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Design, Operation, and Calibration of the Canal "A" Submerged Rectangular Measuring Flume

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DESIGN, OPERATION, AND CALIBRATION

OF THE CANAL "A"

SUBMERGED RECTANGULAR MEASURING FLUME

Performed for the

D.M.A.D. Company
Delta, Utah

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Mr. M. Leon Hyatt has undertaken as a Master of Science thesis the "Design, Calibration, and Evaluation of a Trapezoidal Measuring Flume by Model Study" for Canal "B" of the D.M.A.D. Co. distribution system. The results of Mr. Hyatt's thesis regarding submerged flow were instrumental in providing the basis for analyzing submerged flow in the rectangular flume installed in Canal "A".

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NOMENCLATURE

Symbol	Definition
A	Area, ft.^{2}
A_m	Area in model, ft.^{2}
A_p	Area in prototype, ft.^{2}
A_r	Ratio of A_p/A_m, dimensionless
b	Bottom width, ft.
C_1	Minimum depth in throat for a specified flowrate and Froude number equal to one, ft.
C_2	Discharge for a specified submergence and energy loss equal to one, cfs.
D_1	Depth of flow at entrance, ft.
D_3	Depth of flow at exit, ft.
D_m	Minimum depth of flow in throat, ft.
$(D_1)_m$	Depth of flow at entrance of model, ft.
$(D_3)_m$	Depth of flow at exit of model, ft.
$(D_m)_m$	Minimum depth of flow in throat of model, ft.
$(D_1)_p$	Depth of flow at entrance of prototype, ft.
$(D_3)_p$	Depth of flow at exit of prototype, ft.
$(D_m)_p$	Minimum depth of flow in throat of prototype, ft.
F	Froude number, dimensionless
F_G	Gravity force, lb.
F_I	Inertia force, lb.

NOMENCLATURE (continued)

Symbol	Definition
F_m	Maximum Froude number in flume, dimensionless
F_r	Ratio of prototype Froude number to model Froude number, dimensionless
g	Acceleration due to gravity, 32.2 ft/sec.^{2}
L	Any length, ft.
L_m	Length in model, ft.
L_p	Length in prototype, ft.
L_r	Ratio of L_p/L_m, dimensionless
Q	Actual discharge, cfs.
Q_m	Discharge in model, cfs.
Q_p	Discharge in prototype, cfs.
Q_r	Ratio of Q_p/Q_m, dimensionless
s	Slope, dimensionless
V	Average velocity, ft/sec.
V_m	Velocity in model, ft/sec.
V_p	Velocity in prototype, ft/sec.
V_r	Ratio of V_p/V_m, dimensionless
ρ	Density of fluid, lb. - sec.^{2}/ft.^{4}

Part I

DESIGN AND OPERATION

DESIGN AND OPERATION

Necessity for Submerged Flume

The D.M.A.D. dam and reservoir are located on the Sevier River northeast of Delta, Utah, and serve as a storage reservoir for the winter and spring flows of the Sevier River below Sevier Bridge Reservoir. The D.M.A.D. dam has been constructed with two outlet works, one for feeding Canal "A", which serves the Delta and Melville Irrigation Companies, while the other canal serves the Abraham and Deseret Irrigation Companies.

A gaging station located along Canal "A" has been used for many years to obtain flow measurements. The gaging station measurements appeared to be very inconsistent, and consequently, in 1963 a study was made to evaluate the accuracy of the station. The results of the study (Figure 1) showed that for a constant depth of flow, the flow rate might vary more than 100 cfs or, for a constant flow rate, the depth of flow might vary more than a foot. The flows conveyed by this canal range from 15 to 500 cfs.

Canal "A" is five miles in length and has a total drop in grade of five feet, the average slope therefore being one foot per mile. Regulation of the end of the canal will cause backwater effects over the entire length of the canal. The backwater effects will result in increased seepage losses. The installation of a Parshall flume was contemplated for measuring the flows conveyed by Canal "A", but it would be

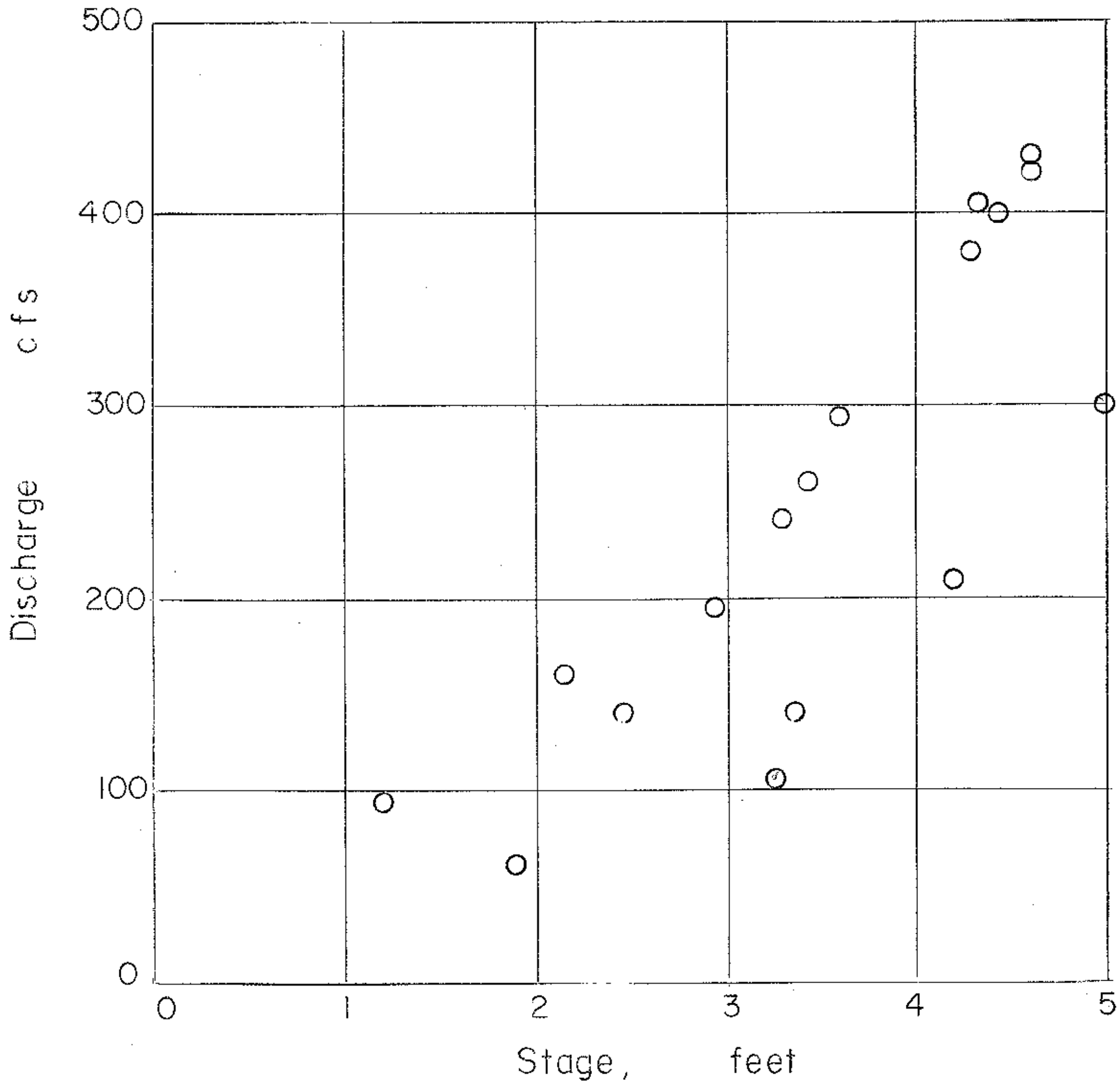

Figure 1. Stage-discharge measurements for Canal "A"

necessary to place the floor of the flume 2.75 feet above the canal grade to insure free flow over the entire flow range. The use of such a flume would significantly increase the seepage losses between the measuring station and the dam for all flows below the design discharge of 500 cfs. Since the D.M.A.D. reservoir is used primarily for regulation, increasing the water surface levels in Canal "A" would reduce the regulating head and the usefulness of the lower storage levels in the reservoir for the Delta and Melville Irrigation Companies.

Design of Flume

As a practical course of action, it was decided to constrict the canal in some manner to produce measurable effects that could be used to rate the section. As a consequence, a rectangular flume was agreed upon wherein submerged flow would occur over the entire flow range. Preliminary computations showed that the total energy loss at maximum flow should not exceed 0.6 feet. The final design for the submerged rectangular flume is depicted in Figure 2.

Operation

Flow characteristics. The submerged rectangular flume was designed for a maximum discharge of 500 cfs. Figures 3 and 4 show the flume at a time when the measured discharge was 494 cfs. The wave pattern entering the throat section is shown in Figure 5 for an intermediate flow rate. Figure 6 illustrates the wave pattern as the flow passes from the throat to the diverging exit section.

