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Memorandum

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PAP 277

Investigation of stoplog discharge coefficients - Water Systems Automation Program

The purpose of the study was to supply discharge coefficients for West Canal Check structures containing stoplog bays. The coefficients were needed to define a part of the mathematical model being correlated with water levels and discharges measured in field studies.

GPO 832-606

A stoplog bay was simulated in an existing box in the Hydraulics Branch laboratory. The structure included an entrance section with guidewalls representing the flow line toward the dividing pier centerline, a 4-inch-wide stoplog, and downstream walls representing the pier sides, (Enclosure 1). The downstream section included the box tailgate. The top of 3.77-foot length of log was 2.4 feet above the floor of the 8-foot-wide box.

Coefficients were computed from the equation

$$Q = CbH^{3/2}$$

where

Q = Venturi meter discharge
H = Head near side of box 2.5-feet upstream from the log
b = Length of log

Discharges and heads were measured for smooth and rough surfaces on the crest of the log and for both partially aerated and aerated nappes.

Results of the study were compared to measurements made by Bazin, contained on page 10 of the Geological Survey Circular 397, Discharge Characteristics of Broad-crest Weirs, 1957 (Enclosure 2). Coefficients have been plotted on the graph, Figure 7, page 10 to show the effect of:

a. A smooth crest and sharp upstream corner, partial aeration,

b. Correction for end contractions simulated in the Hydraulics Branch for West Canal not present in the Bazin experiments,

c. A roughened crest and about 1/8-inch radius rounding of the upstream corner, and

d. Partial aeration and aeration of the roughened log, both possible in the canal flow.

A 1/4-inch mesh hardware cloth was used to roughen the surface because no rough sawed lumber was available in the laboratory.

Coefficients were compared using the survey relation of C and $H/_L$, L being the width of the crest (0.33-foot), and H the total head above the crest. In the Hydraulics Branch study, the measured head was considered to be total head because of the low approach velocity (>0.5 fps) in the box.

The coefficient comparison was satisfactory considering the limited simulation in the laboratory and the scale effects of Bazin's experiments discussed on pages 8, 9, and 10 of the report (Enclosure 2). The largest of the scale models used by Bazin agreed better with the geological survey tests on larger models at Cornell. Hydraulics Branch data from the log experiments show agreement at small $H/_L$ values but lower coefficients as the head increases. Contractions, rounding, and roughness of surface apparently combine to produce a coefficient of discharge less than the lowermost curve on Figure 7, page 10. The coefficients measured in the Hydraulics Branch should be reliable for use in the West Canal mathematical model.

Information used for the comparison is contained in Enclosure 2 tables and curves. Measurements for computing the coefficients for the simulation were placed in Hydraulics Branch data files.

Mr. Luu Huu Dung, South Vietnamese trainee, very ably performed the major part of the laboratory measurements.

Jack C. Schuster

Enclosures

Copy to: 1532 (Luu Huu Dung)

