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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

COMPOUND WEIR STUDY

Hydraulic Laboratory Report No. Hyd. 505

DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

April 5, 1963

CONTENTS

FOREWORD

The studies discussed in this report were performed during November 1959 to February 1960 by the Special Investigations Unit of the Hydraulics Branch. Laboratory experiments were made by W. B. McBirney, S. G. Parker and J. L. Harper under the supervision of J. C. Schuster. The data and analysis contained were compiled for the report by J. M. Bergmann. The Special Investigations Unit is in the Special Investigations Section headed by A. J. Peterka. H. M. Martin is Chief of the Hydraulics Branch.

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Laboratory Report No. Hyd. 505
Compiled by: J. M. Bergmann
Checked by: J. C. Schuster
Reviewed by: A. J. Peterka
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COMPOUND WEIR STUDY

SUMMARY AND CONCLUSIONS

Experiments on five weirs, each composed of a 1-foot-deep V-notch weir with vertical, 1- and 2-foot horizontal or 15° upward sloping extensions (Figure 3) were performed to determine the flow characteristics in terms of head-discharge (H-Q) relationships. An analysis of the data was made to obtain correlations between the (H-Q) relationships that could be used to determine the discharge of 1-foot-deep V-notch weirs having other lengths of extensions.

The V-notch weirs with horizontal extensions produced a smooth head-discharge curve except in the transition zone where the head just exceeded the depth of the V-notch portion of the weir, i.e., heads from 1.0 to 1.1 feet. The thin sheet of water tended to dribble over the extension because the vertical component of velocity at the weir crest was not sufficient to establish a true contraction.

Weirs with sloping extensions from the V-notch produced better contractions of the lower surface of the nappe for very low heads resulting in a more uniform head discharge curve.

At points of change in the slope of the crest, the rates of discharge change in the H-Q relationships were not completely definable. Therefore, compound weirs should be set so that discharge determination in the transition regions will be of minimum importance. In other ranges of flow the compound weirs were as accurate as any weir can be. The head-discharge relationships in the form of equations are cumbersome, but simple graphs and tables can be prepared for determining discharge.

Generalized head-discharge equations derived in this report from the test data need to be confirmed by further testing before they are extended to applications outside the range of the data.

INTRODUCTION

Frequently, a single water-measuring device is desired that will accurately measure a wide range of discharges, e.g., both the normal and flood flows of streams, Figure 1A. Proportional weirs and specially shaped flumes, can be designed to be generally acceptable but these devices are often complicated and may cost more to construct than is warranted by the value of the data obtained. The compound weir resolves the cost problem but introduces the problem of complicated head-discharge relationships.

Five compound weirs were tested in the Bureau's Laboratory to define the flow characteristics in terms of the H-Q relationships and to possibly correlate the discharge equations. The weirs, sharp crested and tested under free flow, contracted conditions, consisted of a 90° V-notch 1 foot deep with one of the following extensions:

1. Vertical
2. Horizontal
   a. 1 foot in length on each side and vertical sides
   b. 2 feet in length on each side and vertical sides
3. Sloping (15° above horizontal)
   a. 1-foot horizontal length each side and vertical sides
   b. 2-foot horizontal length each side and vertical sides

Accurate head and discharge measurements were used to calibrate the weirs. Equations determined by mathematical and graphical methods, were used to generalize the H-Q relationships. The sloping extensions were tested in an attempt to obtain a uniform transition of the flow from the V-notch weir to the compound shape.

LABORATORY INSTALLATION

The weir crests were installed in the side of a 20-foot by 18-foot 9-inch head box, with the root of the V-notch portion of the weir set 3 feet 0 inch above the floor of the box, Figures 1B and 2. This arrangement provided a minimum of 60 square feet in the approach cross-section and allowed the velocity of approach for the discharges used in the study to be neglected in determining the total head on the crest. A 6-inch-thick rock baffle, 13 feet

9 inches upstream from the crest, was placed across the head box to stabilize the flow in the weir pool. Calibrated Venturi meters were used to measure the flows from three pumps discharging up to a total of 32 cubic feet per second into the head box. The pumps and Venturi meters are permanent installations of the laboratory. Static head measurements were made with a hook gage in a stilling well located outside the head box. The stilling well connection was tapped into the side of the head box about 8 feet upstream of the weir bulkhead.

The crests, shown in Figure 3, were formed from 2-1/4- by 1/4-inch brass strips and were bolted to a 3/4-inch plywood bulkhead. The top edge of the strips was beveled to 1/8-inch thickness to form the sharp crest.

WEIR CALIBRATION

The weirs were calibrated by measuring and recording the heads over the weir crest when steady conditions existed in the weir pool for known discharges. The data were plotted as they were obtained to determine the coherency of the tests and to verify the recorded head-discharge relationship. The data, thus obtained, are presented in Tables 1 through 5. Discharges and heads for the V-notch portion of the weirs were measured in conjunction with the first weir tested, Table 1, and periodically checked at random thereafter.

A pictorial record, partially presented as Figures 4 through 8, was kept during the tests. Of particular interest are the photographs shown as Figure 4, where the head on the V-notch portion of the weir is slightly in excess of 1.0 foot and flow is just beginning to pass over the horizontal portion of the weir. It was noted that for heads from approximately 1.0 to 1.1 feet, the discharge over the horizontal crests was neither uniform nor stable due to the draw-down over the V-notch. Figures 5 through 8 show four of the five weirs before and during testing.

DATA ANALYSIS

For analytical purposes, the V-notch weir with vertical extensions was considered a V-notch weir with zero-length horizontal extensions. Thus, two types of compound weirs were analyzed:

1. V-notch with extensions horizontal

2. V-notch with extensions 15° above horizontal

Further, the data for the 90° V-notch portion of the weirs shows good agreement, Figure 9 with the Cone Equation

$$Q = 2.49H^{2.48} \tag{1}$$

therefore, Equation (1) was considered to be representative of the V-notch data in the following analyses.

Horizontal Extensions

The data for the V-notches with horizontal extensions were plotted, head versus discharge, on rectangular and log-log graph paper. From the log-log plot, Figure 10, and observations during the tests, it was noted that a transition zone existed at heads between 1.0 and 1.1 feet for the 1- and 2-foot extensions, caused by the change from a simple weir to a compound weir. Therefore, these data were not included in determining H-Q relationships for the upper portion of the weirs. Next, it was assumed that the H-Q relationship for the remaining data was a polynomial of the form,

$$Q = a_1 + a_2H + a_3H^2 + \ldots + a_nH^{n-1} \tag{2}$$

Successive differences of discharges at equally spaced, increasing heads indicated that the polynomial was of the second degree. Thus, Equation (2) becomes

$$Q = a_1 + a_2H + a_3H^2 \tag{3}$$

The constants were determined from the data in Tables 1 through 3 for heads greater than 1.1 feet by the method of least squares, which resulted in the following equations:

1. Q_0 (zero extensions) = $-2.420 + 2.661H + 2.126H^2$ (4)
2. Q_1 (1-foot extensions) = $-4.579 + 1.792H + 4.732H^2$ (5)
3. Q_2 (2-foot extensions) = $-5.589 - 0.859H + 8.005H^2$ (6)

These equations are shown graphically on Figure 11.

Correlation of the horizontal crest lengths with the constants in Equations (4), (5), and (6), corresponding to a_1, a_2, and a_3 of Equation (3), was performed by plotting the constants against the corresponding length of horizontal crests, Figure 12. The indicated trends of the constants are speculative, since there are only three points, and should not be relied on for accurate formulation. However, if horizontal weir extensions are used, in conjunction with a 1-foot V-notch, an estimate of the constants in Equation (3) may be obtained from Figure 12.

As an alternative to the use of Equation (3) which requires a determination of the constants, a general equation was derived for the head-discharge relationship of V-notch weirs with horizontal extensions when flows exceed the capacity of the V-notch. To derive the general equation, head-discharge relationships were determined for the V-notch with vertical extensions and for the discharge per foot of horizontal extension regardless of total length.

The head-discharge relationship for the V-notch weir with vertical extensions was assumed to be of the form,

$$Q + b = aH^{m} \tag{7}$$

By trial and error, 1.5 cubic feet per second was chosen for b in order to produce a linear relationship between the logarithms of the heads and the corresponding "adjusted" (Q plus b), discharges, Figure 13. The constants a and m of Equation (7) were determined from this graph. The resulting equation is:

$$Q = 3.9H^{1.72} - 1.5 \tag{8}$$

Eleven discharges for the V-notch with vertical extensions were subtracted from the total discharges over the weirs with 1- and 2-foot extensions when under the same head. The remaining fraction of the discharge was then divided by the total length of horizontal crest. This gave a discharge per foot of horizontal crest, q, for various heads above the horizontal crest, h. Equation (9) is the resulting relationship determined from the head-discharge, log-log plot, Figure 14.

$$q = 3.3h^{1.5} \tag{9}$$

A general equation for computing discharges over weirs with horizontal extensions results from the combining of Equations (8) and (9), into Equation (10)

$$Q = 3.9H^{1.72} - 1.5 + 3.3Lh^{1.5} \tag{10}$$

where L is the total length of the horizontal extensions.