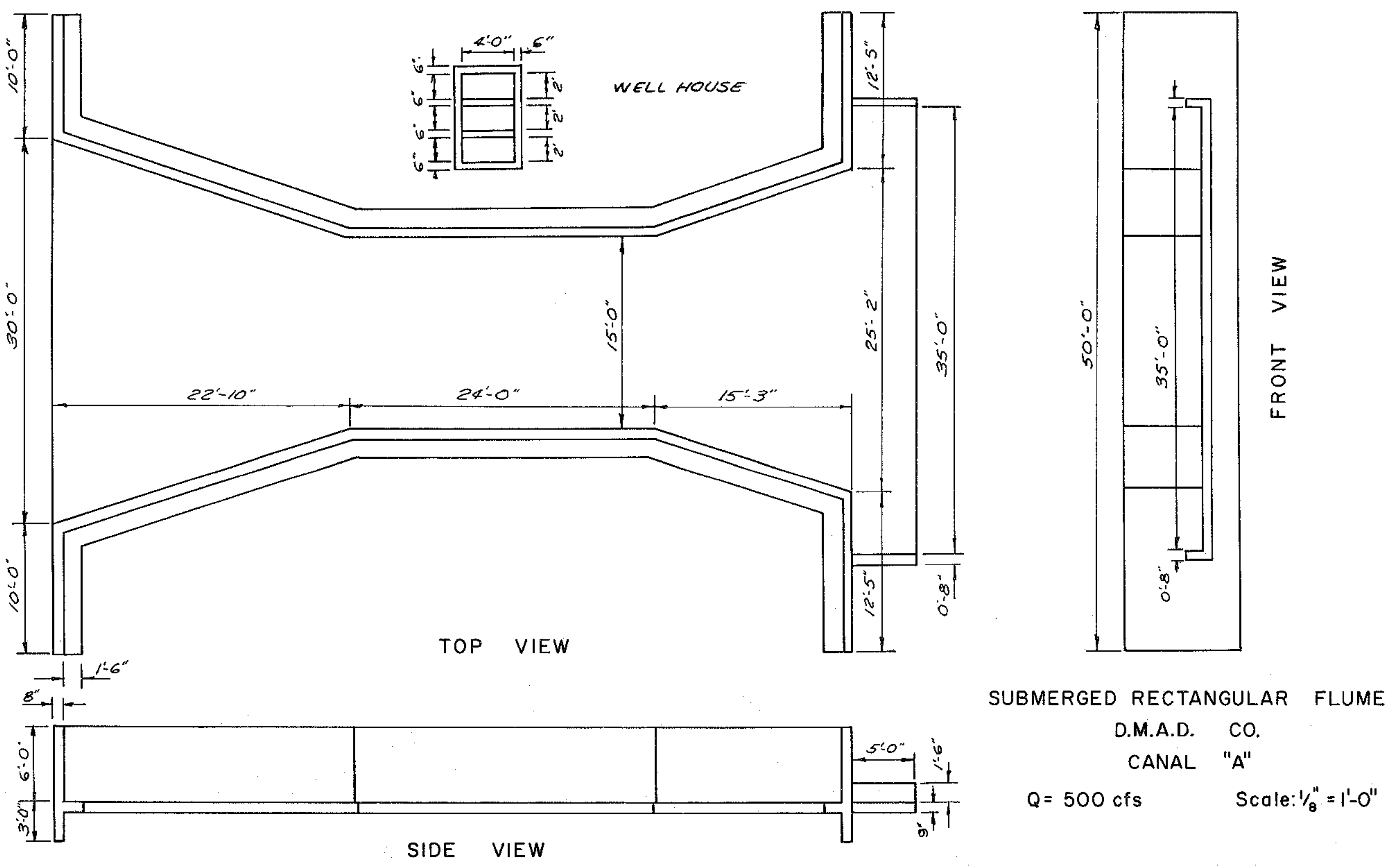

Figure 2. Submerged rectangular flume.

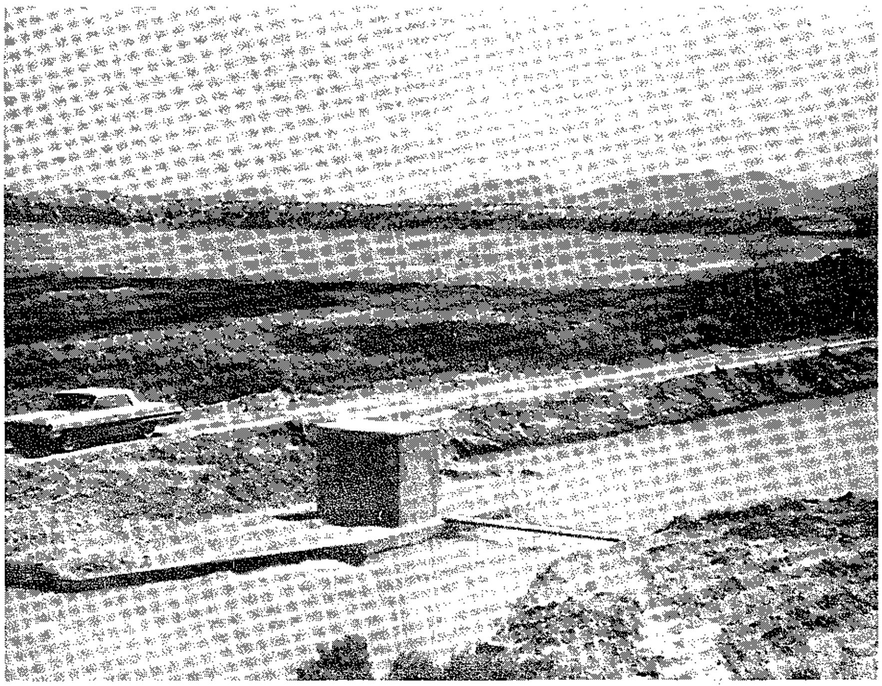

Figure 3. Submerged rectangular flume conveying 494 cfs.

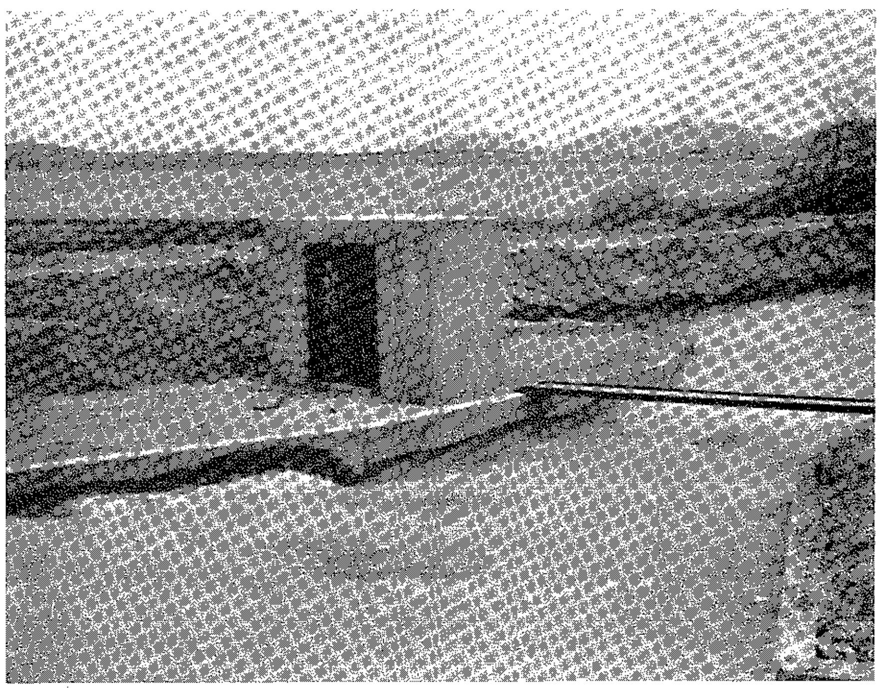

Figure 4. Flume passing 494 cfs showing waves (looking upstream).

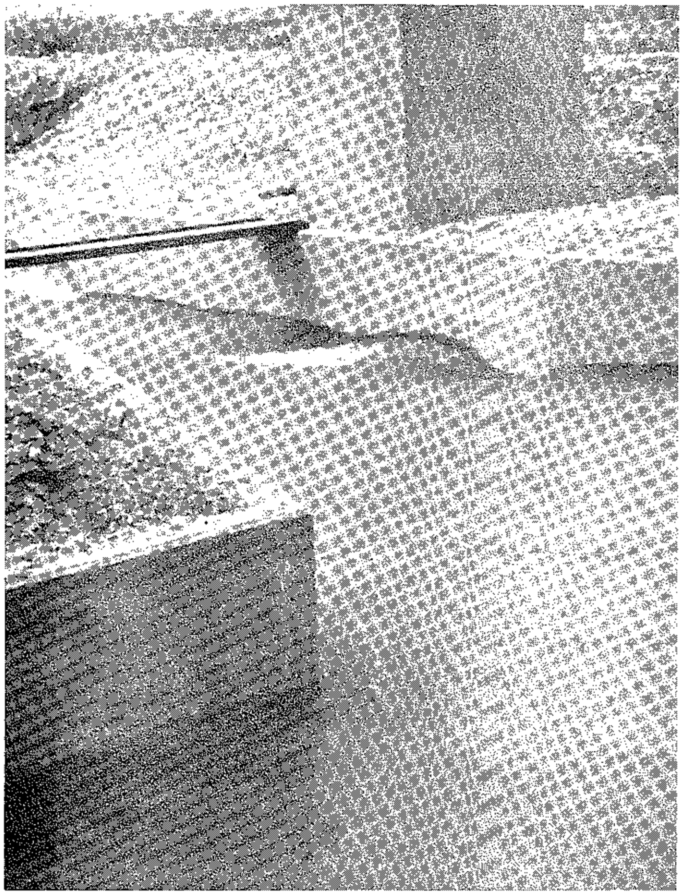

Figure 5. Wave pattern entering throat for an intermediate flow rate.

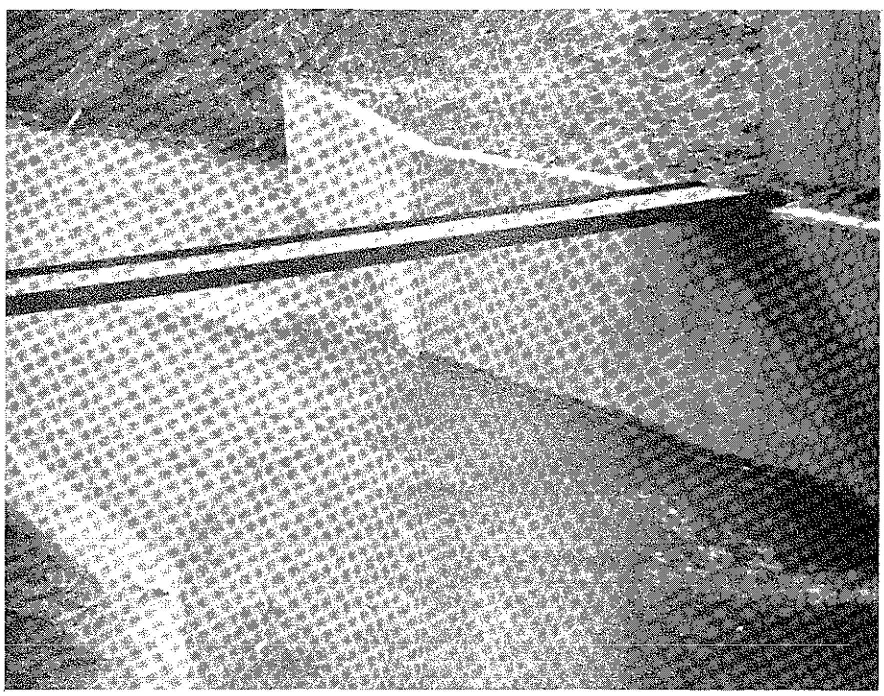

Figure 6. Wave pattern as flow passes from throat to diverging exit section.

