.022	.0617
26	238.5	12.019	.0504
27	241.4	10.017	.0415
28	295.9	10.017	.0339
29	234.6	6.005	.0256
30	198.5	4.005	.0202

DATA FOR SERIES NO. 4, CON.

No.	Cathetometer Reading	Zero Cathetometer Reading	Head in Centimeters
1	57.060	52.655	4.405
2	57.150	52.665	4.485
3	57.175	52.665	4.510
4	57.890	52.665	5.225
5	58.460	52.665	5.795
6	58.965	52.665	6.300
7	59.630	52.665	6.965
8	60.040	52.665	7.375
9	60.600	52.665	7.935
10	61.055	52.665	8.390
11	61.585	52.665	8.920
12	62.145	52.665	9.480
13	62.725	52.665	10.060
14	63.225	52.665	10.560
15	64.095	52.665	11.430
16	64.095	52.665	11.430
17	63.455	52.665	10.790
18	62.990	52.570	10.420
19	62.500	52.570	9.930
20	62.025	52.570	9.455
21	61.480	52.570	8.910
22	61.005	52.570	8.435
23	60.515	52.570	7.945
24	59.990	52.570	7.420
25	59.545	52.570	6.975
26	59.010	52.570	6.440
27	58.510	52.570	5.940
28	58.050	52.570	5.480
29	57.515	52.570	4.945
30	57.075	52.570	4.505

DATA FOR SERIES NO. 4, CON.

No.	Head in Feet	Head to 5/2 Power	Coefficient of Discharge
1	0.1445	0.00794	2.6952
2	.1471	.00830	2.4819
3	.1480	.00843	2.4911
4	.1714	.01216	2.4836
5	.1901	.01576	2.4873
6	.2067	.01942	2.5129
7	.2285	.02496	2.5040
8	.2420	.02881	2.5130
9	.2603	.03457	2.4906
10	.2753	.03977	2.5044
11	.2927	.04635	2.5070
12	.3110	.05394	2.5009
13	.3301	.06261	2.4677
14	.3465	.07067	2.5244
15	.3750	.08611	2.5328
16	.3750	.08611	2.5305
17	.3540	.07456	2.5040
18	.3419	.06835	2.4989
19	.3258	.06059	2.4955
20	.3102	.05359	2.4911
21	.2923	.04619	2.4746
22	.2767	.04027	2.4832
23	.2607	.03470	2.4553
24	.2434	.02923	2.4598
25	.2288	.02504	2.4641
26	.2113	.02052	2.4561
27	.1949	.01677	2.4747
28	.1798	.01371	2.4726
29	.1619	.01055	2.4265
30	.1478	.00840	2.4048

DATA FOR SERIES NO 5.

Plate Smooth: Grease Removed.

Note: All time observations mean of 2 readings.

No.	Mean Time in Seconds	Cubic Feet of Water	Discharge in Second Feet
1	279.8	6.005	0.0215
2	200.9	6.005	.0299
3	249.3	10.017	.0402
4	192.7	10.017	.0520
5	195.2	12.019	.0516
6	216.3	16.022	.0741
7	240.4	20.035	.0833
8	207.4	20.035	.0966
9	194.7	22.037	.1132
10	205.0	26.040	.1270
11	209.9	30.053	.1432
12	208.7	34.058	.1628
13	207.9	34.058	.1638
14	214.0	30.053	.1404
15	202.7	34.058	.1680
16	213.5	40.070	.1872
17	195.0	42.072	.2158
18	206.5	40.070	.1940
19	204.3	34.058	.1667
20	199.9	30.053	.1503
21	227.4	30.053	.1322
22	209.5	24.040	.1147
23	240.0	24.040	.1002
24	228.9	20.035	.0875
25	217.7	16.022	.0736
26	224.6	14.022	.0624
27	198.7	10.017	.0504
28	239.1	10.017	.0419
29	300.5	10.017	.0333
30	239.2	6.005	.0251
31	200.2	4.005	.0200
32	261.6	4.005	.0153
33	324.1	4.005	.0124

DATA FOR SERIES NO. 5, CON.