Equation (9) is in good agreement with equations determined by various investigators as reported by King (Reference 1),

$$q = Kh^{3/2}, \tag{11}$$

where K depends on the velocity of approach and weir pool shape.

Discharges in the transition zone, heads between 1.0 and 1.1 feet, are affected by the approach flow characteristics and weir crest sharpness and roughness. The laboratory tests indicated the simple V-notch Equation (1) to be applicable for heads up to 1.05 feet when the V was 1.00 foot deep. However, in a field installation, where weir crest imperfections and small waves are more likely to occur, the decision as to when Equation (1) no longer applies may not be well defined. Therefore, the size and vertical placement of the compound weir, based on anticipated flows, should be such that heads of 1.0 foot to 1.1 feet will be in minimum usage.

The discharge over a compound weir composed of a 1.0-foot V-notch with horizontal extensions may be computed by either Equation (3) or Equation (10). Equation (3) requires the use of Figure 12 for determining constants in addition to knowing the head over the weir and the length of the horizontal extensions, which is required when Equation (10) is used.

Two example problems follow. The first illustrates the use of Figure 11 and the second illustrates the use of Equations (3) and (10).

Example 1. Determine from Figure 11, the discharge over a 1-foot V-notch weir with 1-foot horizontal extensions on each side, when the head is 1.8 feet.

The discharge is obtained by going horizontally from H = 1.8 until the 1-foot horizontal extension line is intersected. At the intersection, go vertically down to read Q = 14 cubic feet per second.

Example 2. Determine the discharge over a 1-foot V-notch weir with 18-inch horizontal extensions on both sides of the V-notch when operating under a 2.0-foot head.

From Figure 12, for L = 3.0 feet

$a_1 = -5.13$
$a_2 = 0.69$
$a_3 = 6.30$

therefore, by Equation (3) for H = 2.0 feet

$$Q = -5.13 + 0.69(2) + 6.30(4) = 21.45$$

cubic feet per second

By Equation (10), for H = 2.0 feet, h = 1.0 foot and L = 3.0 feet,

$$Q = 3.9(2)^{1.72} - 1.5 + 3.3(3)(1)^{1.5} = 21.28$$

cubic feet per second

Sloping Extensions

Compound weirs with sloping extensions necessitate the use of three equations to adequately express the head-discharge relationship of the weir. The three relationships correspond to the following portions of the weir:

1. The V-notch, previously discussed

2. The sloping extensions, a straight-line plot on log-log paper

3. The portion above the sloping extensions, which was assumed to be of the same form as Equation (3).

The H-Q relationship for the sloping extension portion of these compound weirs was found to be

$$Q = 2.22H^{3.21} \tag{12}$$

from a log-log plot of the test data, Figure 15.

The relationship for the portion of the weirs above the sloping extensions was computed by the method of least squares after the form of the equation was assumed. The equations for the two weirs are

1. Q_1 (1-foot extensions) $= -11.345 + 7.484H + 3.360H^2$ (13)

2. Q_2 (2-foot extensions) $= -14.106 + 6.943H + 5.110H^2$ (14)

Equations (12), (13), and (14) are shown graphically on Figure 16.

There was no apparent advantage in sloping the extensions in comparison with having them horizontal, therefore, no further analysis of the data was undertaken. The sloping extensions do produce a more uniform transition zone at the top of the V-notch; however, another transition zone, at the top of the sloping extension, is encountered. Both transition zones cover a larger range of heads than the one transition zone for the horizontal extensions.

Example 3 illustrates the use of Figure 16.

Example 3. Determine, from Figure 16, the discharge over a 1-foot V-notch weir with 1-foot, 15° upward sloping extensions on each side, when the head is 1.8 feet.

The discharge is obtained by going horizontally from H = 1.8 until the 1-foot sloping extension line is intersected. At the intersection, go vertically down to read Q = 13.2 cubic feet per second.

REFERENCES

1. King, H. W., Handbook of Hydraulics, Third Edition, McGraw-Hill Book Company, Inc., 1939.

2. USBR, Water Measurement Manual, First Edition. U.S. Government Printing Office, Washington, 1953.

Table 1

CALIBRATION OF COMPOUND WEIR
1-FOOT DEPTH 90° V-NOTCH
WITH 2-FOOT HORIZONTAL BLADE

Date run	Head (H ft)	Flow (Q cfs)	Remarks
October 29, 1959	0.670	0.903	
	0.040	0.0148	
	0.339	0.166	
	0.555	0.560	
	0.379	0.216	
	0.495	0.424	
	0.272	0.096	
	0.201	0.037	
October 30, 1959	0.670	0.903	
	0.879	1.779	
	0.384	0.216	
	0.772	1.287	
	0.956	2.209	
November 2, 1959	1.014	2.552	Surface tension holding bead above crest
	1.021	2.599	Bead above crest
	1.027	2.625	Flow over part of crest
	1.031	2.688	Flow over all of crest except near V-notch drawdown
	1.038	2.764	
	1.049	2.888	
	1.058	2.986	Flow over entire crest
November 3, 1959	1.075	3.193	
	1.095	3.442	
	1.107	3.589	
	1.142	4.096	
	1.182	4.769	
	1.207	5.041	
	1.236	5.656	
	1.267	6.207	
	1.311	7.031	
	1.372	8.292	
	1.479	10.607	
	1.479	10.621	
November 4, 1959	1.537	11.712	
	1.577	12.928	Hook gage difficult to set because of head box vibration
	1.633	14.261	
	1.671	15.177	
	1.713	16.319	

Table 1--Continued

Date run	Head (H ft)	Flow (Q cfs)	Remarks
November 4, 1959	1.752	17.420	
	1.819	19.301	
	1.877	20.978	
	1.919	22.189	
	1.982	24.209	Head box not vibrating
	2.028	25.648	
	2.079	27.158	
	2.127	28.788	
	2.183	31.152	
	2.214	31.619	Columns of air noted to form in the nappe from floor at discharge back into the tank through the V-notch. The columns would collapse and then dissipate into the discharge with an audible noise.

Table 2

CALIBRATION OF COMPOUND WEIR
1-FOOT DEPTH 90° V-NOTCH
WITH 1-FOOT HORIZONTAL BLADES

Date run	Head (H ft)	Flow (Q cfs)	Remarks
December 1, 1959	1.027	2.60	Impending flow over horizontal crest
	1.047	2.758	Flow over horizontal crest
	1.064	2.914	
	1.084	3.095	
	1.101	3.261	
	1.102	3.263	
	1.143	3.703	
	1.193	4.294	
	1.247	4.967	
	1.293	5.577	
	1.344	6.283	
	1.398	7.098	
	1.449	7.894	
	1.497	8.649	
	1.542	9.363	
	1.594	10.258	
	1.647	11.159	
	1.697	12.041	
	1.748	13.003	
	1.798	13.918	
	1.842	14.743	
	1.897	16.066	
	1.963	17.174	
December 2, 1959	1.991	17.814	
	2.040	18.851	
	2.088	19.835	
	2.148	21.197	
	2.218	22.728	
	2.274	24.003	
	2.314	25.044	
	2.378	26.437	
	2.444	28.007	
	2.507	29.529	
	2.550	30.660	

Note: V-notch portion not run.