ENCLOSURE 2

CIRC. 397

GEOLOGICAL SURVEY CIRCULAR 397

DISCHARGE CHARACTERISTICS OF BROAD-CRESTED WEIRS

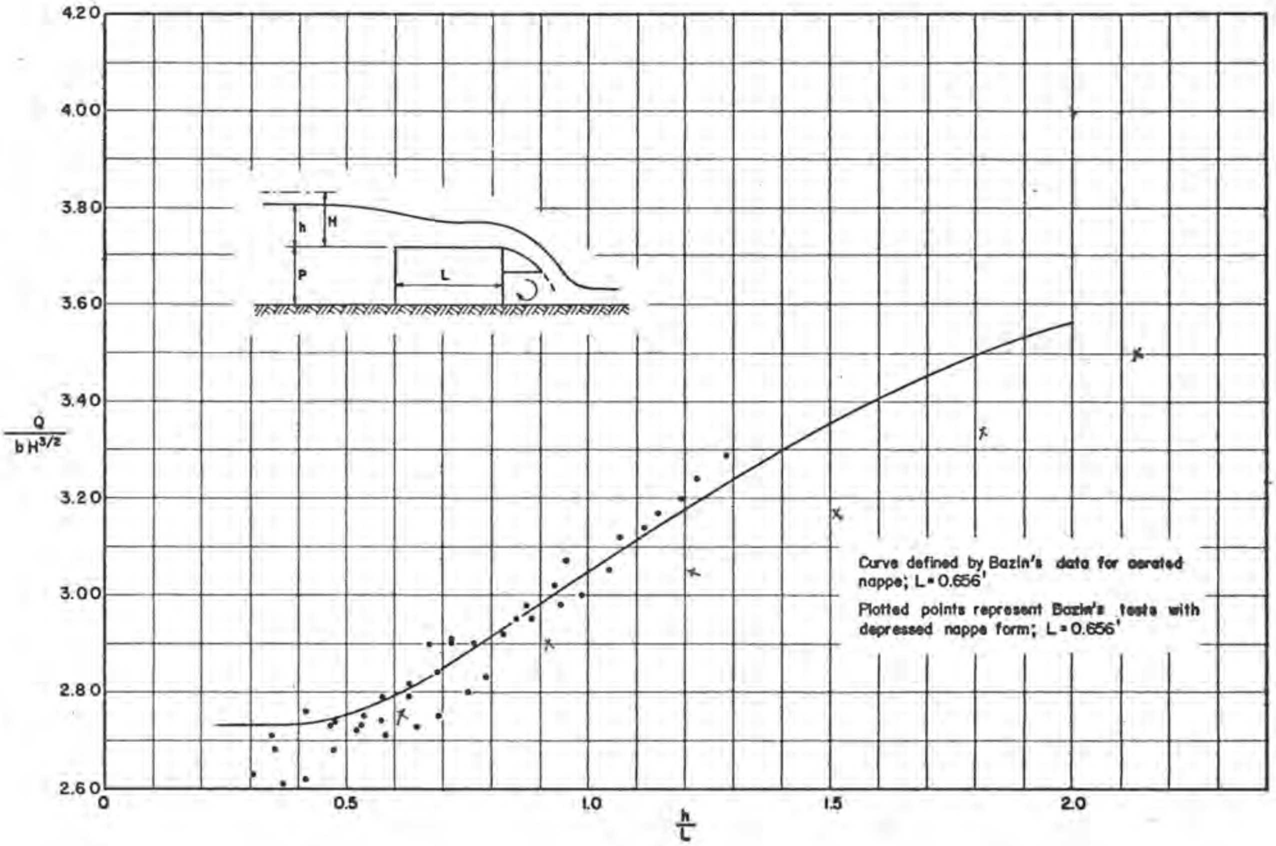


Figure 5. --Effect of the depressed nappe form on the discharge coefficient.

4. Free altogether of the flat crest of the weir and in contact with the weir only at the upstream face.

These nappes were named by Bazin (1896), who was among the first to investigate their effect on the discharge over the weir. The adhering nappe is usually of negligible importance and occurs only when the head is extremely low. The point at which one nappe form disappears and the next appears is somewhat indeterminate. These limits also change according to whether the discharge is increasing or decreasing, and are dependent upon the shape of the weir itself.

Complete data for the establishment of these transition ranges does not exist. The data of Bazin does, however, enable a comparison to be made between the coefficient of discharge for an aerated nappe and the coefficients for the wetted-underneath and depressed nappes, as shown in figures 4 and 5, respectively. In these figures, the plotted data represent the coefficient of discharge for these nappe forms, and the curves represent the coefficient of discharge for weirs with aerated nappes. These tests were made on level broad-crested weirs with vertical upstream and downstream faces. Apparently, from these figures, the overall change in the discharge coefficient due to a change from the aerated to the depressed or wetted-underneath nappe forms is on the order of 1 or 2 percent. This is almost inconsiderable for any except very precise discharge determinations.

The point at which the nappe becomes detached at the upstream crest entrance and springs clear of the weir crest varies somewhat, depending upon the completeness of aeration of the space beneath the downstream nappe, the h/P ratio, and upon the sharpness of the entrance; it usually occurs suddenly. The tests made by Bazin indicate that it may occur at an h/L as low as 1.5, or as high as 2.0, for aerated weirs. Once the nappe springs clear of a broad-crested weir, it is usual to assume that the weir acts as a thin-plate, sharp-crested weir. In figure 6, the tests made by Bazin on level broad-crested weirs with vertical faces, square entrances, and detached nappes are compared with the curve defined by Bazin's data for thin-plate, sharp-crested weirs. It will be noted that the agreement of the plotted points with the curve is somewhat less than ideal; this may possibly be attributed to the lack of true sharpness of the entrance to the broad-crested weir.