"Walker" differential head measuring system. The calibration of the submerged rectangular flume requires that the flow depth upstream from the flume, D_1, and the flow depth downstream from the flume, D_3, be measured. The "Walker" differential head measuring device is used to measure D_1 and $D_1 - D_3$. The measuring device is sensititve enough to detect differences in water surface levels of two-thousandths (0.002) of a foot, thus providing an excellent means of obtaining flow depths for submerged flumes.

The differential head measuring device consists of two fixed length cables, 3 pound weight for cables, balance arm with pivot, pulleys, and bracket with a calibrating screw. A stage recorder is attached to the calibrating screw. Each cable is attached to the float, brought over an end pulley, over a center pivot pulley, and fastened to the weight. Because of the weight, each cable remains taut and, being of constant length, any difference of water level in the two wells must be compensated for by a movement of the arm ends and weight travel up or down. Water level alone can make no change in position of the balance arm. Change occurs only when there is a difference of water levels, the arm ends adjusting to make the distance from float over end, over center pivot, then to weight, constant for each cable. The arm is balanced and pivoted on a sealed ball bearing assembly. Forces acting at comparatively long distances from the pivot make it possible for small changes to be recorded. By different arm pivot and pulley arrangements, various scales are

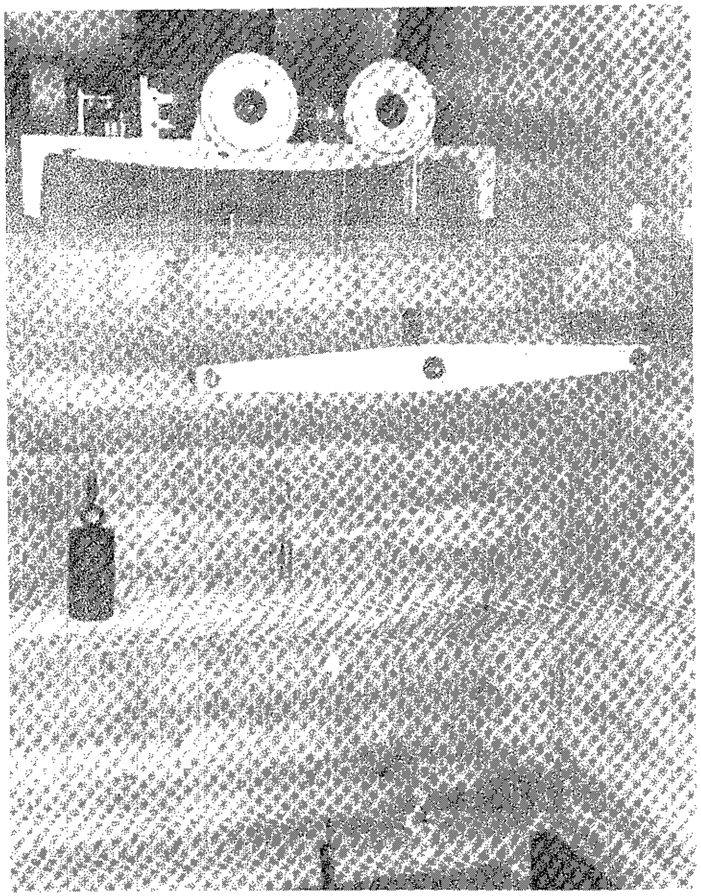

Figure 7. Typical hookup of "Walker" differential head recording system.

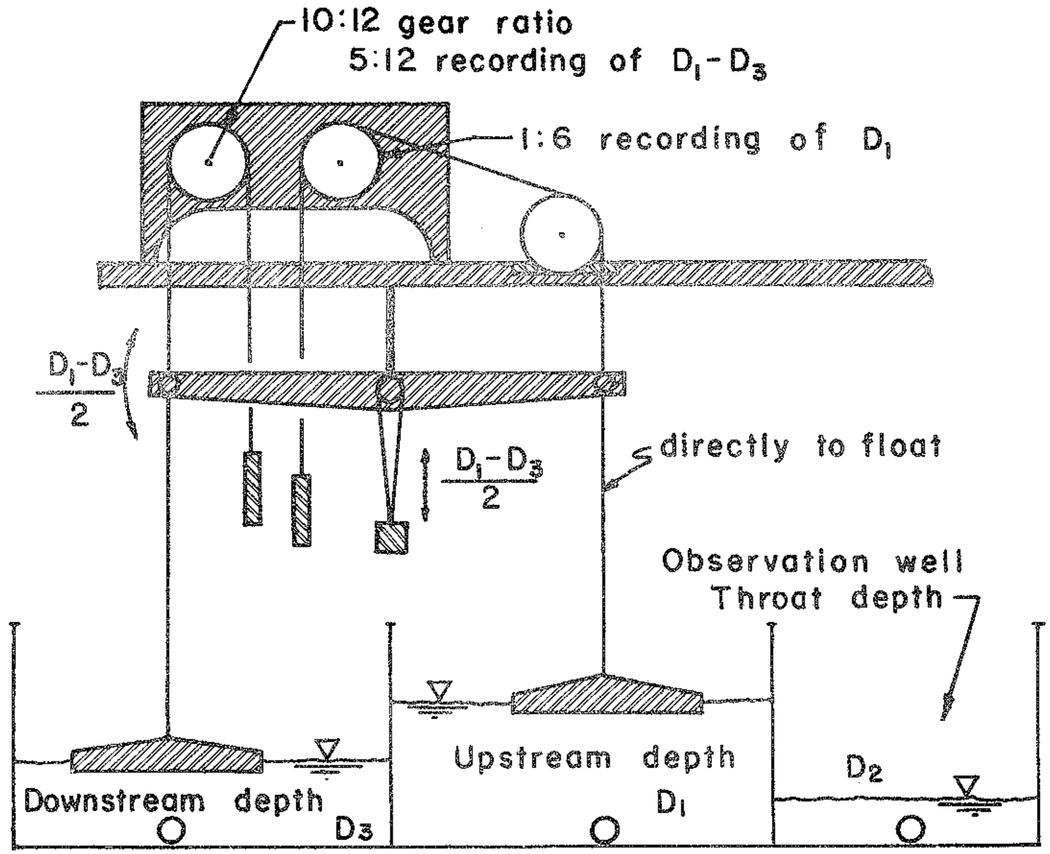

Figure 8. Diagram of "Walker" differential head measuring system for submerged rectangular flume.

possible. Figure 7 illustrates a typical hookup now being used. A diagram of the recording system being used for the submerged rectangular flume is shown in Figure 8.

Part II

CALIBRATION BY MODEL STUDY

CALIBRATION BY MODEL STUDY

Purpose of Calibration

A calibration of the submerged rectangular flume by means of a hydraulic model was felt necessary to substantiate which flow depth measurements should be made and to provide a complete calibration of the flume over a wide range of submergence values. A few field measurements were obtained during the summer of 1964, but not enough to provide a complete calibration. The calibration of the flume in the laboratory provided a more rapid and economical set of discharge curves than would have been obtained with field measurements. The model calibration will be field checked during the summer of 1965.

Theory

In the open channel flow problem being studied, laminar flow will not occur and surface tension will have no significant effect (Ackers and Harrison, 1963). The predominant forces acting on the flow will be those of gravity and inertia. Both forces are exerted on the model and the prototype. The ratio of inertia forces to gravity forces is the Froude number. The inertia forces are given by

$$F_I = \rho L^2 V^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; 1$$

in which

F_I = inertia forces, lb.

ρ = density of fluid, lb-sec/ft.^{4}

L = length, ft.

V = average velocity of flow, ft/sec.

The gravity forces are given by

$$F_G = \rho\, L^3 g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

in which

F_G = gravity forces

g = acceleration due to gravity, 32.2 ft/sec.^{2}

The Froude number is defined by

$$F = \frac{F_I}{F_G} = \frac{\rho\, L^2 V^2}{\rho\, L^3 g} = \frac{V^2}{Lg}$$

Normally, the square root of the ratio of the inertia forces to the gravity forces is used as the Froude number, which can be defined as

$$F = \frac{V}{\sqrt{g\,L}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

The length, L, in the Froude number may be any length, but in open channel flow, L is usually taken to be the depth of flow. The Froude number to be evaluated will use L as D_m, the minimum depth in the throat. The Froude number will then indicate if the flow is supercritical or subcritical.

Field studies indicate that regulation of the end of the canal causes backwater effects, at all depths and any rate of flow, the entire length of of the canal. As a result of these backwater effects the prototype is always at a subcritical flow. Therefore, only subcritical flow, or Froude number less than one, will be analyzed in this report.

Any flow passing through the flume and failing to pass through critical depth is said to be submerged. Submergence is defined by Wells and Gotaas (1948) as "the percent ratio of tailwater depth to upstream depth where the tailwater depth is referred to the channel invert at the point of upstream measurements."

Model measurements are converted to corresponding prototype measurements by the laws of similitude. The subscript "p" will be used to denote prototype properties, "m" to designate model properties, and "r" to denote the ratio of the prototype properties to the model properties.

The fundamental requirement for the design of a Froude model is that the Froude number be the same in the model and in the prototype (Murphy, 1950), thus F_r (ratio of prototype Froude number, F_p, to model Froude number, F_m) is equal to one.