Table 3

CALIBRATION OF COMPOUND WEIR
1-FOOT DEPTH 90° V-NOTCH WITH VERTICAL EXTENSION

Date run	Head (H ft)	Flow (Q cfs)	Remarks
December 21, 1959	1.026	2.596	
	1.048	2.736	
	1.093	3.023	
	1.113	3.167	
	1.143	3.382	
	1.179	3.631	
	1.241	4.114	
	1.294	4.537	
	1.291	4.517	
	1.360	5.091	
	1.414	5.549	
	1.485	6.182	
	1.546	6.737	
	1.615	7.396	
	1.661	7.845	
	1.730	8.548	
	1.805	9.308	
	1.843	9.823	
	1.917	10.515	
December 22, 1959	1.739	8.533	
	1.954	10.868	
	2.095	12.521	
	2.239	14.231	
	2.383	16.043	
	2.534	17.992	
	2.655	19.627	
	2.804	21.682	

Table 4

CALIBRATION OF COMPOUND WEIR
1-FOOT DEPTH 90° V-NOTCH 2-FOOT 15° BLADE

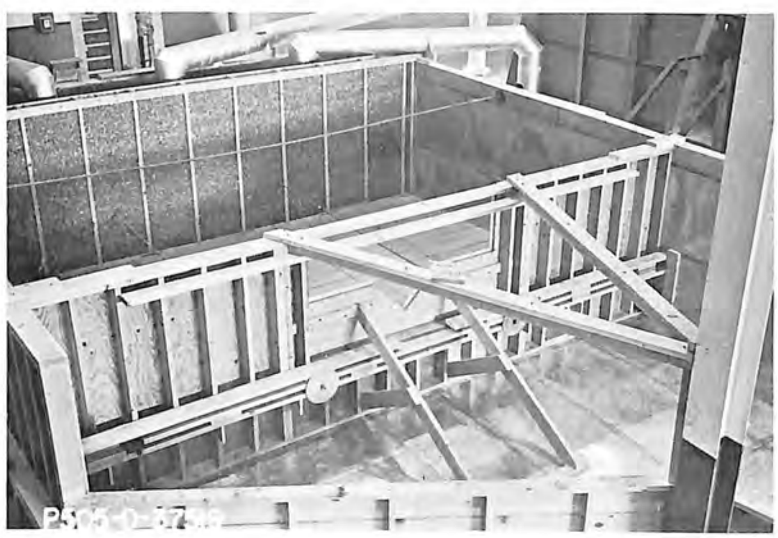
Date run	Head (H ft)	Flow (Q cfs)	Remarks
January 21, 1960	0.990	2.390	Check point on V-notch weir
	0.715	1.032	Check point on V-notch weir
	1.008	2.464	
	1.031	2.628	
	1.051	2.753	Flow drawn down through V
	1.074	2.918	Flow drawn over 15° weir. Nappe is drawn back against V-notch
	1.104	3.149	
	1.206	4.051	
	1.276	4.834	
	1.368	6.017	Nappe getting sufficient air, but is clinging
	1.451	7.307	
	1.533	8.755	Top of trapezoidal weir
	1.607	10.263	Rectangular portion of weir
	1.654	11.280	
	1.683	11.972	Nappe has sufficient air not clinging
	1,810	15.012	
	1.924	17.949	High ridge in center of draw-down
	2.036	20.944	Beautiful nappe, no clinging
	2.111	23.171	
	2.211	26.469	
	2.329	30.149	
	2.427	33.205	

Table 5

CALIBRATION OF COMPOUND WEIR
1-FOOT DEPTH 90° V-NOTCH
WITH 1-FOOT 15° BLADES

Date run	Head (H ft)	Flow (Q cfs)	Remarks
February 25, 1960	1.041	2.716	Well aerated nappe
	1.088	2.933	Nappe began clinging on edge of 15° blade
	1.134	3.418	Nappe clinging
	1.184	3.874	Nappe clinging slightly
	1.233	4.366	
	1.286	4.951	Nappe springing free
	1.334	5.563	
	1.385	6.220	
	1.434	6.935	
	1.485	7.674	
	1.534	8.435	
	1.585	9.263	
	1.634	10.040	
	1.684	10.901	
	1.734	11.789	
February 26, 1960	1.809	13.138	
	1.869	14.262	
	1.944	15.747	
	2.013	17.104	
	2.108	19.292	Head box surging noted
	2.183	20.991	Head box surging noted
	2.220	21.719	Head box surging noted
	2.247	22.324	
	2.319	24.808	Surging in head box, difficult to read head accurately
	2.532	28.992	Surging in head box, difficult to read head accurately

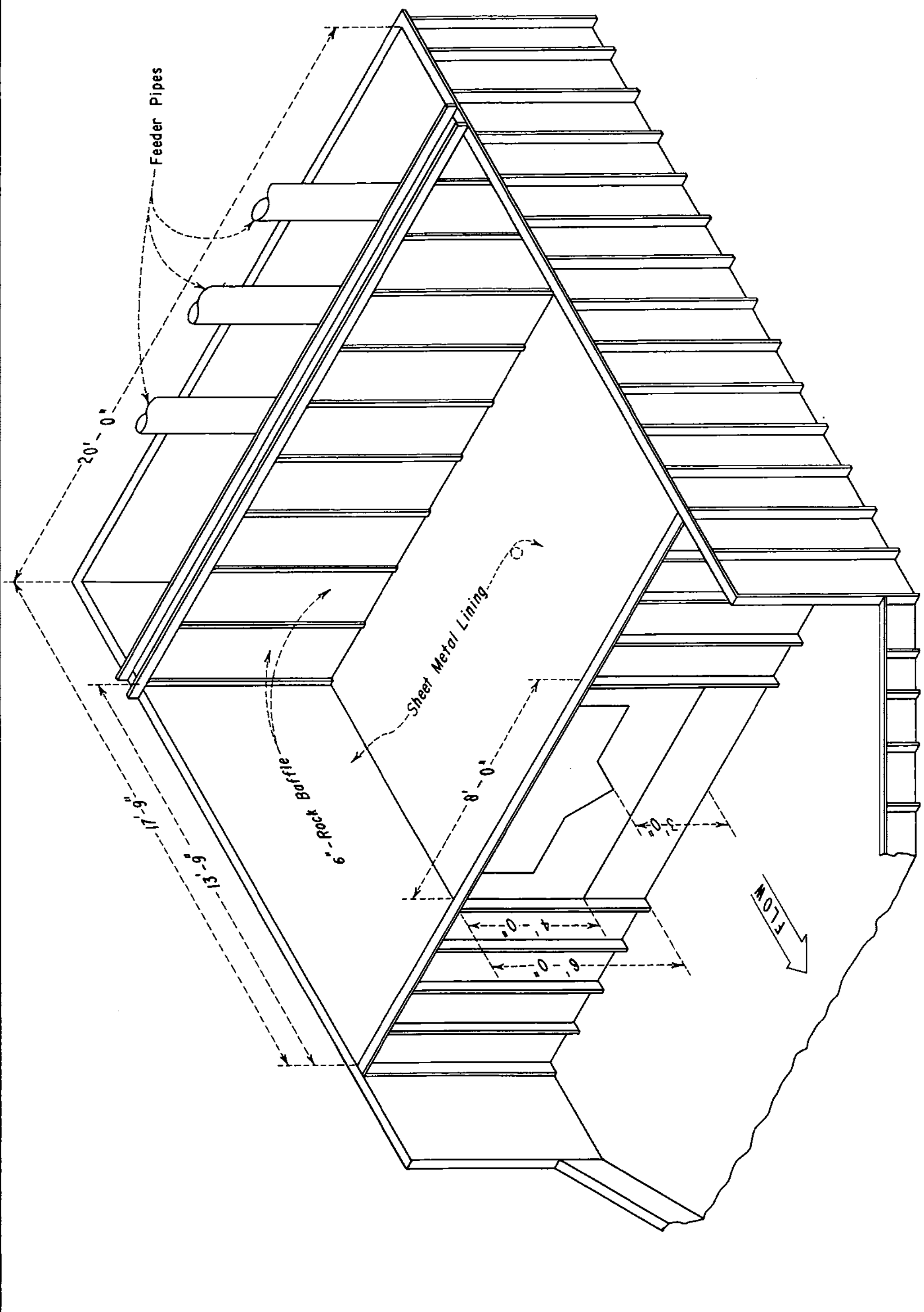
A. Compound weir, 90° V-notch with horizontal extensions, used to measure stream flows by the United States Department of Agriculture Forest Service.