Reynolds Number

A definite variation in the coefficient of discharge with scale ratio is to be expected. This so-called scale effect is the result of the action of the forces due to the viscosity of the fluid. The Reynolds number is used to describe the relative importance of the viscous forces; the larger the Reynolds number, the less important the influence of viscosity upon the flow pattern. The Reynolds number of equation 3, for a given fluid, is proportional to $h^{3/2}$, or to the discharge per foot of width of the weir. From this, it is obvious that the Reynolds numbers of model and prototype can be equal only at the same scale. It is thus usually impracticable to satisfy the Reynolds law

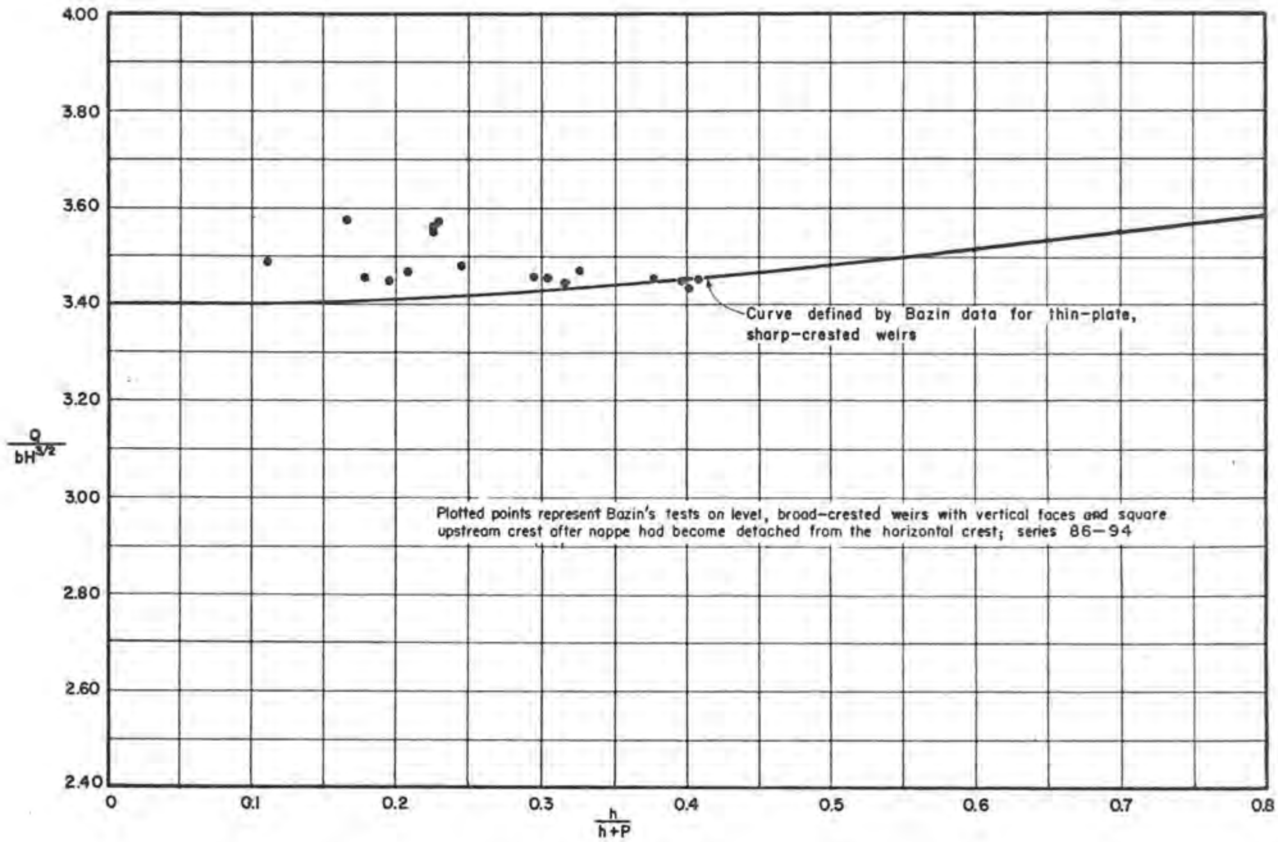


Figure 6.--Effect of the detached nappe form on the discharge coefficient.

completely. Generally, however, it is possible to obtain Reynolds numbers in the laboratory sufficiently high to include the range in which the effects of fluid viscosity may be ignored.