No.	Cathetometer Reading	Zero Cathetometer Reading	Head in Centimeters
1	57.155	52.455	4.700
2	57.820	52.455	5.365
3	58.455	52.455	6.000
4	59.115	52.455	6.660
5	59.565	52.455	7.110
6	60.090	52.455	7.635
7	60.470	52.455	8.015
8	60.930	52.455	8.475
9	61.485	52.455	9.030
10	61.900	52.455	9.445
11	62.360	52.455	9.905
12	62.905	52.455	10.450
13	62.835	52.455	10.380
14	62.265	52.575	9.690
15	63.025	52.575	10.450
16	63.435	52.575	10.860
17	64.060	52.575	11.485
18	63.575	52.575	11.000
19	62.905	52.575	10.330
20	62.425	52.395	10.030
21	61.955	52.395	9.560
22	61.430	52.395	9.035
23	60.980	52.395	8.585
24	60.535	52.395	8.140
25	60.000	52.395	7.605
26	59.515	52.395	7.120
27	58.965	52.395	6.570
28	58.530	52.395	6.135
29	58.000	52.395	5.605
30	57.435	52.395	5.040
31	57.000	52.395	4.605
32	56.580	52.395	4.185
33	56.240	52.395	3.845

DATA FOR SERIES NO. 5, CON.

No.	Head in Feet	Head to 5/2 Power	Coefficient of Discharge
1	0.1542	0.00934	2.3062
2	.1760	.01299	2.3018
3	.1969	.01720	2.3372
4	.2185	.02226	2.3360
5	.2333	.02629	2.3431
6	.2505	.03141	2.3591
7	.2630	.03547	2.3485
8	.2781	.04079	2.3688
9	.2963	.04779	2.3687
10	.3099	.05346	2.3756
11	.3250	.06021	2.3783
12	.3428	.06880	2.3663
13	.3406	.06770	2.4195
14	.3179	.05698	2.4640
15	.3428	.06880	2.4419
16	.3563	.07578	2.4703
17	.3768	.08715	2.4762
18	.3609	.07825	2.4792
19	.3389	.06686	2.4933
20	.3291	.06213	2.4191
21	.3136	.05507	2.4006
22	.2964	.04783	2.3981
23	.2817	.04212	2.3789
24	.2671	.03687	2.3732
25	.2495	.03109	2.3673
26	.2336	.02637	2.3663
27	.2156	.02158	2.3355
28	.2013	.01818	2.3047
29	.1839	.01450	2.2966
30	.1654	.01113	2.2552
31	.1511	.00888	2.2523
32	.1373	.00699	2.1888
33	.1261	.00565	2.1947

DATA FOR SERIES NO. 6.

Plate Rusted By Corroder.

Note: All time observations mean of 2 readings.