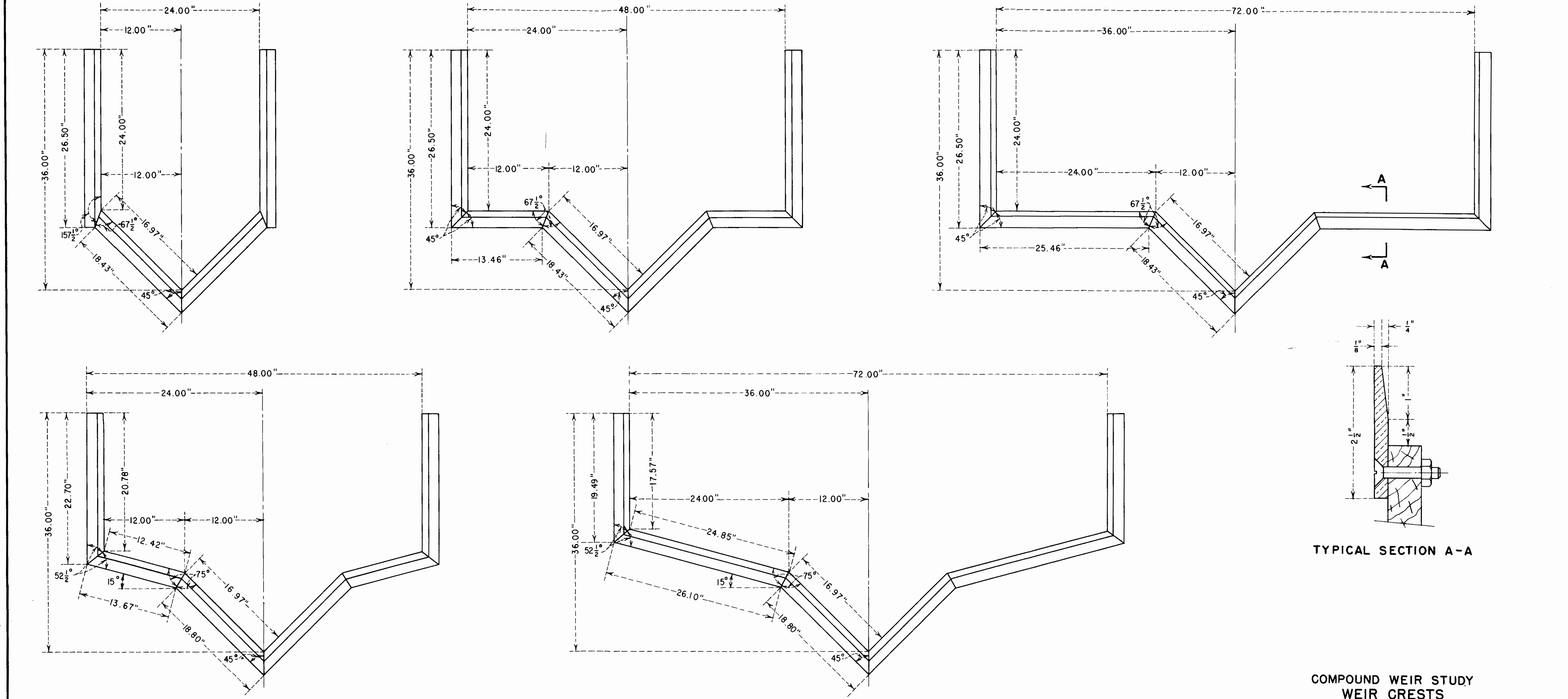
B. A general view of test facility used to study the compound weir.

COMPOUND WEIR STUDY

Field and Laboratory Weir Installations

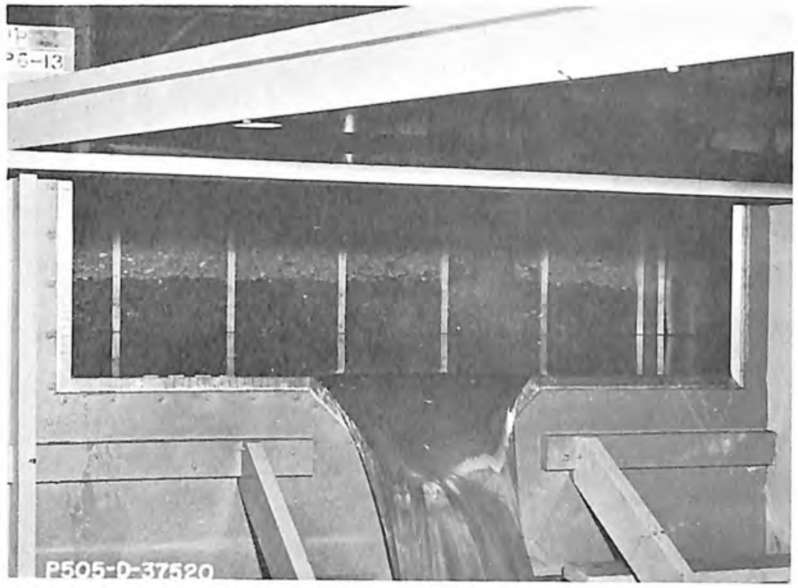


COMPOUND WEIR STUDY
LABORATORY TEST FACILITY



TYPICAL SECTION A-A

COMPOUND WEIR STUDY
WEIR CRESTS



A. 2-foot horizontal extensions.

Head = 1.02 feet Discharge = 2.60 cfs

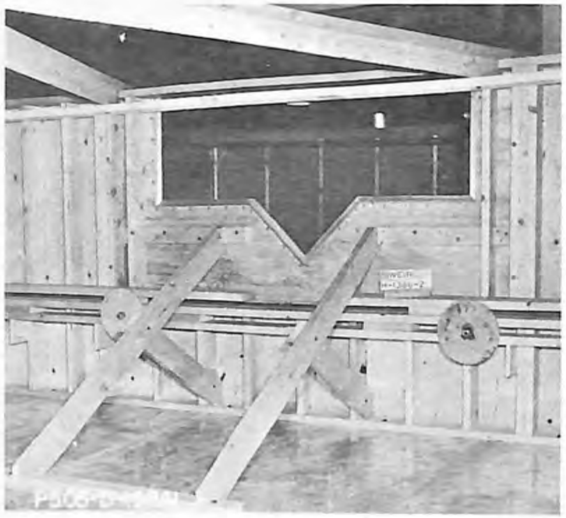
Note that surface tension reduces flow over extensions.

B. 1-foot horizontal extensions.

Head = 1.12 feet Discharge = 3.50 cfs

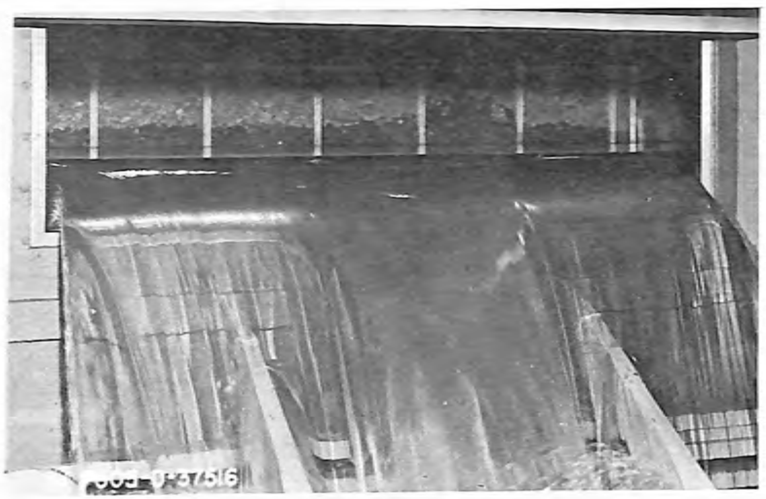
COMPOUND WEIR STUDY

90° V-notch 1-foot deep with horizontal extensions. Note that head exceeds capacity of V-notch but flow over horizontal extensions is not fully developed.



A. No flow.

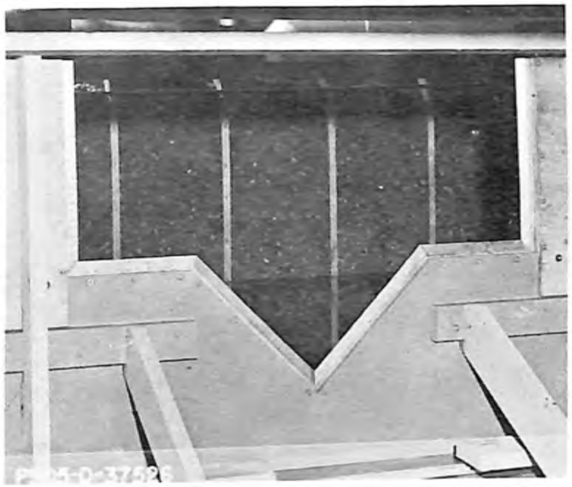
C. Head = 1.6 feet
Discharge = 13 cfs



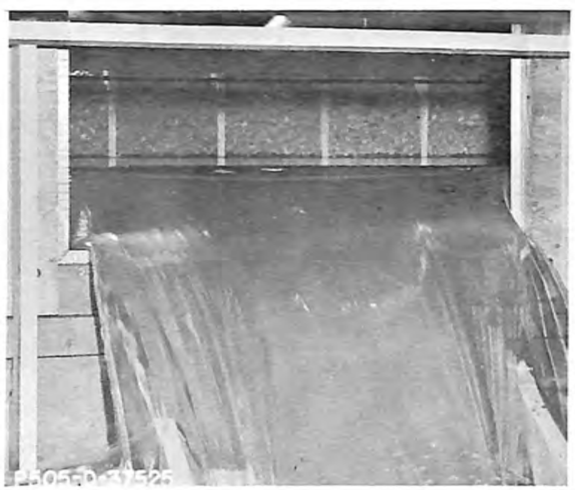
B. Head = 1.6 feet Discharge = 13 cfs

COMPOUND WEIR STUDY

90° V-notch 1-foot deep with 2-foot horizontal extensions.