The laboratory is equipped with a five-foot-wide flume which is one-seventh the width of the 35-foot-wide canal in which the prototype flume is located. Consequently, after consideration of the available laboratory facilities, a decision was made to use a length ratio of 1 : 7 (model : prototype).

$$L_r = \frac{L_p}{L_m} = 7$$

$$L_p = 7\,L_m \quad . . . . \quad 4$$

From the definition of the Froude number

$$F = \frac{V}{\sqrt{gL}}$$

we obtain

$$F_r = \frac{V_r}{\sqrt{g_r L_r}}$$

and, since $F_r = 1$ and $g_r = 1$,

$$\frac{V_r}{\sqrt{L_r}} = 1$$

$$V_r = \sqrt{L_r} = \sqrt{7} = 2.65$$

$$V_p = 2.65\ V_m \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad 5$$

From the equation of continuity

$$Q = AV$$

in which

Q = flow rate, ft.^{3}/sec.

A = cross-sectional area of flow, ft.^{2}

Therefore

$$Q_r = A_r\ V_r = L_r^{\ 2}\ L_r^{\ 1/2} = L_r^{\ 5/2} = 7^{5/2} = 129.85$$

$$Q_p = 129.85\ Q_m \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad 6$$

In the prototype structure, pipe has been extended into the flow both upstream and downstream from the flume to measure the depth of flow at these locations. These pipes lead to stilling wells placed alongside the flume, in which floats and a recorder are located. To duplicate this condition in the model flume, tubing was used to measure the upstream and downstream flow depth. The upstream and downstream depth measurements, as read in the model stilling wells, were correlated with the discharge rates through the flume to yield the necessary calibration.

The prototype flume has been constructed of concrete. The model was constructed of plywood with a sanded painted surface to obtain an equivalent roughness.

Experimental Facilities

After the construction of the model rectangular measuring flume was completed, it was properly placed in the five-foot by five-foot flume located in the Fluid Mechanics Laboratory.

Two pumps were used, operating together and capable of delivering approximately four cfs. The flow rate was regulated by means of a valve located on the line as it just enters the laboratory. Where smaller flows were desired, it was necessary to use only one pump. The water was pumped through a 12-inch diameter pipeline which feeds into the five-foot by five-foot flume. At the beginning of this flume is a screen which provides an even distribution of the flow.

The flow passed through the flume and discharged into weighing tanks. The flow rate was calculated from the weight of water measured during a particular time period. The water was discharged from the weighing tanks into the sump, where it was recirculated (Figure 9).

When the flow was passing through the rectangular flume, measurements were made of (1) upstream depth, (2) minimum depth in the throat, and (3) downstream depth. All depth measurements were made by the use of a point gage, and readings were to the nearest 0.001 of a foot. Copper tubing running from upstream and downstream of the rectangular flume into stilling wells, located near the middle of the flume, provided the upstream and downstream depths; whereas a cross bar across the flume was used to support a point gage provided to measure the minimum depth occurring in the throat.

A tailgate was placed downstream from the flume exit in order to regulate the tailwater depth corresponding to that to be encountered in the field.

Analysis of Data

Considerable thought was given to an approach for analyzing submerged flow conditions. The submergence, D_3/D_1, was considered to be a very appropriate parameter. The proper criterion for super-critical or subcritical flow in the throat is the Froude number. Consequently, the Froude number was evaluated at the cross-section of the throat where minimum depth occurred. This Froude number,

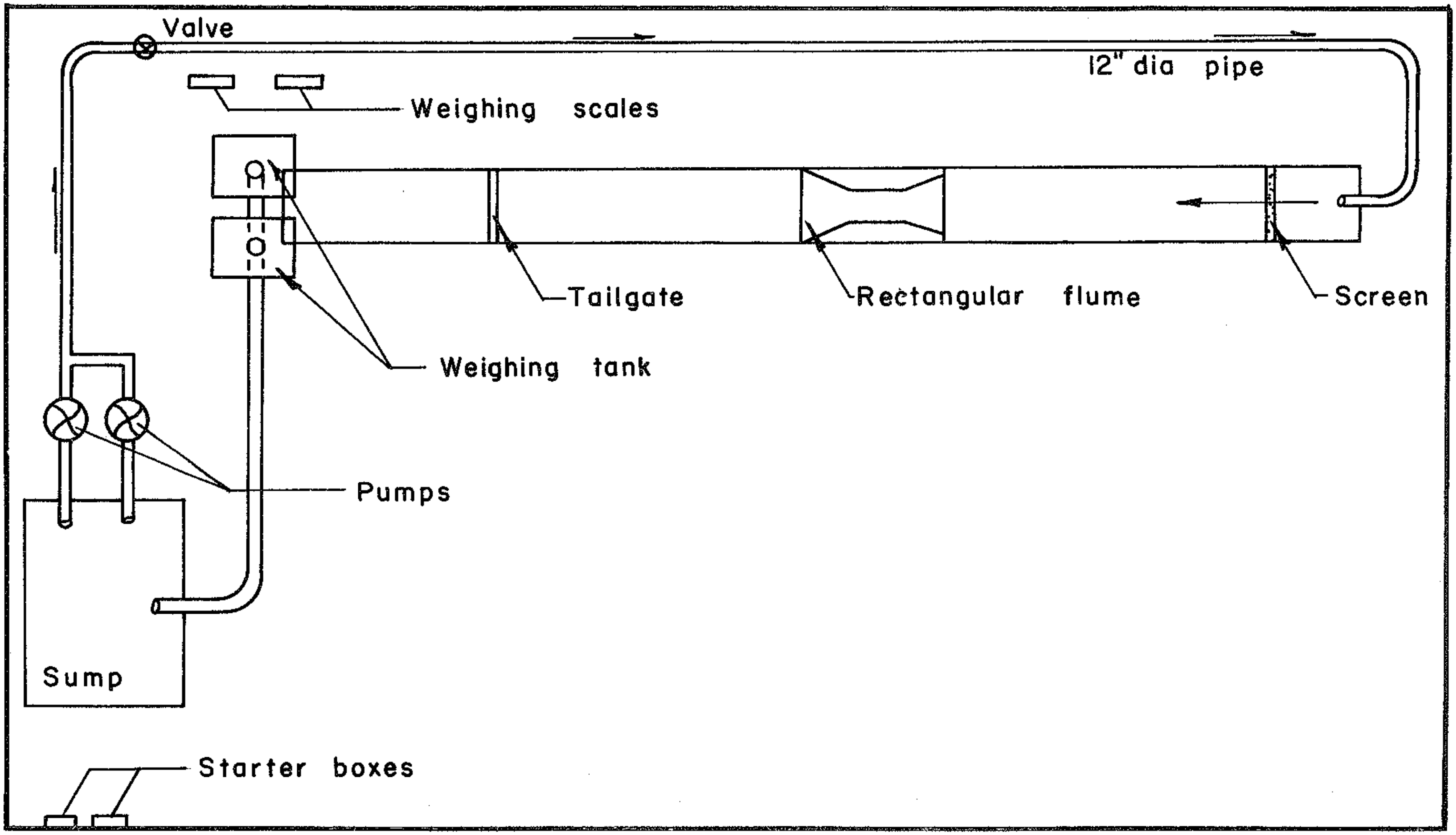

Figure 9. Schematic of laboratory facilities.

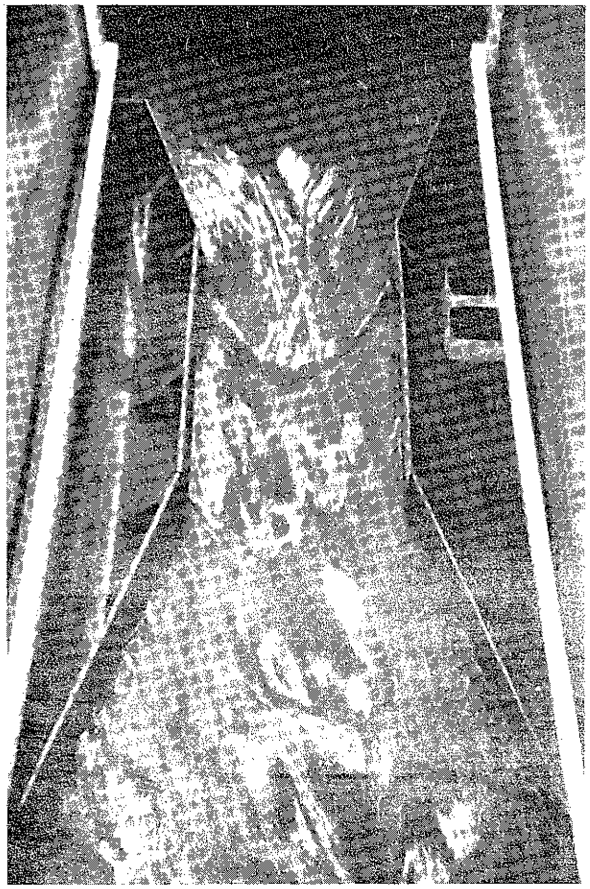

Figure 10. View of model rectangular measuring flume looking upstream with prototype discharge of 494 cfs and downstream depth of 4.3 feet.