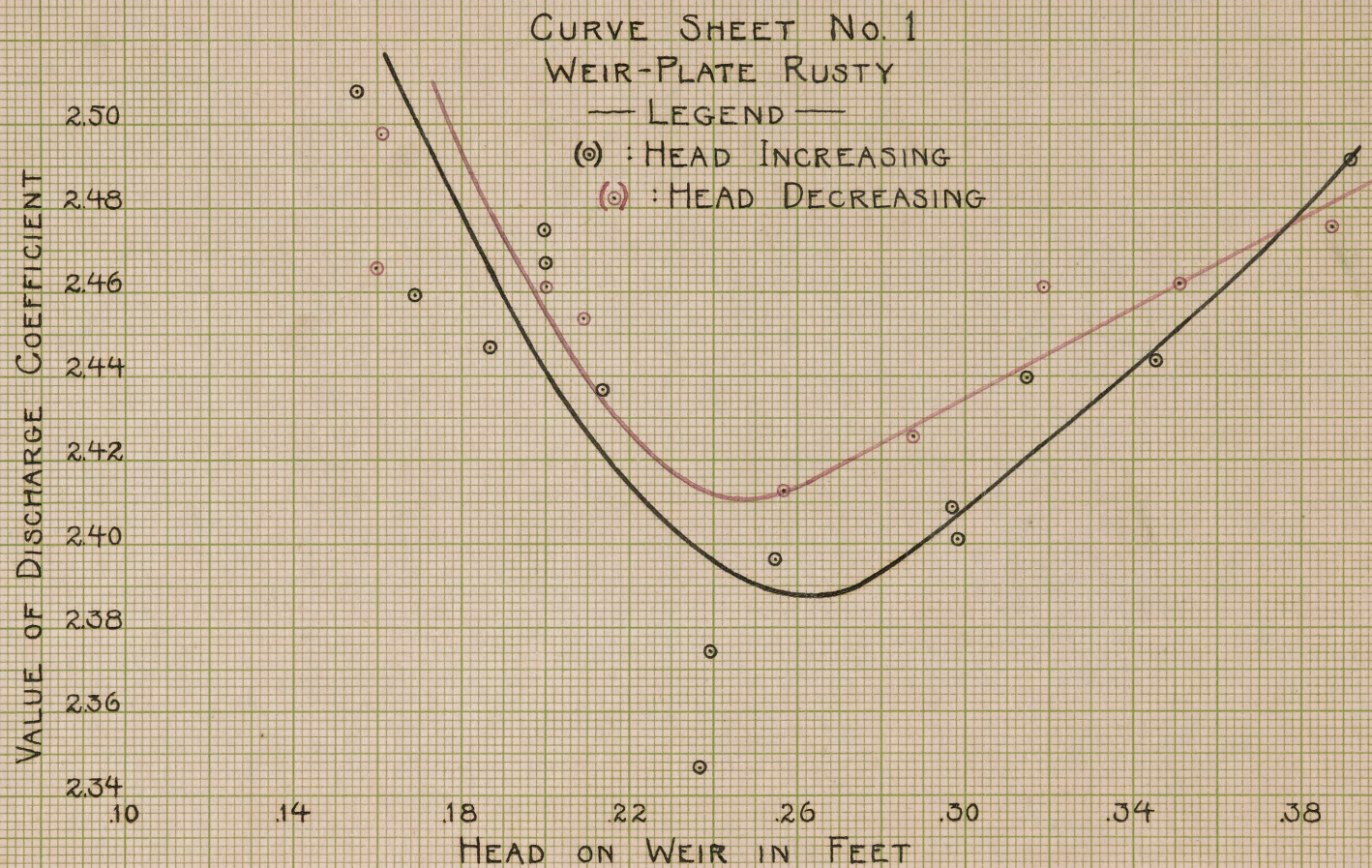
No.	Mean Time in Seconds	Cubic Feet of Water	Discharge in Second Feet
1	225.7	4.005	0.0177
2	236.1	6.005	.0254
3	291.0	10.017	.0344
4	219.0	10.017	.0457
5	224.0	12.019	.0537
6	217.6	14.022	.0644
7	211.8	16.022	.0756
8	223.8	20.035	.0895
9	213.1	22.037	.1034
10	201.0	24.040	.1196
11	222.9	30.053	.1348
12	210.1	32.055	.1526
13	197.1	34.058	.1728
14	206.0	40.070	.1945
15	179.9	40.070	.2227
16	188.0	42.072	.2238
17	204.4	40.070	.1960
18	228.2	40.070	.1756
19	210.6	32.055	.1522
20	206.6	26.040	.1260
21	200.6	22.037	.1099
22	208.5	20.035	.0961
23	241.2	20.035	.0831
24	204.0	14.020	.0687
25	215.3	12.019	.0558
26	204.4	10.017	.0490
27	257.4	10.017	.0389
28	199.1	6.005	.0302
29	246.6	5.005	.0244
30	210.6	4.005	.0190
31	262.1	4.005	.0153