A. No flow.

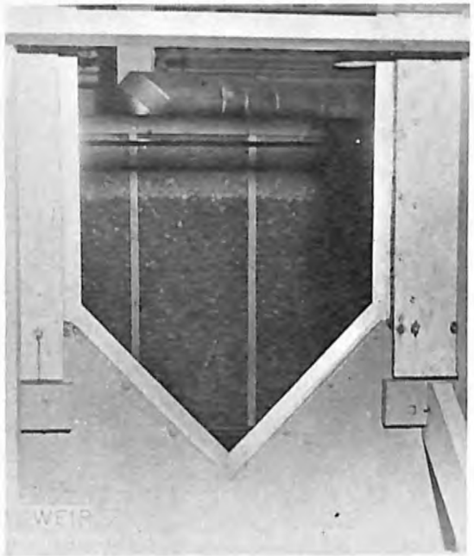


B. Head = 1.7 feet
Discharge = 12 cfs

C. Head = 1.7 feet
Discharge = 12 cfs

COMPOUND WEIR STUDY

90° V-notch 1-foot deep with 1-foot horizontal extensions.



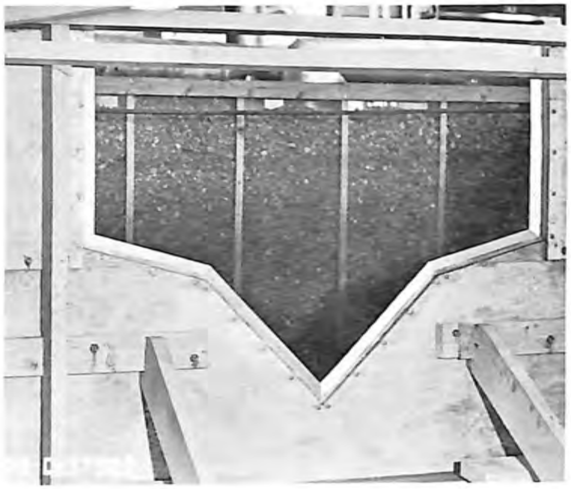
A. No flow.

B. Head = 1.9 feet
Discharge = 9.8 cfs

C. Head = 1.9 feet
Discharge = 9.8 cfs

COMPOUND WEIR STUDY

90° V-notch 1-foot deep with vertical extensions.



A. No flow.

B. Head = 1.2
Discharge = 3.7

C. Head = 1.2
Discharge = 3.7

COMPOUND WEIR STUDY

90° V-notch 1-foot deep with extensions on 15° slope.

Figure 8
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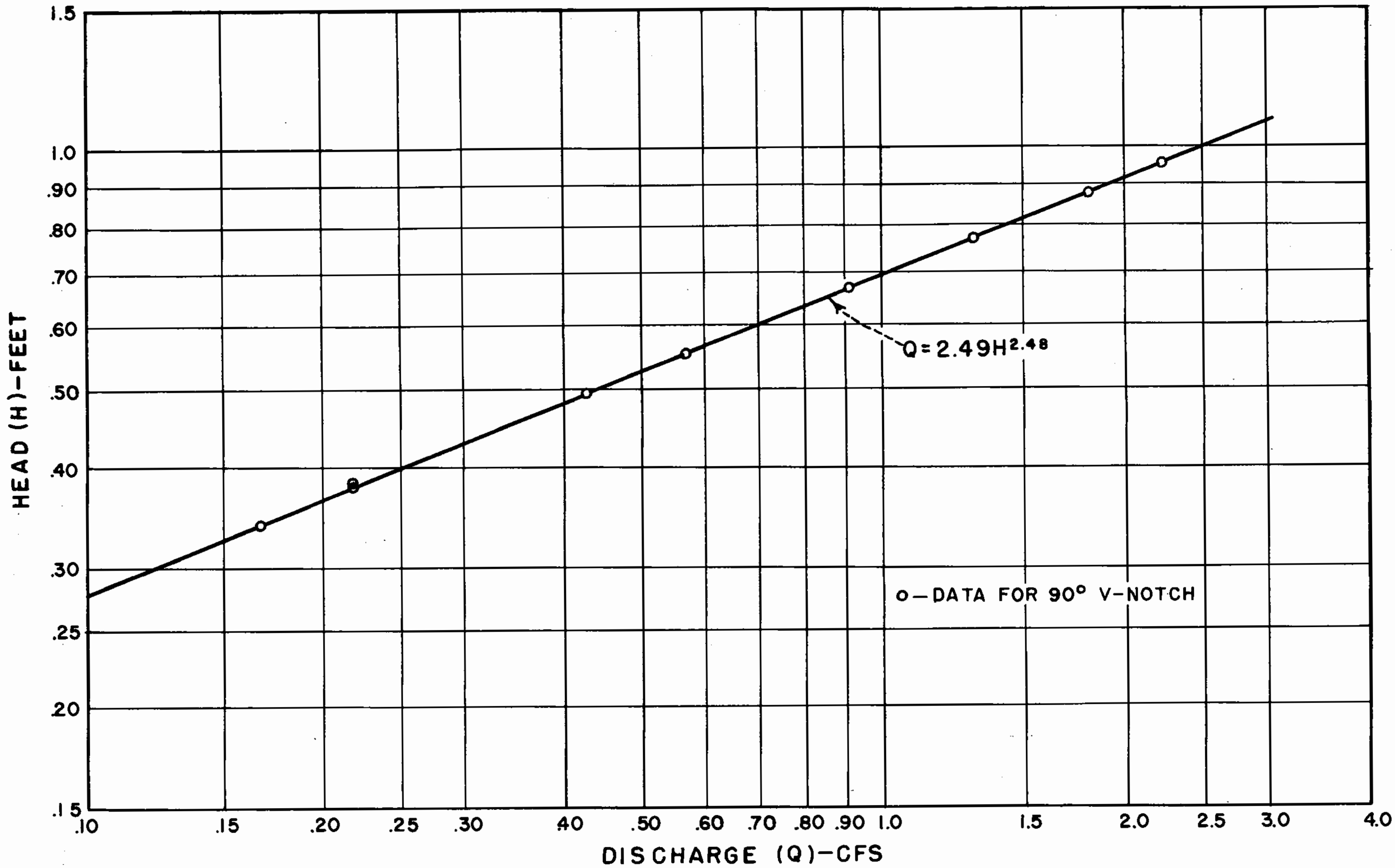

COMPOUND WEIR STUDY

V-NOTCH DATA COMPARISON WITH CONE EQUATION

FIGURE 9
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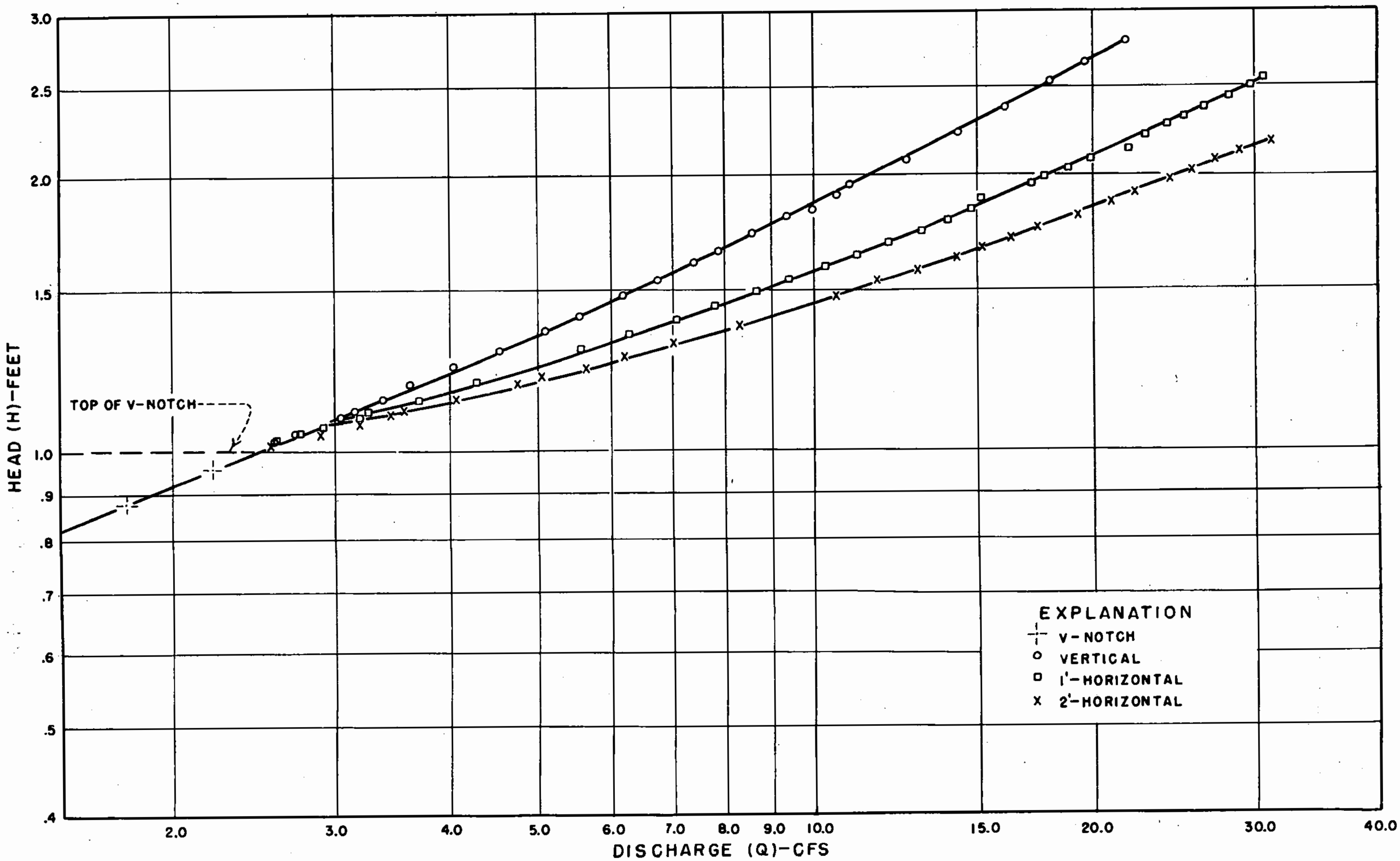