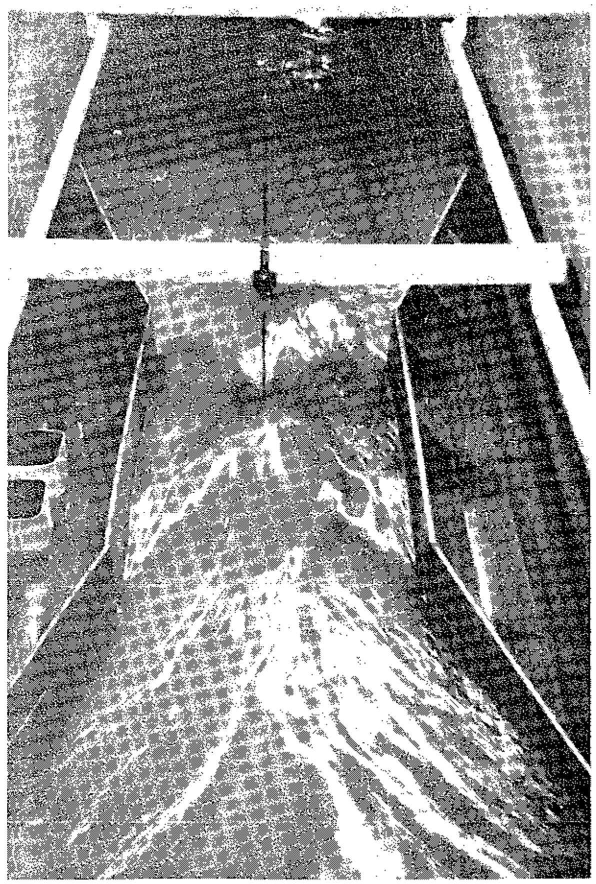

Figure 11. View of model rectangular measuring flume looking downstream with prototype discharge of 494 cfs and downstream depth of 5.0 feet.

F_m, is actually the maximum Froude number occurring in the flume. The other parameter, which will be referred to as the energy-loss parameter, is defined as $(D_1 - D_3)/D_m$. The energy-loss parameter was obtained from the realization that the energy loss, $D_1 - D_3$, was significant and then using the minimum depth of flow in the throat, D_m, to arrive at a dimensionless parameter. The use of minimum depth, D_m, also had the advantage of relating the flow conditions at the three cross-sections.

The parameters involved in submerged flow in rectangular measuring flumes can be obtained from dimensional analysis, as follows:

$$V = f(g, D_1, D_3, D_m) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 7$$

With five independent quantities and two dimensions, three pi-terms are necessary.

$$\pi_1 = \frac{V}{\sqrt{g D_m}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 8$$

$$\pi_2 = \frac{D_3}{D_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 9$$

$$\pi_3 = \frac{D_1 - D_3}{D_m} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 10$$

Equation 8 can be modified by replacing V with Q/A_m

$$\pi_1 = \frac{Q}{A_m \sqrt{g D_m}} = F_m \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 11$$

where

Q = flow rate, cfs.

A_m = area, equals $(b D_m)$, ft.^{2}

b = flume throat bottom width, ft.

D_m = minimum depth of flow in the throat, ft.

g = acceleration due to gravity, 32.2 ft/sec.^{2}

The relationship between submergence and the energy-loss parameter was developed on a rectangular plot with the log of submergence as the ordinate and the energy-loss parameter as the abscissa. The relationship was essentially a straight line (Figure 12) which can be written as an equation

$$\log D_3/D_1 = 0.34 (D_1 - D_3)/D_m - 0.004$$

or simplifying

$$\text{Submergence} = D_3/D_1 = \frac{0.99}{10^{0.34 (D_1 - D_3)/D_m}}$$

A log-log plot was prepared between the energy-loss parameter and the maximum Froude number, F_m, (Figure 13). The energy-loss parameter was plotted as the ordinate and F_m was plotted as the abscissa. The relationship was essentially a straight line and resulted in the equation

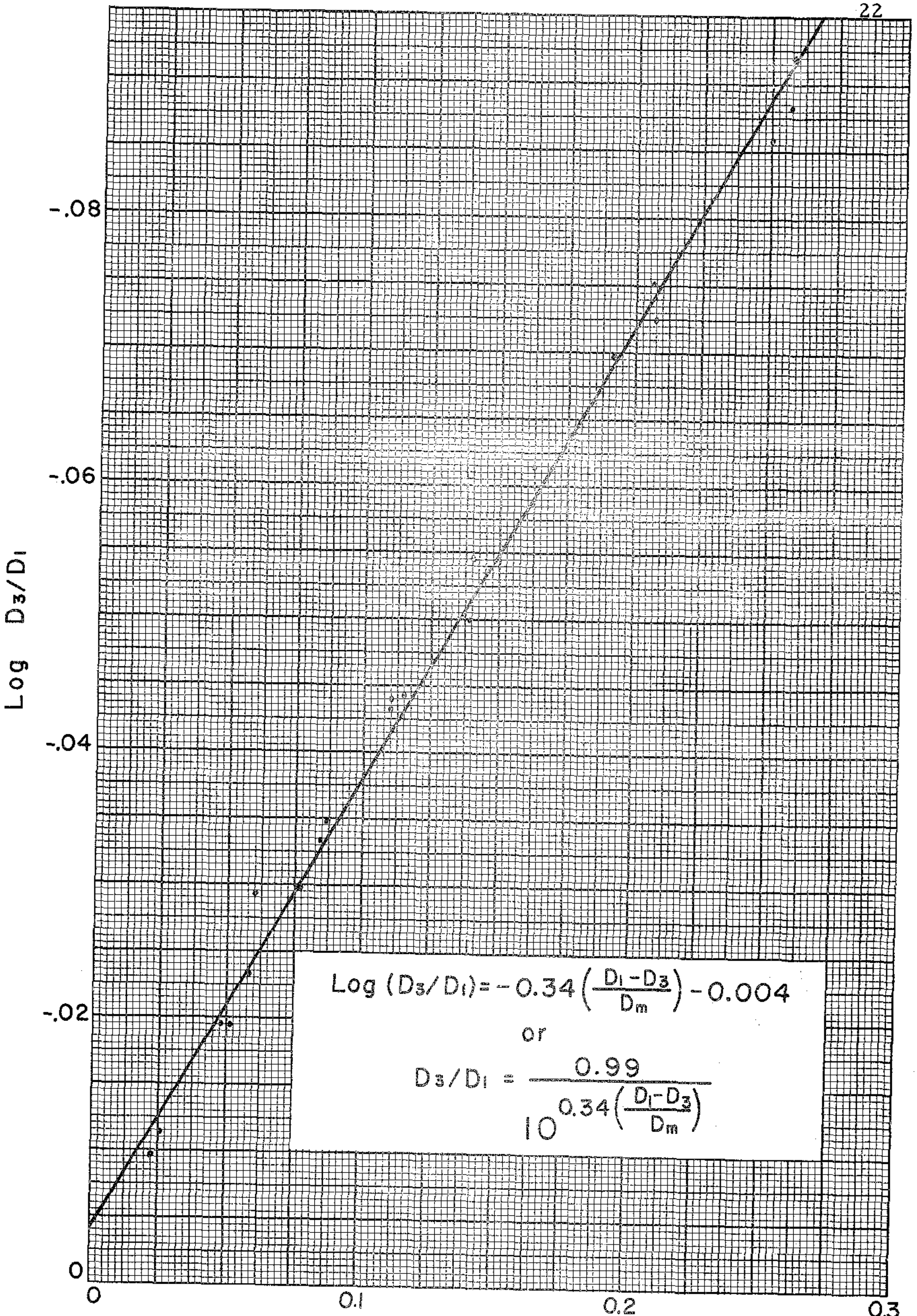

Figure 12. Relationship between energy-loss parameter and log of submergence.

$$\frac{D_1 - D_3}{D_m} = 0.350\, F_m^{\ 1.96} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad 13$$

To show the relationship between the three pi-terms F_m, D_3/D_1, and $(D_1 - D_3)/D_m$, an additional plot was made between submergence and the energy-loss parameter. The energy-loss parameter was plotted on the log scale as the ordinate and to the same scale as in Figure 13. Submergence was plotted as the abscissa on a rectangular scale. This plot (Figure 13) yields a practical graphical solution of F_m when the submergence is known as well as showing the relationship between the three parameters or pi-terms.

With the relationship between submergence and the Froude number known, it was desired to relate these two parameters to discharge. First, since $D_1 - D_3$ and $(D_1 - D_3)/D_m$ is known, D_m can be computed. Next, a three-dimensional log-log plot was prepared of D_m, F_m, and discharge, Q. Here D_m was plotted as the ordinate, F_m as the abscissa, and discharge as the varying quantity which yields a family of curves of discharge (Figure 14). The solution for any discharge, given the upstream and downstream depths, would entail obtaining a value of D_m; the use of Figure 13 to obtain the Froude number; and then from Figure 14 a value of discharge could be interpolated.

However, the general solution for evaluating the discharge from Figure 14 can be obtained by writing the equation of each of the lines