Two noteworthy studies have been made to determine the effect of scale on the discharge coefficient. These experiments were made on nappe-shaped weirs. The first, reported by Eisner (1933), describes tests made on models at scales of 1:70, 1:35, 1:17.5, 1:8.75, and 1:4.375. An increase in discharge coefficients was noted with an increase in model scale; this effect was attributed by Eisner to the relative roughness of the boundary surface--absolute roughness being the same in each of the several models.

From measurements made on geometrically similar models of the nappe-shaped Pickwick Landing spillway at scales of 1:200, 1:100, and 1:500, Kirkpatrick (1955) concluded that the scale of the model does not affect the relation between head and discharge coefficient. He found no consistent deviation of the discharge coefficient at the three scales and therefore attributed the small variations to experimental error.

For the broad-crested weir, Bazin's experiments furnish sufficient data to determine the Reynolds number effect qualitatively. In figure 7 are plotted the results of Bazin's measurements on weirs of rectangular shape and square upstream entrances, and at various scale ratios. For the lowermost curve the scale is 8 times as large as that for the uppermost curve, for the next curve 4 times as large, and for the third curve twice as large. The scale of P is not considered in these tests as it has been shown to have no effect on the discharge coefficient. For Bazin's tests the coefficient of discharge decreases with increasing scale, or with increasing Reynolds number.

With a very few exceptions, these plotted points represent tests on short weirs. The heads for the uppermost curve are very small, so that the deviation of these points may perhaps be ascribed primarily to effects of surface tension. The slight variation between the remaining three curves is due to some differences in energy required to maintain the eddy motion in the separation zone as the weir scale increases. For the rounded-entrance weir, this trend is probably reversed; that is, it would be expected that the coefficient will increase with increased scale, and for the same reasons that the Eisner coefficients were found to increase.

Because the U. S. Geological Survey tests at Cornell (see fig. 3), made at a much greater scale than Bazin's tests, agree fairly well with the lowermost of Bazin's curves on figure 7, it is assumed that for weirs at least as large as Bazin's largest, the Reynolds number is large enough so that the effects of fluid viscosity may be ignored. Most structures found in the field are of much greater size. For these, the the lowermost curve of figure 7 should be used to select a discharge coefficient.

Rounded Weir Entrance

The effect of rounding the upstream entrance to the weir is to increase the discharge coefficient by removing the cause of the flow separation at the crest entrance, which is the primary source of energy loss. This variation in the discharge coefficient has been shown to be a function of r/h in equation 2, but sufficient data to completely define the function do not exist. Woodburn ran a series of tests in which he systematically varied the upstream crest-entrance radius of rounding from 0 to 8 inches in 2-inch increments. The discharge coefficients for the 2-, 4-, 6-, and 8-inch roundings $(r/h > 0.15)$ superpose and are about 9 percent greater than the corresponding coefficients for the square entrance $(r/h = 0)$.

This data may be interpreted by analogy with similar data for the contracted opening. Kindsvater and Carter (1955) demonstrated that the discharge coefficient for contracted openings increased almost linearly with the values for r/b from $r/b = 0$ to $r/b = 0.14$; the coefficient remained constant after r/b exceeded 0.14. A similar variation in the coefficient of discharge for orifices has been demonstrated in the literature.