COMPOUND WEIR STUDY

CALIBRATION DATA
90° V-NOTCH WITH VERTICAL AND HORIZONTAL EXTENSIONS

FIGURE 10
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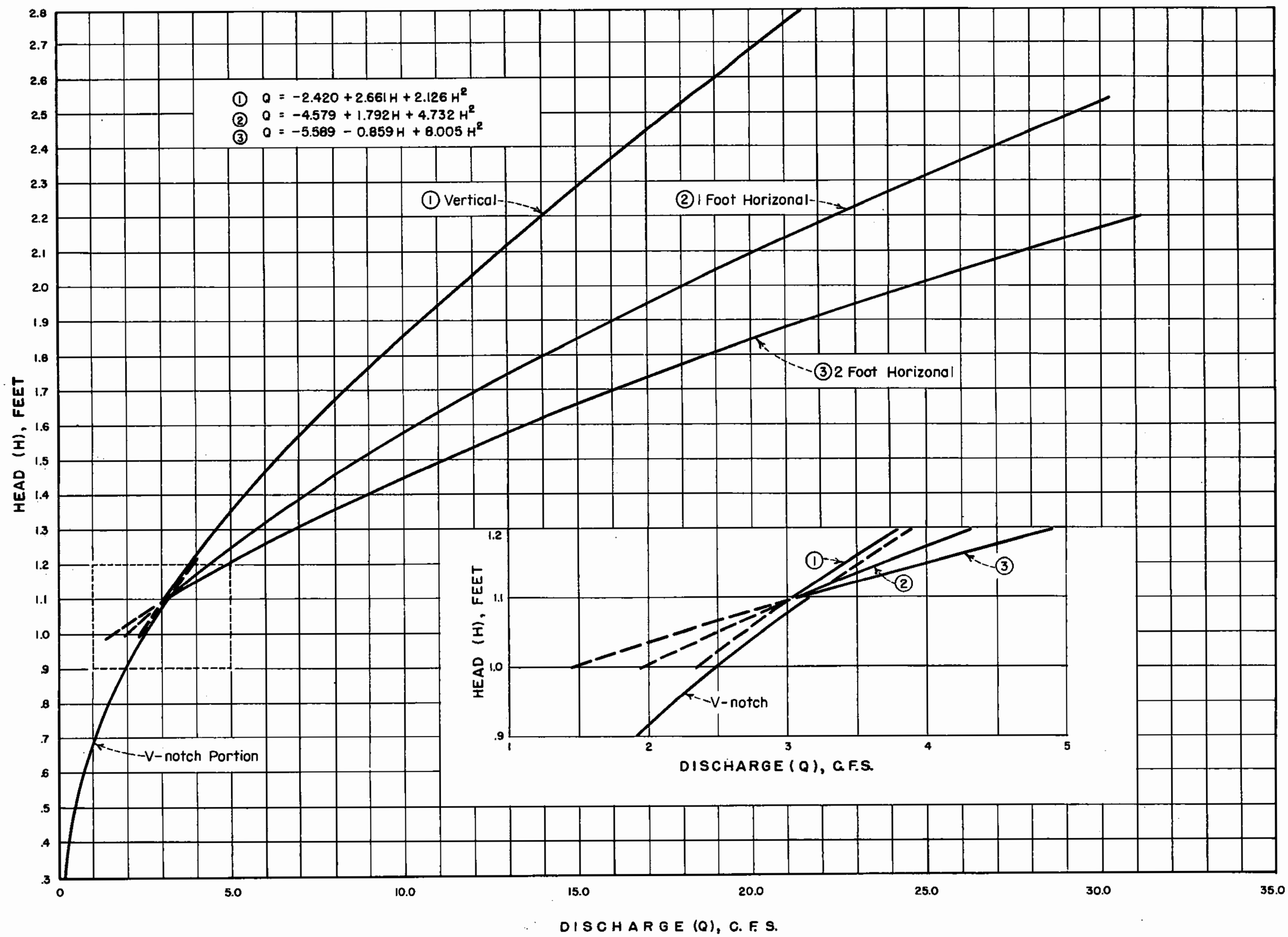
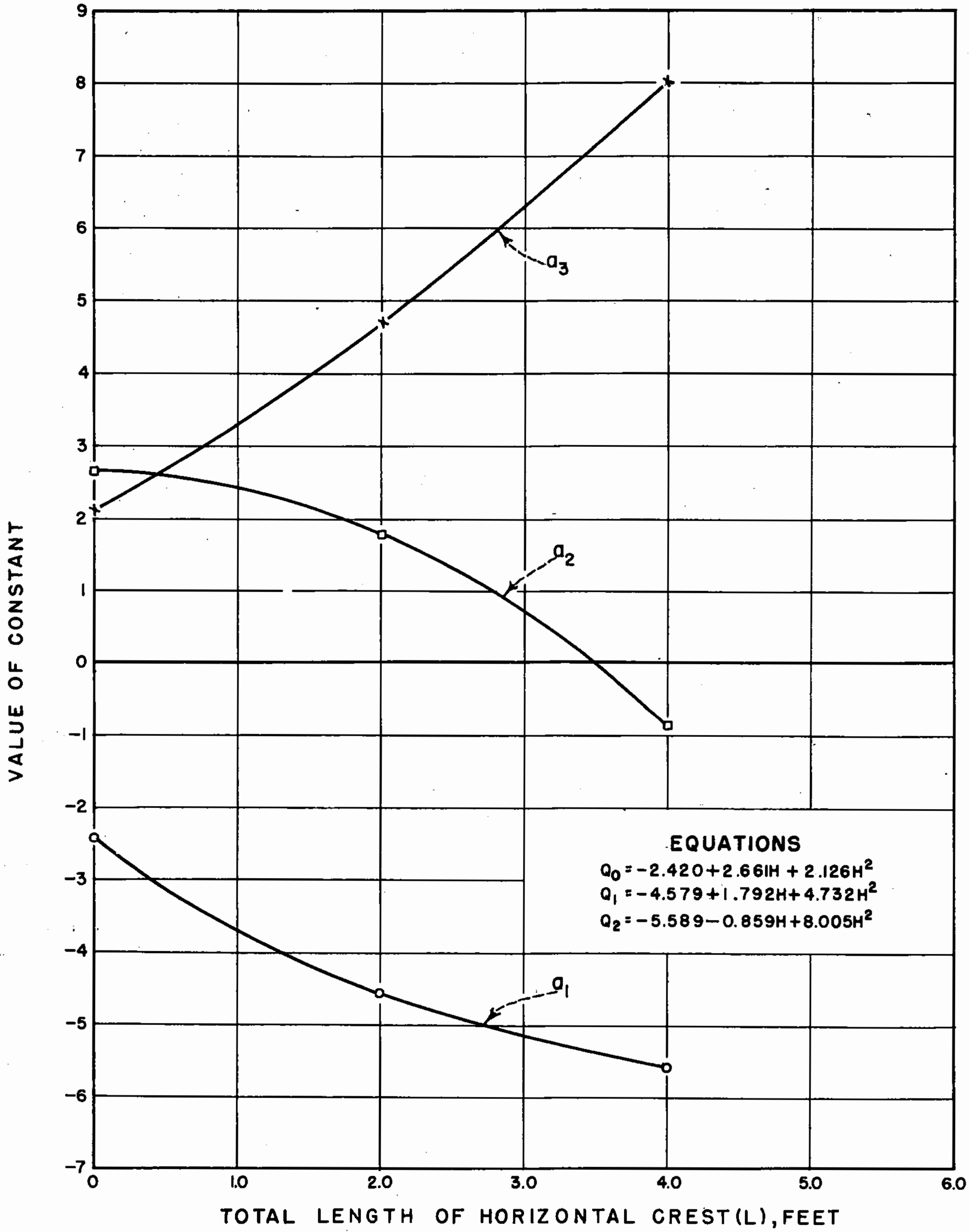