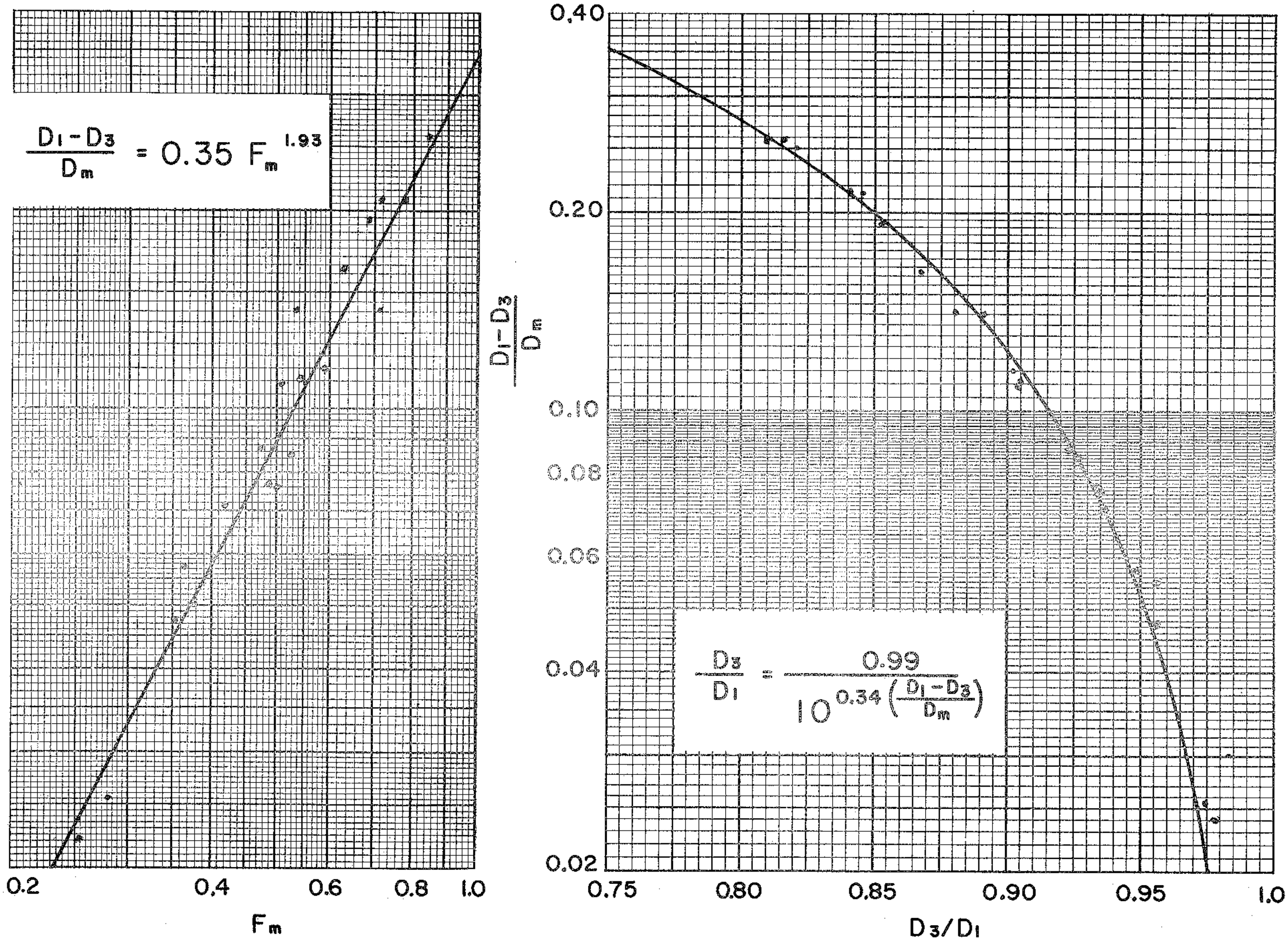

Figure 13. Relationship between pi-terms.

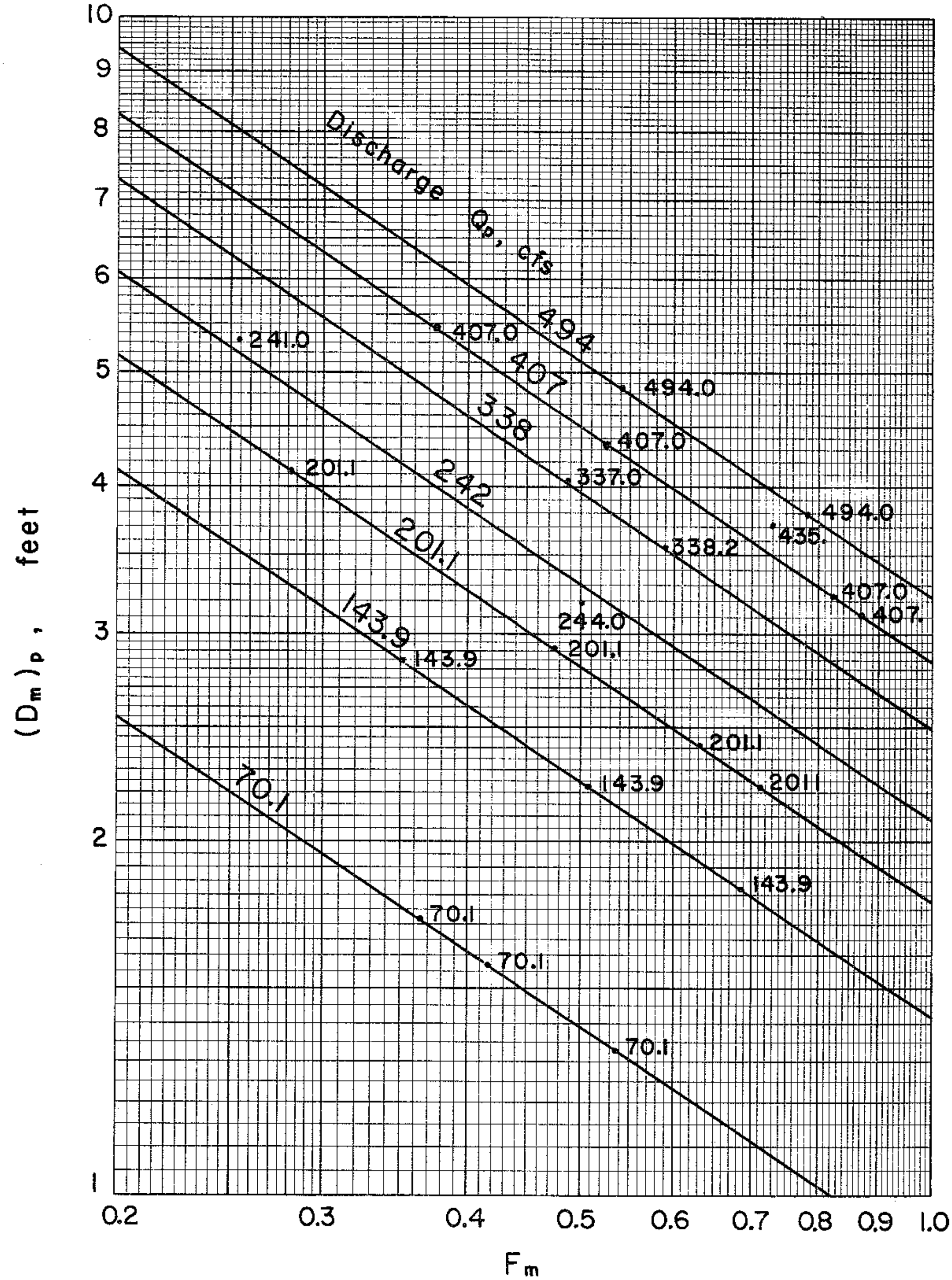

Figure 14. Relationship between Froude number, minimum depth in throat, and discharge.

$$D_m = C_1 F_m^{s}$$

The coefficient, C_1, is the value of D_m for F = 1.0. Consequently, a value of C_1 is obtained for each line of constant discharge. A log-log plot was then prepared between the parameter C_1 and discharge (Figure 15). The straight-line relationship between discharge, Q, and C_1 can be expressed by

$$Q = 82.0\, C_1^{1.53} \qquad 14$$

From Figure 14, h_m and F_m are related to C_1 as

$$D_m = C_1 F_m^{-0.67}$$

or

$$C_1 = D_m F_m^{0.67} \qquad 15$$

Combining Equations 14 and 15

$$Q = 82.0\, F_m D_m^{1.53} \qquad 16$$

To obtain the relationship between Q and D_3/D_1, Equations 13 and 10 are combined to yield

$$Q = 140\,(D_1 - D_3)^{0.51} D_m^{1.02}$$

which, when combined with Equation 9 and simplified, yields

$$Q = \frac{-46.6\,(D_1 - D_3)^{1.53}}{(\log \frac{D_3}{D_1} + 0.004)^{1.02}} \qquad 17$$

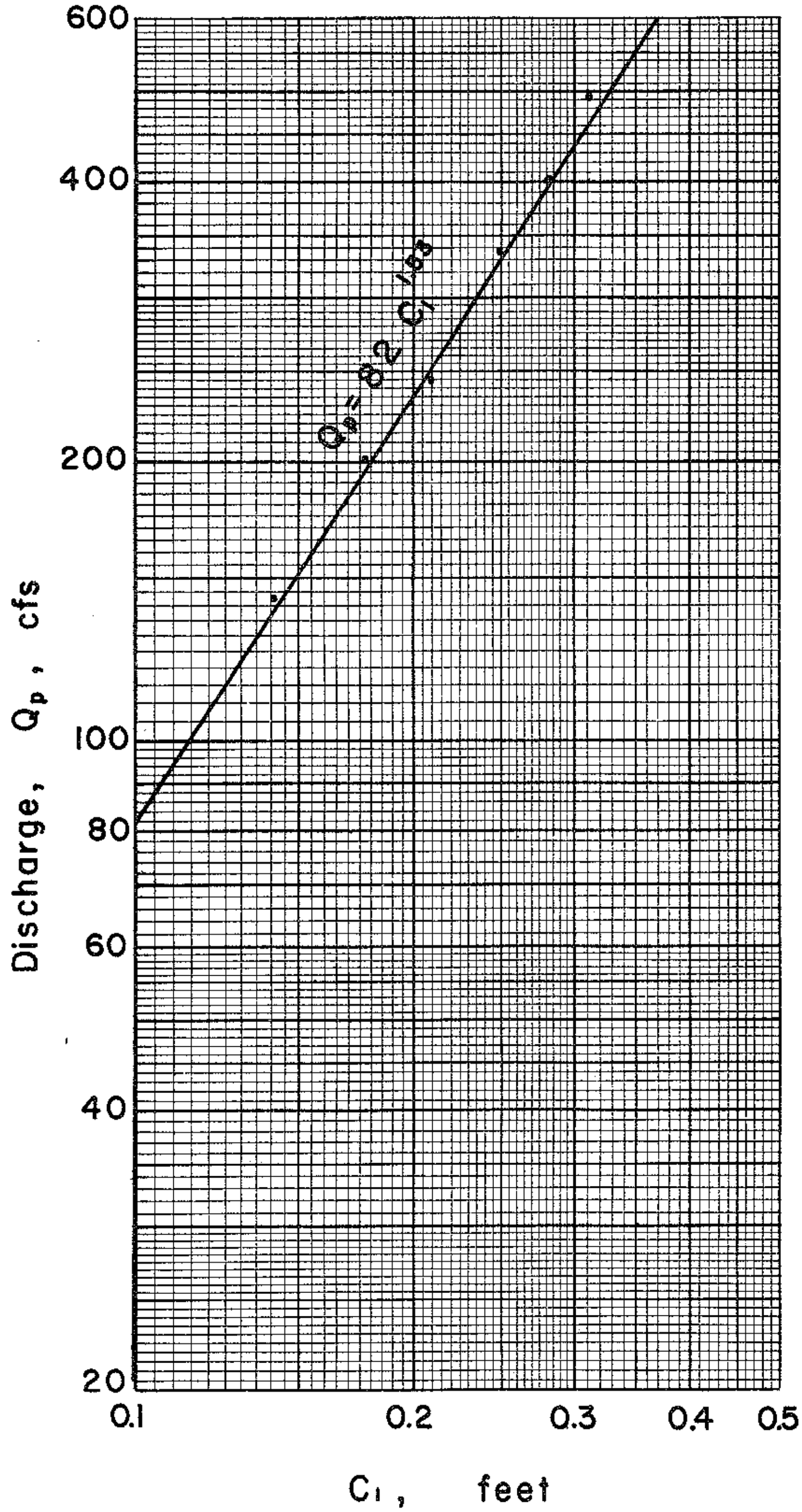

Figure 15. Development of relationship between discharge, Froude number, and minimum depth in throat.