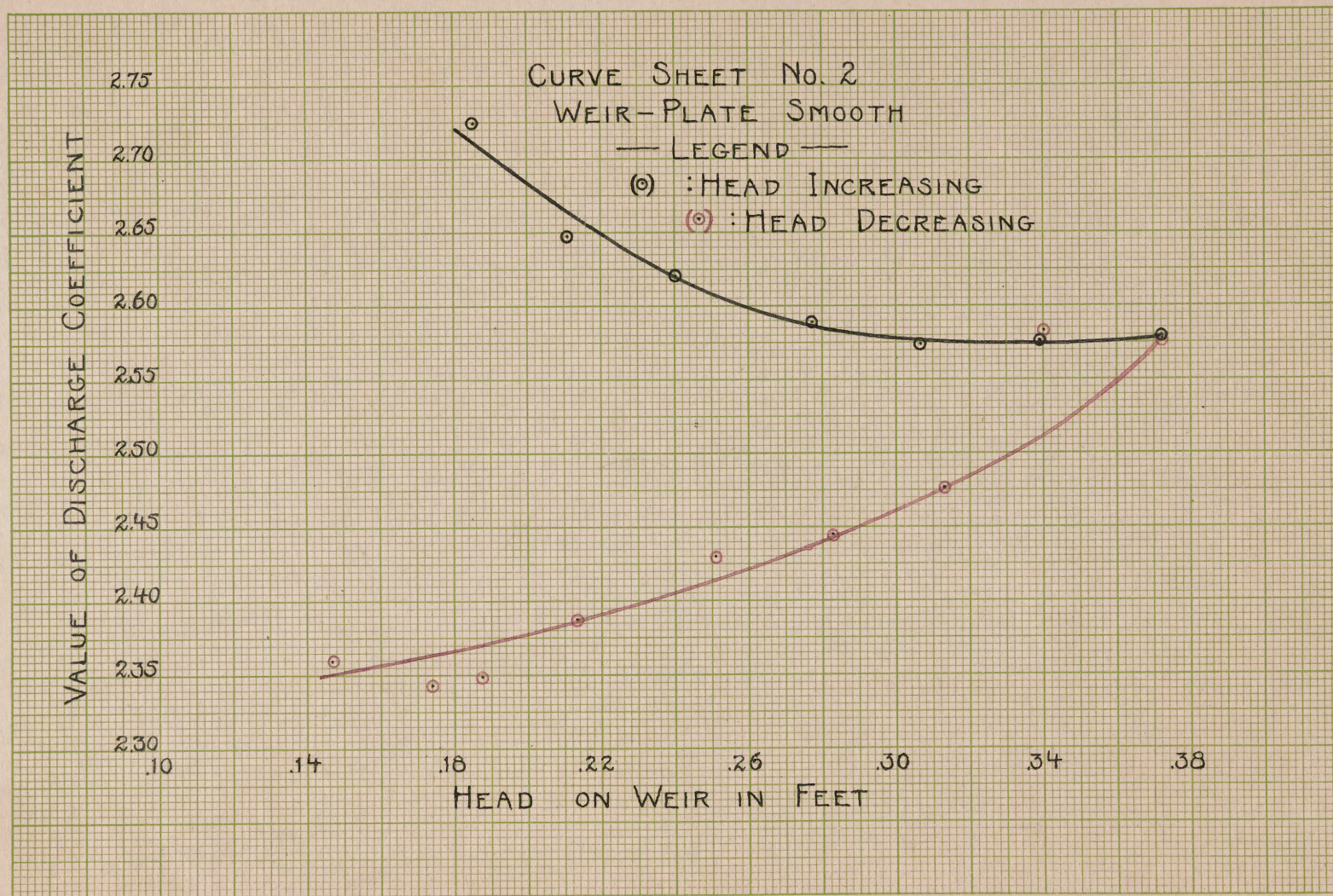
DATA FOR SERIES NO. 6, CON.