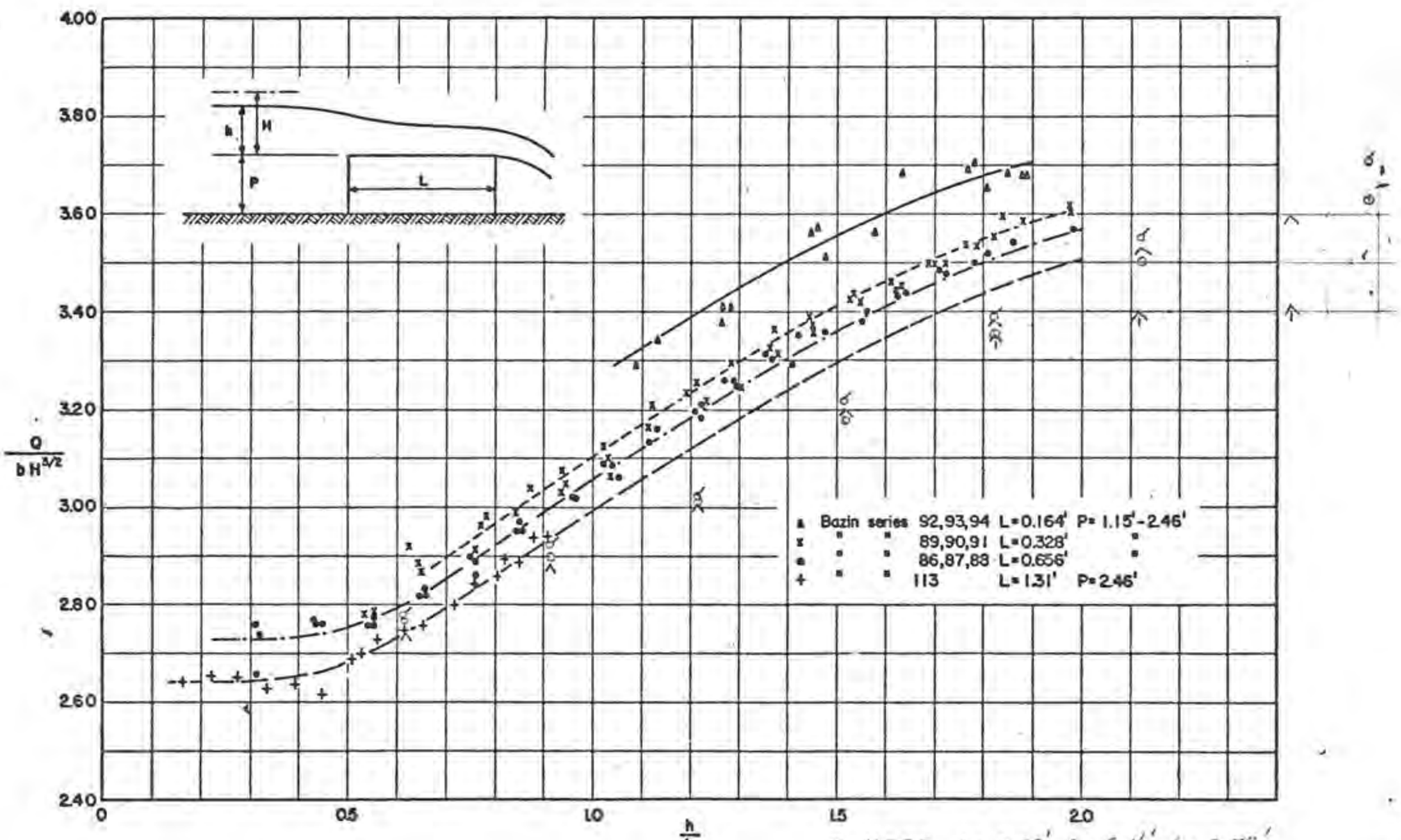
For the lack of a more exact procedure, it is suggested that a discharge coefficient be chosen for the rounded-entrance weir equal to 1.09 times the coefficient for the square entrance if the value of r/h is greater than 0.14. For intermediate values of r/h the adjustment may be interpolated between the extremes of unity and 1.09.

Boundary Roughness

One of the most troublesome aspects of model testing is the difficulty involved in duplicating in the model the surface resistance of the prototype. For a given test structure having a given boundary roughness, the energy losses due to boundary resistance are a function of a characteristic Reynolds number and the relative roughness. As the scale is decreased, the relative roughness increases, and the boundary shear force thus becomes disproportionately large if the boundary surfaces are of the same material for the various scales.