Although Equation 17 is only valid for the rectangular measuring flume studied, it does show that only the upstream and downstream depths need to be measured to determine the discharge under submerged flow conditions in any rectangular flume.

The relationships arrived at in the preceding equations are valid and the inaccuracy can be accounted for as due to experimental procedure. The minimum depth in the throat, D_m, was particularly difficult to measure, due to the wave action present. The accuracy is sufficient for most field flow measurements.

Calibration Curves

The primary purpose of this investigation has been the calibration of a prototype submerged rectangular flume which has been constructed in Canal "A" of the distribution system of the D.M.A.D. Company. The flume operates under submerged flow conditions and does not pass through critical depth. Therefore, it will be necessary to measure the upstream depth, D_1, and the tailwater depth, D_3, in order to determine discharge.

Hyatt (1965) showed that only the upstream and tailwater depths need be measured in a submerged trapezoidal flume. The primary purpose of this model study was to show that the same analysis was valid for a submerged rectangular flume. Consequently, only a meager amount of data was necessary from the model. The data allow the prediction of the prototype calibration curves, but it was realized from the beginning, that these curves would have to be adjusted based on field measurements.

To prepare calibration curves for submerged flow, a three-dimensional log-log plot was prepared of Q, $D_1 - D_3$, and D_3/D_1. The discharge, Q, was plotted as the ordinate, energy loss, $D_1 - D_3$, as the abscissa, and submergence, D_3/D_1, as the plotted variable (Figure 16). A series of parallel lines of varying submergence were then drawn for submergences between 80 percent and 97 percent. In the field, for a measured upstream and downstream depth, the energy loss, $D_1 - D_3$, and the submergence, D_3/D_1, can be computed, thus allowing a determination of the discharge from Figure 18 for the prototype rectangular measuring flume.

Field Calibration

A number of discharge measurements were made with a current meter at the prototype rectangular flume during the 1964 irrigation season. The prototype discharge measurements indicate that the predicted prototype calibration curves based upon the model study (Figure 18) result in discharges five percent less than the true discharge. Additional prototype measurements will be obtained during the 1965 irrigation season. Prior to the 1966 season, the predicted calibration curves of Figure 18 will be adjusted to conform to the field measurements.

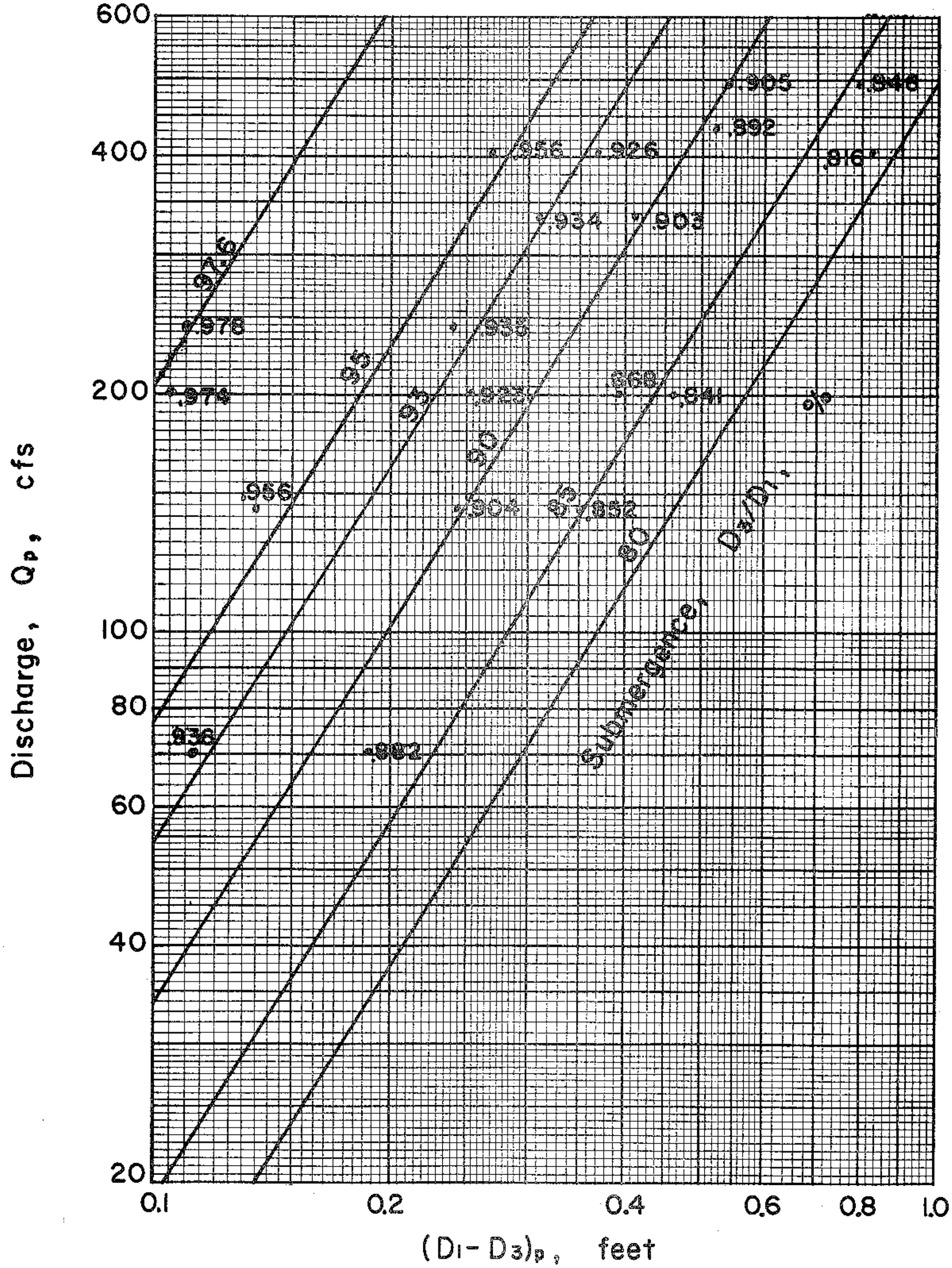

Figure 16. Relationship between discharge, energy loss, and submergence.

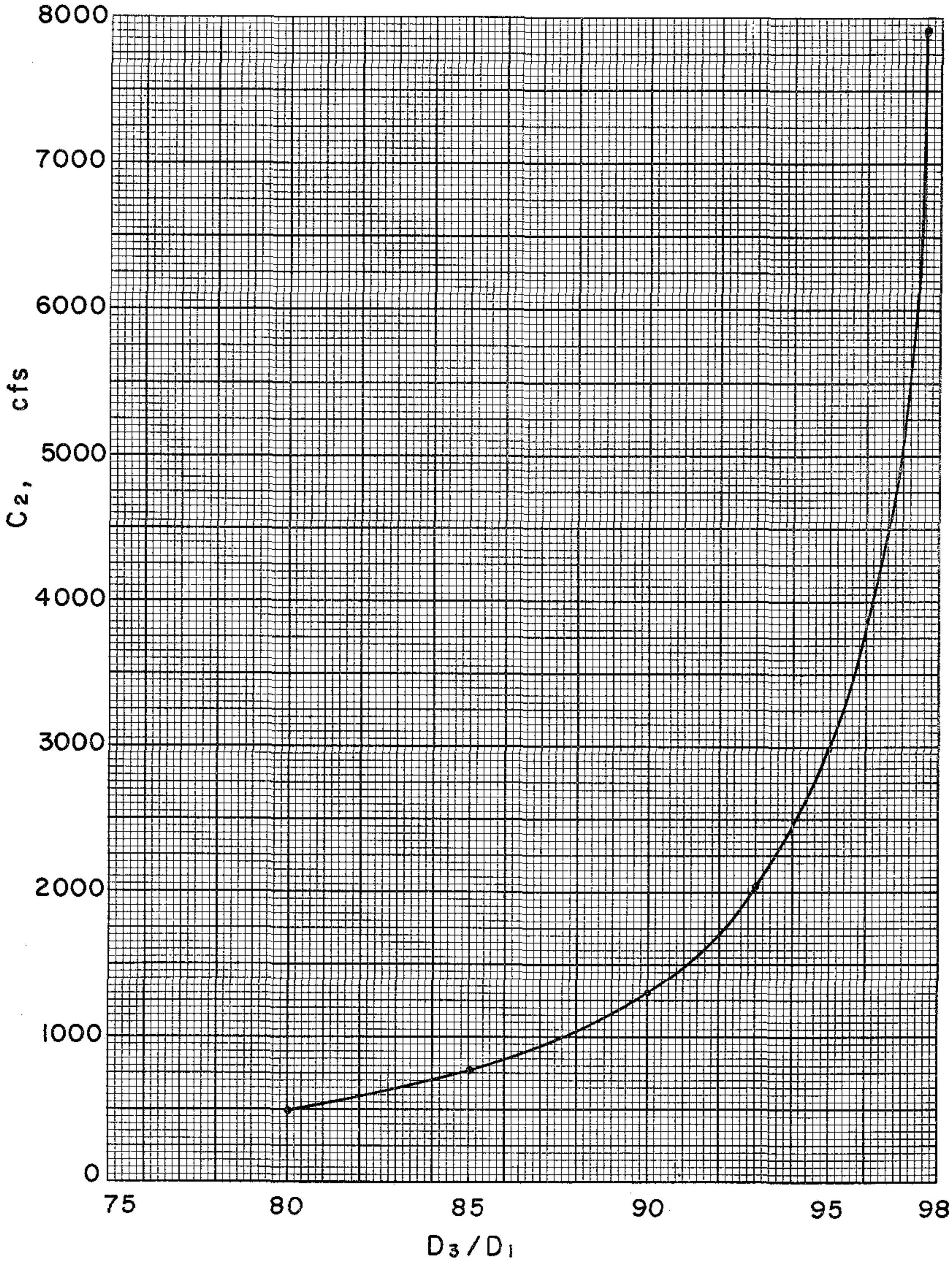

Figure 17. Development of relationship between discharge, energy loss, and submergence.