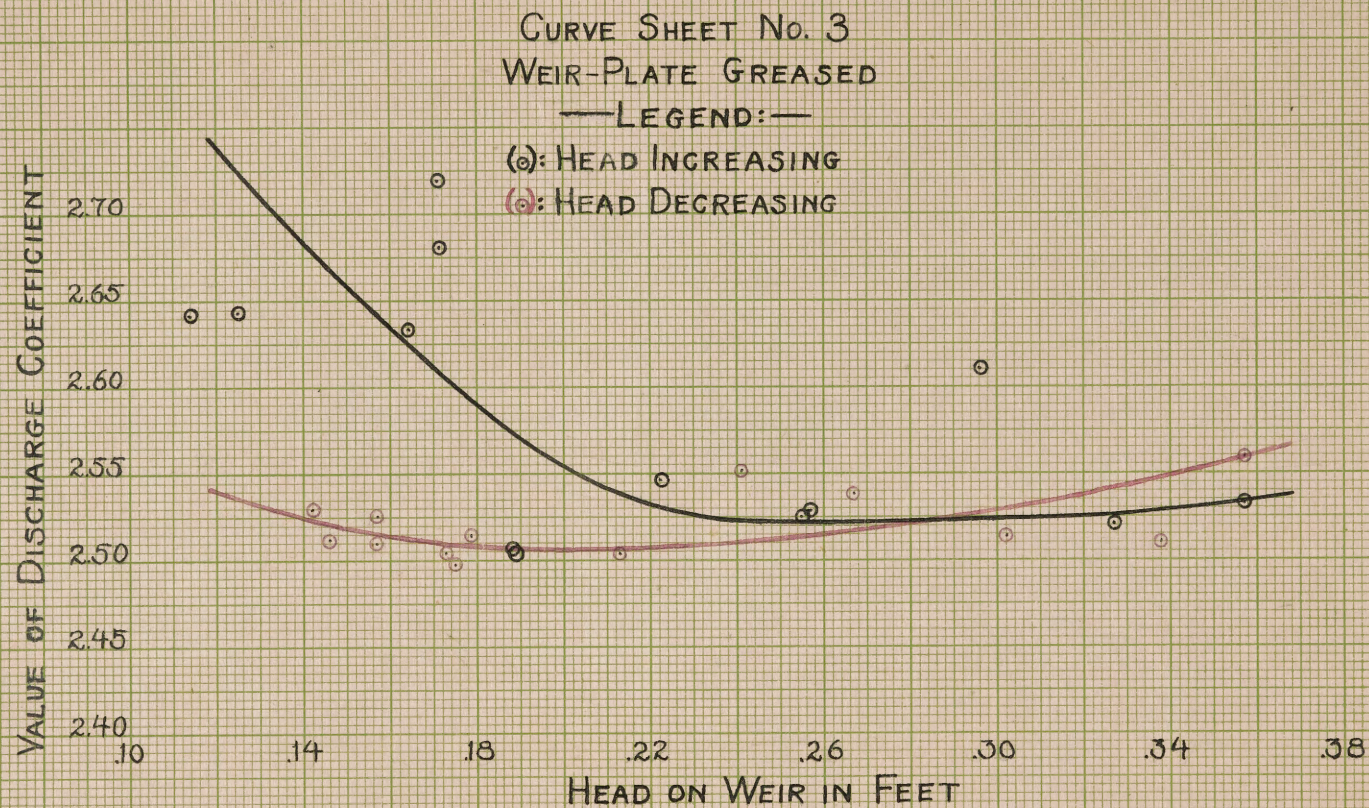
No.	Cathetometer Reading	Zero Cathetometer Reading	Head in Centimeters
1	56.830	52.515	4.315
2	57.495	52.515	4.980
3	58.100	52.515	5.585
4	58.740	52.515	6.225
5	59.105	52.515	6.590
6	59.590	52.565	7.025
7	60.050	52.565	7.485
8	60.550	52.565	7.985
9	61.025	52.565	8.460
10	61.550	52.565	8.985
11	62.050	52.565	9.485
12	62.455	52.565	9.890
13	62.950	52.565	10.385
14	63.435	52.565	10.870
15	64.080	52.565	11.515
16	64.080	52.565	11.515
17	63.480	52.565	10.915
18	63.005	52.565	10.440
19	62.460	52.565	9.895
20	61.790	52.460	9.330
21	61.290	52.460	8.830
22	60.820	52.460	8.360
23	60.365	52.460	7.905
24	59.835	52.460	7.375
25	59.280	52.460	6.820
26	58.925	52.460	6.465
27	58.380	52.460	5.920
28	57.845	52.460	5.385
29	57.420	52.460	4.960
30	56.980	52.460	4.520
31	56.620	52.460	4.160