COMPOUND WEIR STUDY

HEAD - DISCHARGE CURVES

90° V-NOTCH WITH VERTICAL AND HORIZONTAL EXTENSIONS

FIGURE 11
REPORT HYD. 505



GENERAL FORM OF EQUATION: $Q = a_1 + a_2H + a_3H^2$

COMPOUND WEIR STUDY

VARIATION OF THE CONSTANTS IN THE DISCHARGE EQUATIONS FOR V-NOTCH WEIRS WITH HORIZONTAL EXTENSIONS

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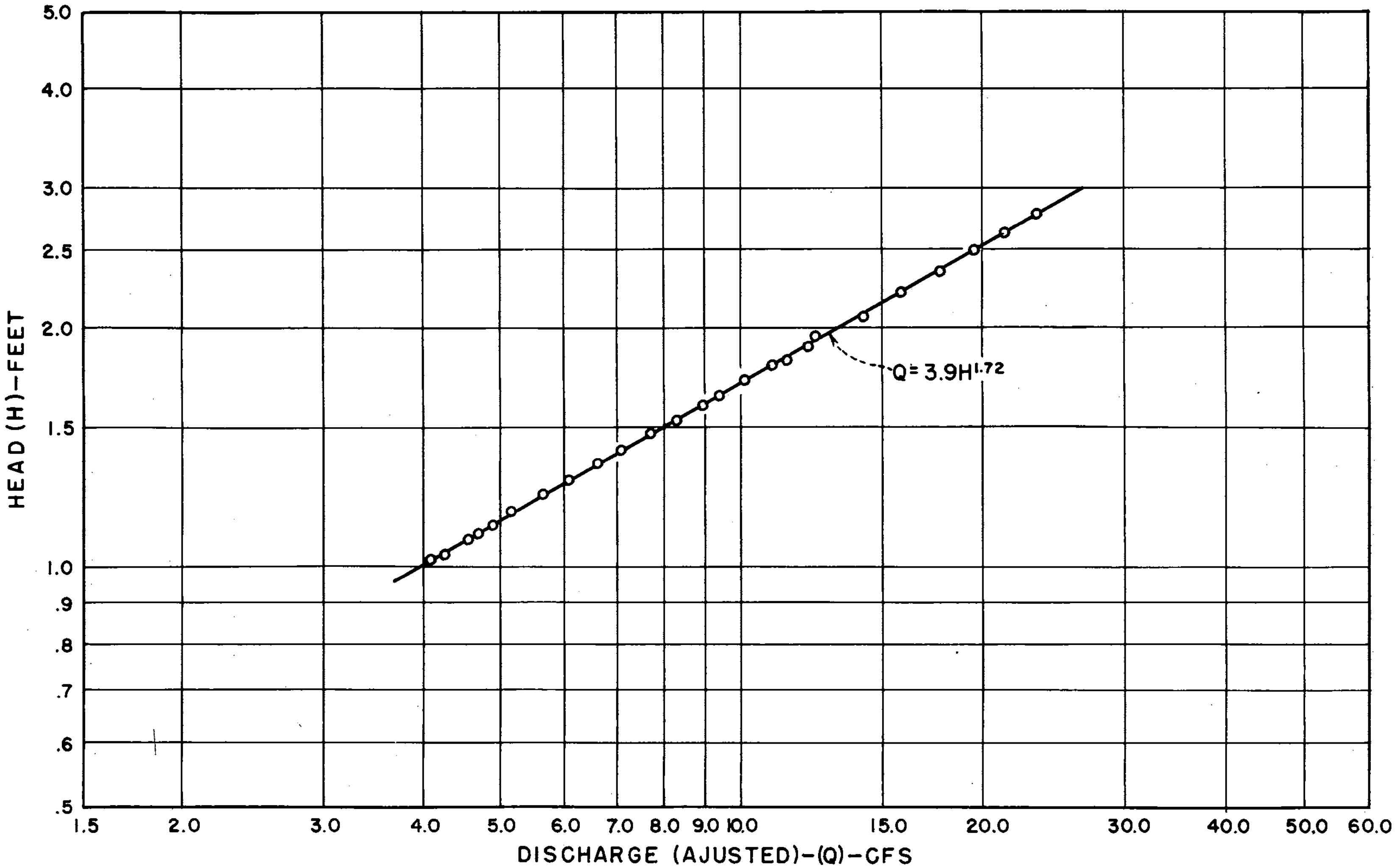
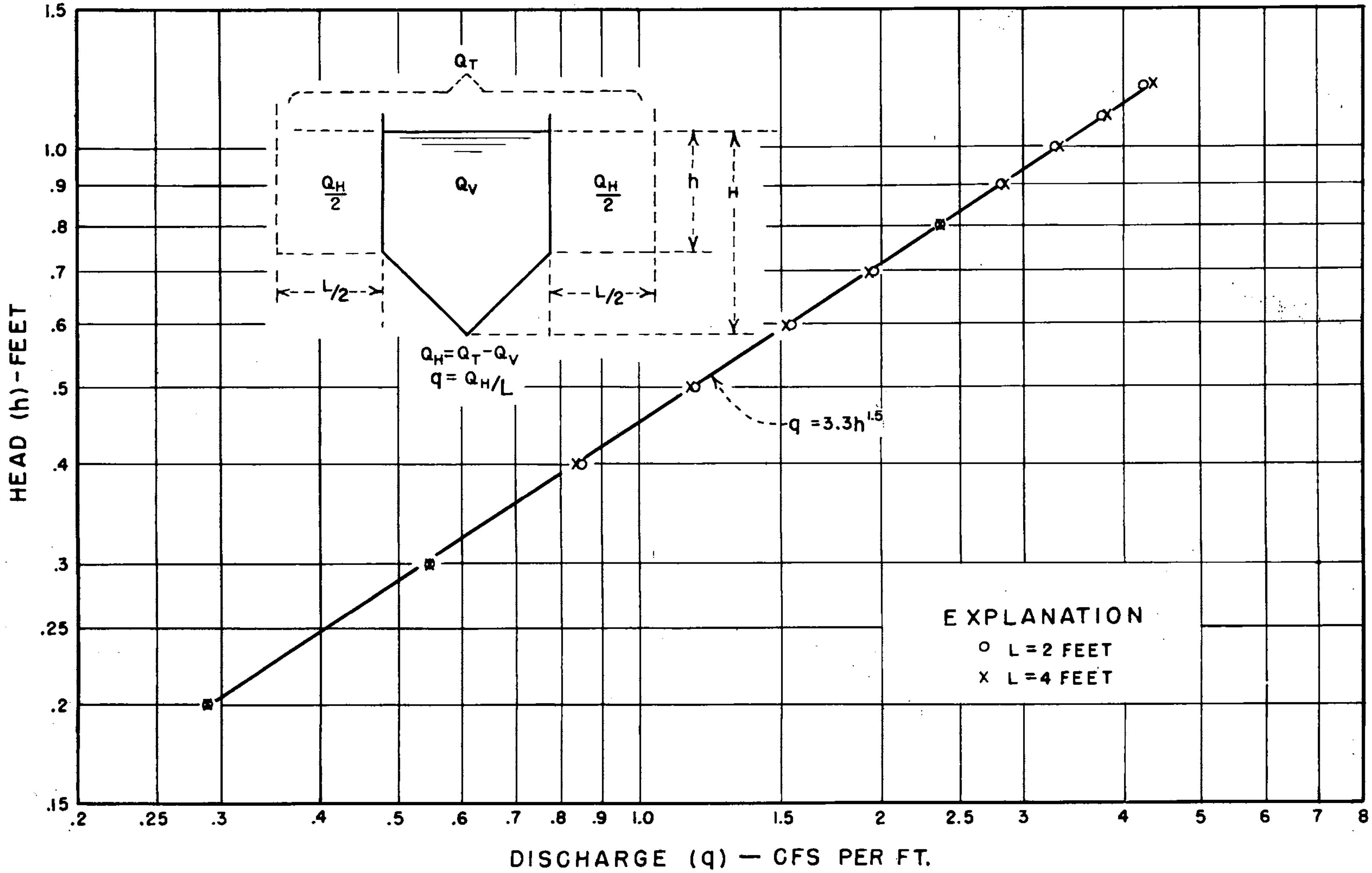