The relative roughness is usually described by relating the mean height of the boundary projections above the nominal surface level to some significant length. Here, the ratio h/k is used, where k is the mean roughness height. Thus, only if the relative roughness and the Reynolds number are equal in model and prototype is there assurance that the relative effect of boundary resistance is the same at both scales. It is generally impractical, if not impossible, to arrange equal values of either R or h/k. Requirements of similitude are compromised by either ignoring the difference in relative roughness or by extension to the scale of the prototype by the use of some method based on experience.

Here, again, definitive data for a determination of the effect of boundary roughness are not at hand. Unless the model is extremely small, it is usual to apply the results from it to much larger scale structures. In general, if the influence of boundary roughness is considered separate from other effects, the discharge coefficient should increase slightly as the scale of the model increases.



o USBR L = 0.33' P = 2.4' b = 3.77'
σ " CORRECTED (b − 0.1xH) SIDE CONTRACTION

Figure 7.--Variation of the discharge coefficient with scale of weir. (Data from Bazin, 1896.)

∧ " , U.S. EDGE ROUNDED > 1/8-INCH, SURFACE ROUGHENED BY 1/8-INCH HARDWARE CLOTH, PARTIAL AERATION

↑ " , AERATED

J.G.H. 03/04/72

$b = 3.77$

$L = 0.33$

H	$H^{3/2}$	C	$Q = CbH^{3/2}$	$b' = b - .1 \cdot H$	$C' = \frac{Q}{b'H^{3/2}}$	H/L
.2	.0894	2.76	0.9302	3.75	2.775	.606
.3	.1643	2.90	1.7963	3.74	2.923	.909
.4	.2530	3.04	2.8996	3.73	3.073	1.212
.5	.3536	3.18	4.2392	3.72	3.223	1.515
.6	.4648	3.34	5.8527	3.71	3.394	1.818
.7	.5857	3.50	7.7283	3.70	3.566	2.121
.857	.7934	3.62	10.8278	3.68	3.709	2.597