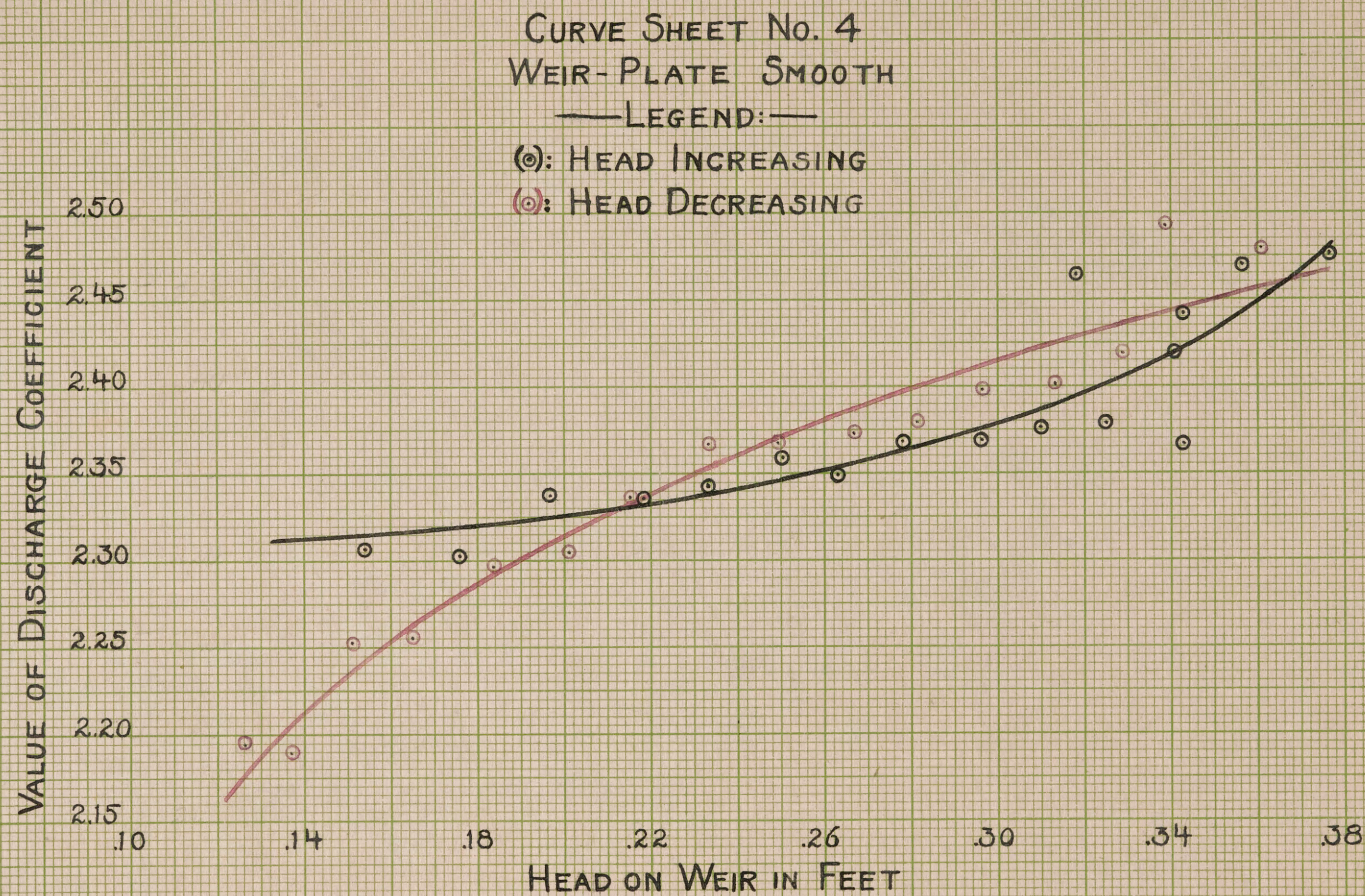
DATA FOR SERIES NO. 6, CON.

No.	Head in Feet	Head to 5/2 Power	Coefficient of Discharge
1	0.1416	0.007545	2.3475
2	0.1634	.01079	2.3540
3	0.1832	.01437	2.3939
4	0.2042	.01884	2.4257
5	0.2162	.02173	2.4712
6	0.2305	.02551	2.5245
7	0.2456	.02989	2.5293
8	0.2620	.03514	2.5470
9	0.2776	.04060	2.5468
10	0.2948	.04719	2.5344
11	0.3112	.05403	2.4949
12	0.3245	.05998	2.5442
13	0.3407	.06775	2.5506
14	0.3566	.07594	2.5612
15	0.3778	.08773	2.5385
16	0.3778	.08773	2.5510
17	0.3581	.07674	2.5541
18	0.3425	.06865	2.5579
19	0.3246	.06003	2.5354
20	0.3061	.05184	2.4306
21	0.2897	.04517	2.4330
22	0.2743	.03941	2.4385
23	0.2594	.03427	2.4249
24	0.2420	.02881	2.3846
25	0.2238	.02369	2.3554
26	0.2121	.02072	2.3649
27	0.1942	.01662	2.3406
28	0.1767	.01312	2.3018
29	0.1627	.01068	2.2846
30	0.1483	.00847	2.2432
31	0.1365	.00688	2.2238