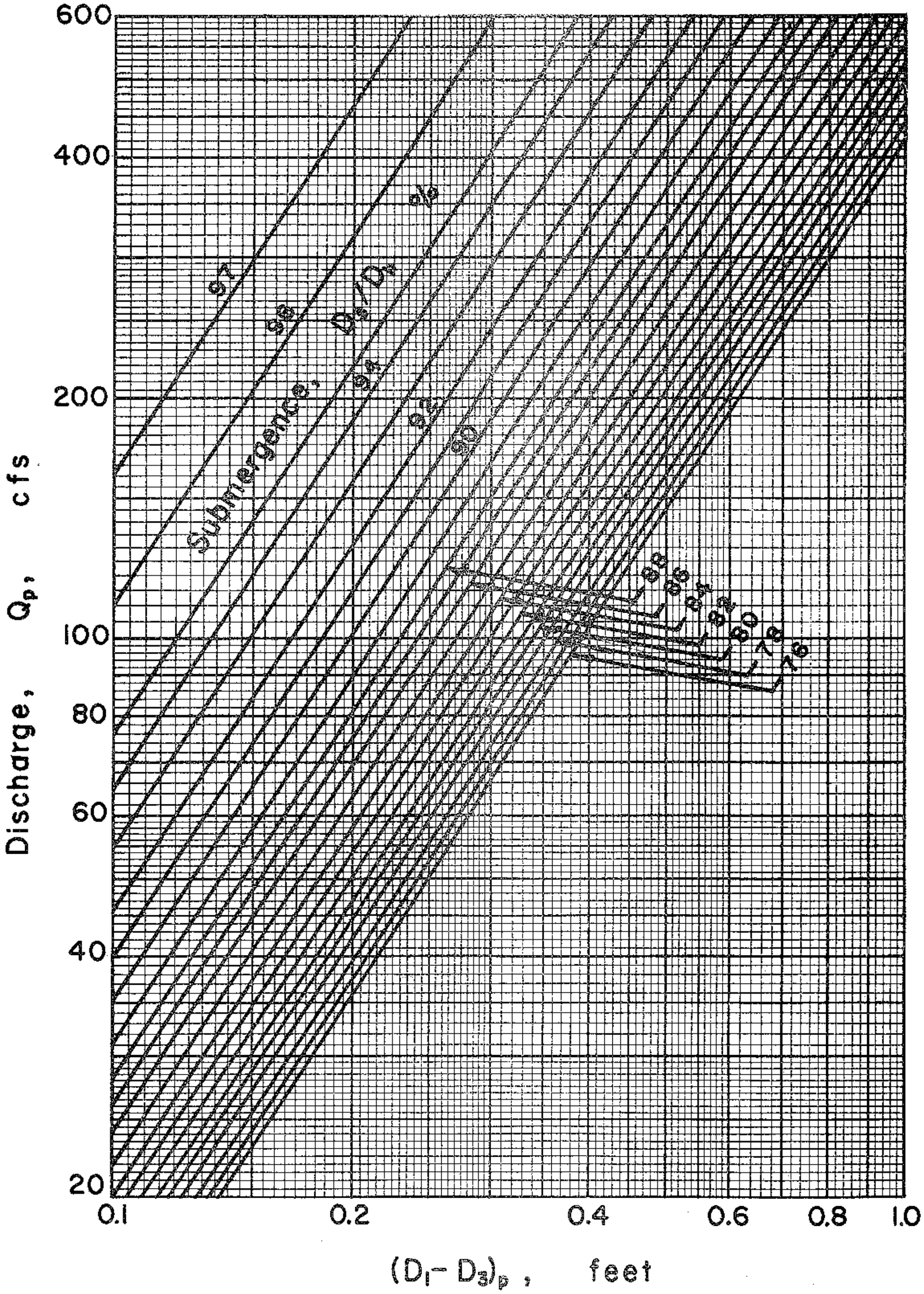

Figure 18. Calibration curves for rectangular measuring flume.

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APPENDIX

Data and Computations

Table 1. Basic measurements

Run no.	Q_m	$(D_1)_m$	$(D_3)_m$	$(D_m)_m$	Type of flow
1	0.540	0.253	0.237	0.224	subcritical
2	0.540	0.267	0.253	0.245	subcritical
3	0.540	0.229	0.202	0.190	subcritical
4	1.108	0.336	0.286	0.260	subcritical
5	1.108	0.440	0.421	0.407	subcritical
6	1.108	0.366	0.331	0.319	subcritical
7	1.550	0.414	0.348	0.317	subcritical
8	1.550	0.430	0.374	0.344	subcritical
9	1.550	0.617	0.602	0.587	subcritical
10	1.550	0.472	0.436	0.416	subcritical
11	3.810	0.729	0.616	0.542	subcritical
12	3.810	0.791	0.714	0.694	subcritical
13	3.810	0.714	0.549	0.430	supercritical
*14	3.140	0.629	0.449	0.445	subcritical
15	3.140	0.730	0.677	0.621	subcritical
16	3.140	0.849	0.810	0.777	subcritical
17	3.140	0.635	0.518	0.458	subcritical
18	2.607	0.604	0.544	0.509	subcritical
19	2.595	0.661	0.618	0.576	subcritical
20	2.610	0.559	0.447	0.337	supercritical
21	1.880	0.461	0.384	0.269	supercritical
22	1.880	0.526	0.492	0.454	subcritical
23	1.855	0.758	0.743	0.720	subcritical
24	3.345	0.657	0.515	0.396	supercritical
25	3.345	0.694	0.619	0.530	subcritical
26	3.350	0.667	0.548	0.470	subcritical
27	3.445	0.680	0.551	0.502	subcritical

*Measurements in error.

Table 2. Prototype measurements

Run no.	Q_p	$(D_1)_p$	$(D_3)_p$	$(D_m)_p$
1	70.1	1.771	1.659	1.568
2	70.1	1.869	1.771	1.715
3	70.1	1.602	1.414	1.330
4	143.9	2.351	2.001	1.820
5	143.9	3.080	2.945	2.850
6	143.9	2.561	2.317	2.232
7	201.1	2.895	2.435	2.220
8	201.1	3.010	2.617	2.408
9	201.1	4.320	4.215	4.110
10	201.1	3.305	3.051	2.910
11	494.0	5.100	4.315	3.795
12	494.0	5.540	5.000	4.860
13	494.0	5.000	3.840	3.010
*14	407.0	4.400	3.145	3.115
15	407.0	5.110	4.740	4.350
16	407.0	5.940	5.670	5.440
17	407.0	4.450	3.625	3.205
18	338.2	4.220	3.810	3.560
19	337.0	4.630	4.320	4.040
20	339.0	3.910	3.135	2.360
21	244.0	3.230	2.690	1.885
22	244.0	3.685	3.445	3.180
23	241.0	5.310	5.200	5.040
24	435.0	4.610	3.605	2.775
25	435.0	4.860	4.340	3.710
26	435.0	4.660	3.835	3.290
27	446.0	4.760	3.855	3.520

*Measurements in error.

Table 3. Computation of parameters.

Run no.	Q_p	F_m	D_3/D_1	$(D_1 - D_3)_p$	$(D_m)_p$	$\frac{(D_1 - D_3)}{D_m}$
1	70.1	0.419	0.936	0.112	1.568	0.0712
2	70.1	0.366	0.948	0.098	1.715	0.0571
3	70.1	0.534	0.882	0.188	1.330	0.1410
4	143.9	0.687	0.852	0.350	1.820	0.1920
5	143.9	0.352	0.956	0.135	2.850	0.0470
6	143.9	0.508	0.904	0.244	2.232	0.1090
7	201.1	0.714	0.841	0.460	2.220	0.2070
8	201.1	0.632	0.868	0.393	2.408	0.1630
9	201.1	0.282	0.974	0.105	4.110	0.0260
10	201.1	0.474	0.923	0.254	2.910	0.0870
11	494.0	0.783	0.846	0.785	3.795	0.2070
12	494.0	0.541	0.905	0.540	4.860	0.1110
13	494.0	1.115	0.768	1.160	3.010	0.3850
*14	407.0	0.871	0.715	1.255	3.115	0.4030
15	407.0	0.527	0.926	0.370	4.350	0.0850
16	407.0	0.378	0.956	0.270	5.440	0.0500
17	407.0	0.821	0.816	0.825	3.205	0.2580
18	338.2	0.590	0.903	0.410	3.560	0.1150
19	337.0	0.489	0.934	0.310	4.040	0.0770
20	339.0	1.100	0.802	0.775	2.360	0.3280
21	244.0	1.110	0.833	0.540	1.885	0.2860
22	244.0	0.501	0.935	0.240	3.180	0.0760
23	241.0	0.254	0.978	0.110	5.040	0.0220
24	435.0	1.105	0.782	1.005	2.775	0.3620
25	435.0	0.715	0.892	0.520	3.710	0.1400
26	435.0	0.834	0.821	0.825	3.290	0.2500
27	446.0	0.796	0.809	0.905	3.520	0.2570

*Measurements in error.