COMPOUND WEIR STUDY

CALIBRATION CURVE OF VERTICAL EXTENSIONS
ABOVE 90° V-NOTCH

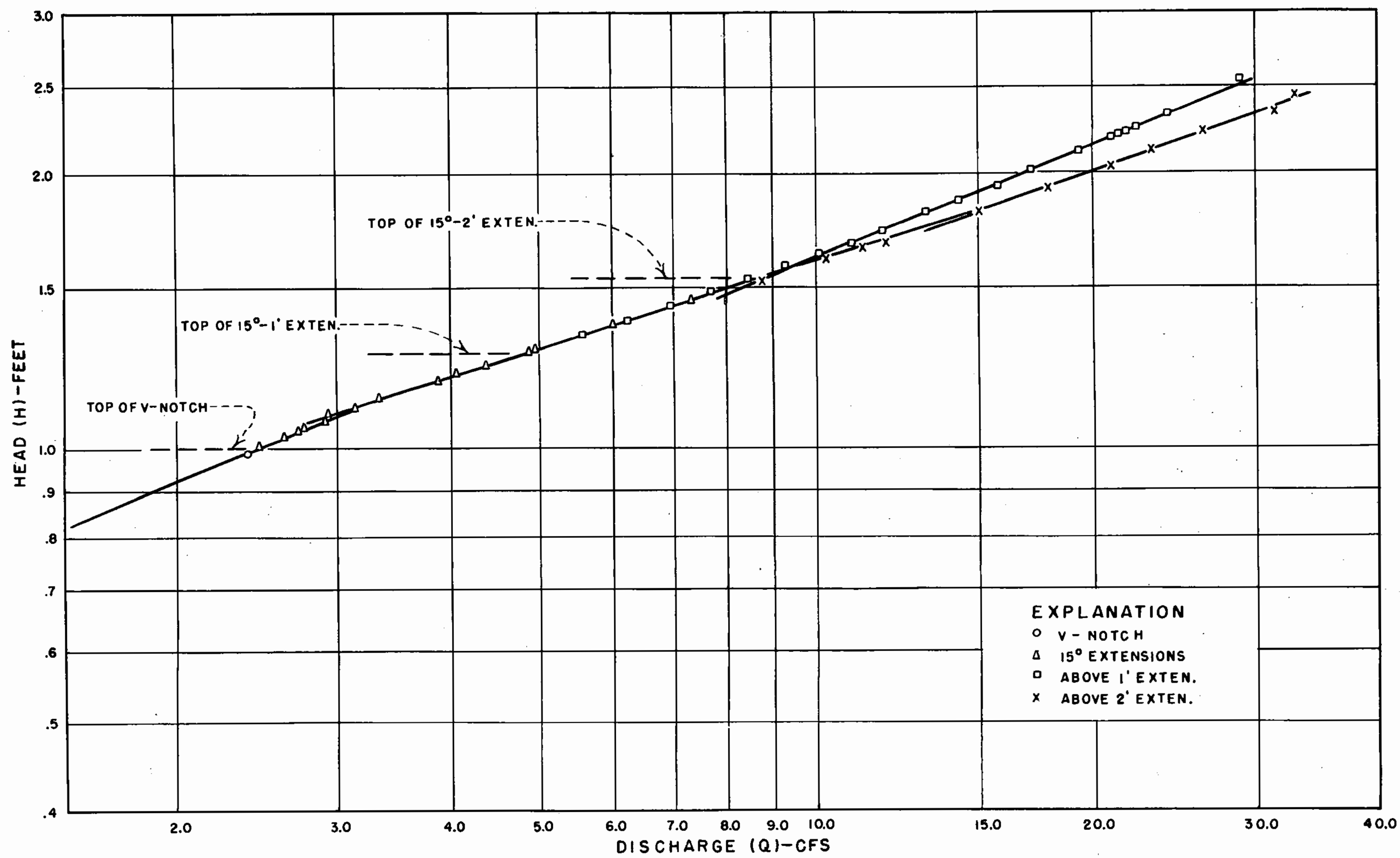
FIGURE 13
REPORT HYD. 505



COMPOUND WEIR STUDY

CALIBRATION CURVE OF HORIZONTAL EXTENSIONS ABOVE 90° V-NOTCH WEIR

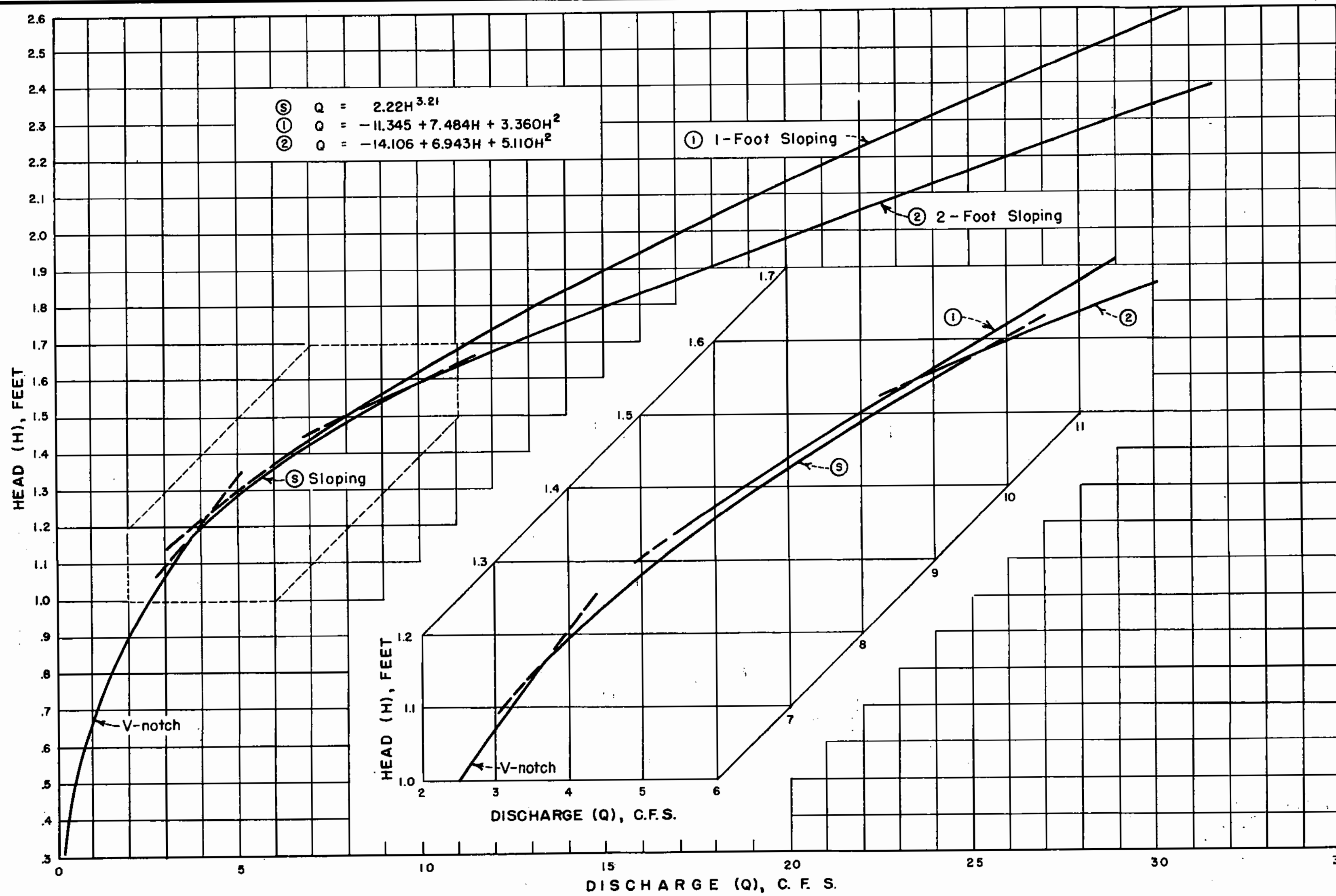
FIGURE 14
REPORT HYD. 505



COMPOUND WEIR STUDY

CALIBRATION DATA
OF 90° V-NOTCH WITH 15° UPWARD SLOPING EXTENSIONS

FIGURE 15
REPORT HYD. 505



COMPOUND WEIR STUDY

HEAD - DISCHARGE CURVES

90° V NOTCH WITH 15° UPWARD SLOPING EXTENSIONS

FIGURE 16

GPO 832660

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