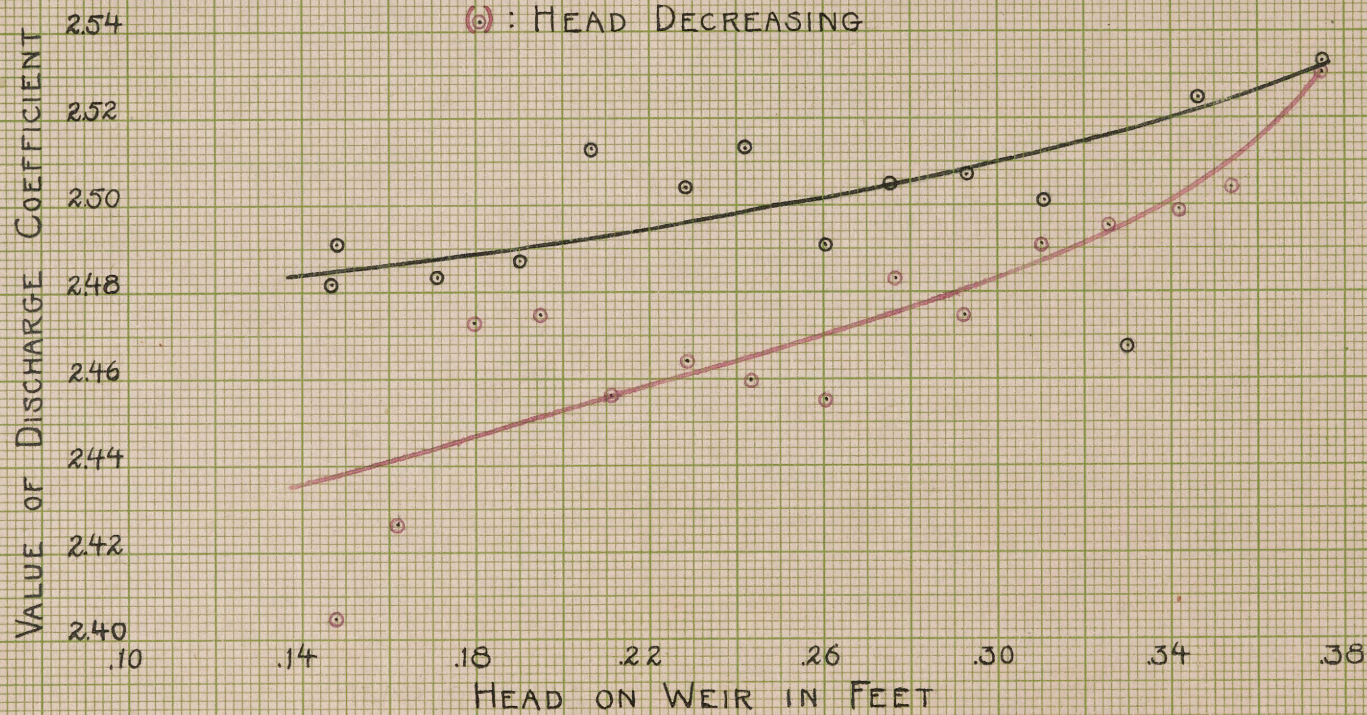


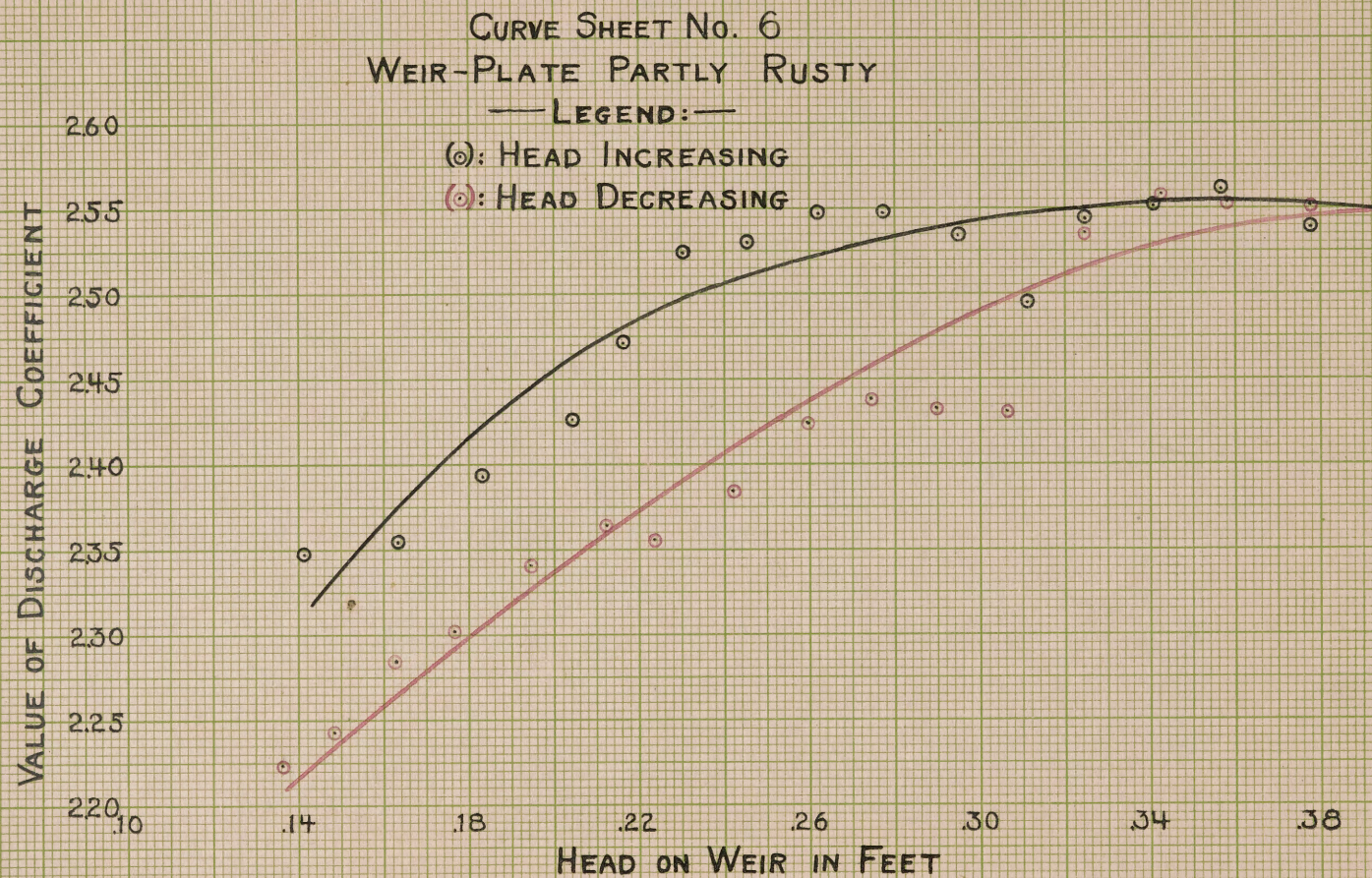
CURVE SHEET No. 5
WEIR-PLATE GREASED

— LEGEND —

⊙ : HEAD INCREASING

⊙ : HEAD DECREASING





SUMMARY OF DATA.

Series No. 1: Plate in Original Rusty Condition.

Coefficient		Per cent Difference	Mean Coefficient
Highest	Lowest		
2.5360	2.3463	8.1 %	2.4613

Series No. 2: Plate Smooth After Removal of Rust.

Coefficient		Per cent Difference	Mean Coefficient
Highest	Lowest		
2.7248	2.3436	16.3 %	2.5276

Series No. 3: Smooth Plate Greased.

Coefficient		Per cent Difference	Mean Coefficient
Highest	Lowest		
2.7197	2.4980	8.9 %	2.5525

Series No. 4: Smooth Plate Greased.

Coefficient		Per cent Difference	Mean Coefficient
Highest	Lowest		
2.6952	2.4048	12.1 %	2.4929

Series No. 5: Plate Smooth: Grease Removed.

Coefficient		Per Cent Difference	Mean Coefficient
Highest	Lowest		
2.4933	2.1888	13.9 %	2.3659

Series No. 6: Plate Rusted by Corroder.

Coefficient		Per Cent Difference	Mean Coefficient
Highest	Lowest		
2.5579	2.2238	15.0 %	2.4462

APPROVAL SHEET.

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degrees for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statements made, opinion expressed, or conclusion drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name

J. A. Switzer

Title

Prof. of Hydraulic
and Sanitary Engineering