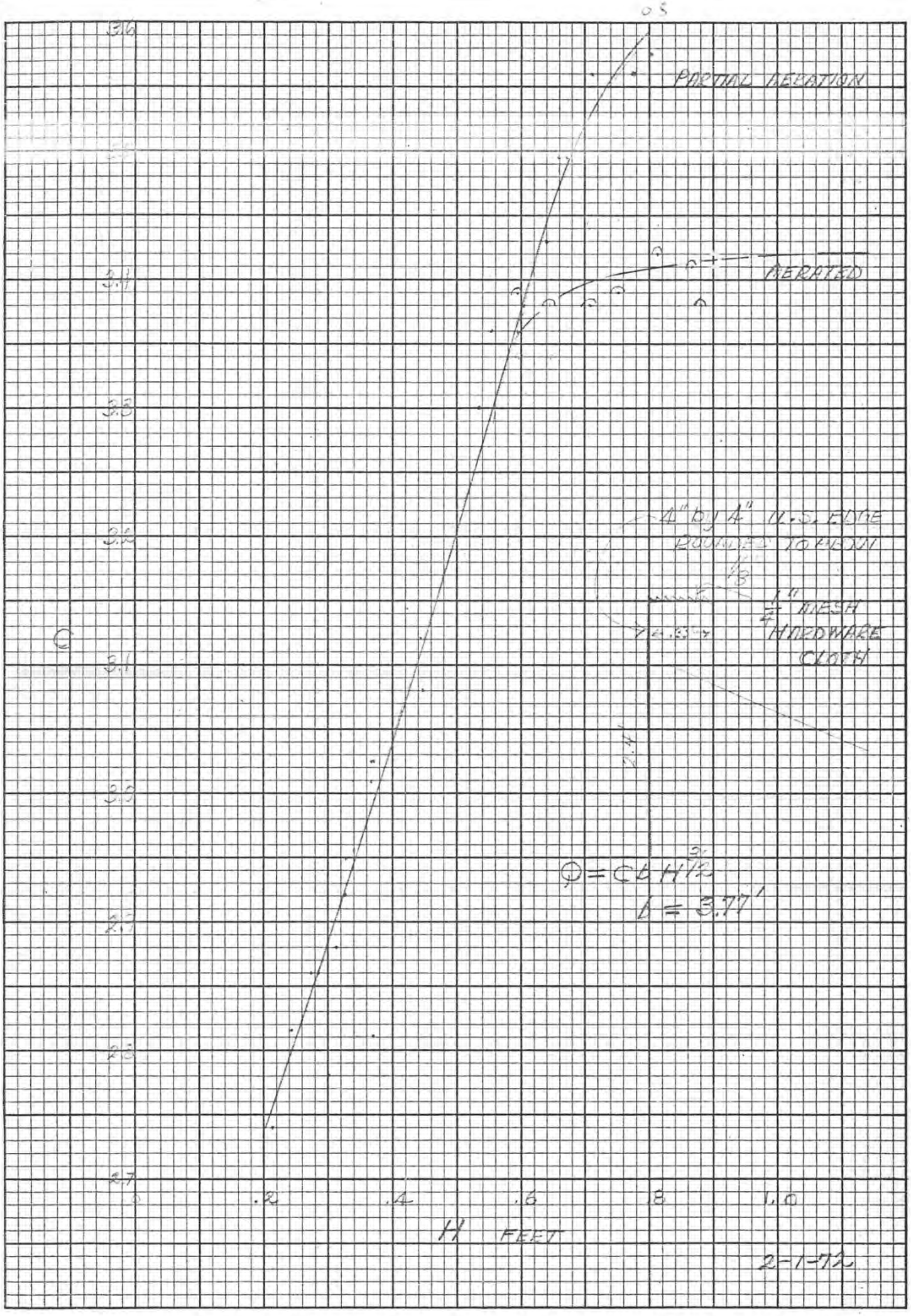
JCS 3/8/72

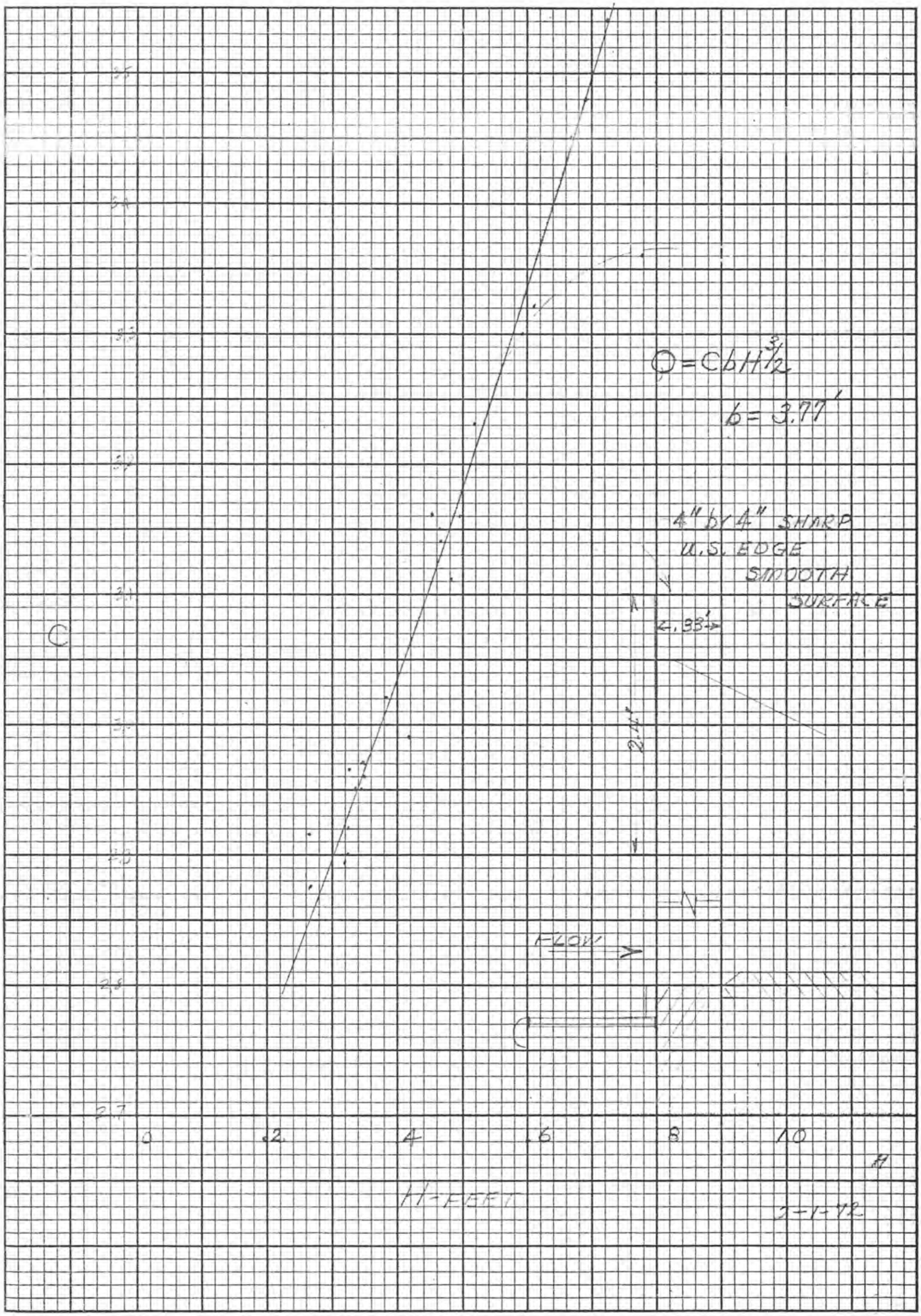
BROADCREST WEIR $b = 3.77'$ $L = 0.33'$

U.S. EDGE ROUNDED, SURFACE ROUGHENED

WITH 1/4-INCH MESH HARDWARE CLOTH

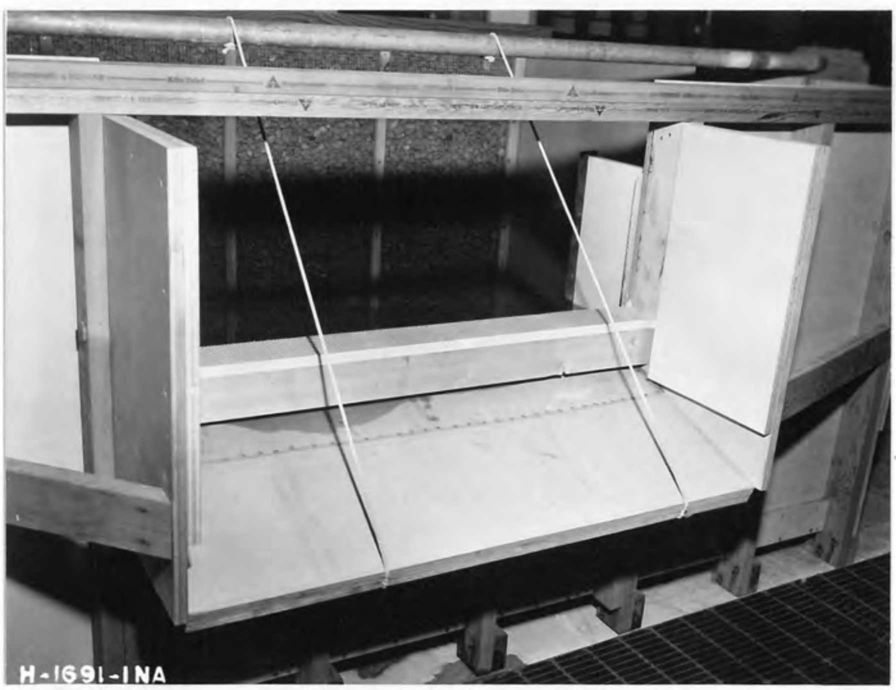
H	H/L	C AERATED	C
.2	.604	2.74	
.3	.91	2.88	
.4	1.212	3.04	
.5	1.515	3.20	
.6	1.818	PARTIAL AERATION 3.38	AERATED 3.36
.7	2.121	3.52	3.40
.8	2.42	3.59	3.41
.9	2.73	--	3.41(5)


PARTIAL AERATION
AERATED
4" by 4" U.S. EDGE
ROUNDED TO 1/8"
1/4" MESH
HARDWARE
CLOTH
$Q = CLH^{3/2}$
$L = 3.77'$
C
3.4
3.3
3.2
3.1
2.7
.2
.4
.6
.8
1.0
H FEET
2-1-72



C
$Q = CbH^{3/2}$
$b = 3.77'$
4" by 4" SHARP
U.S. EDGE
SMOOTH
SURFACE
.33'
2.11'
FLOW
0
.2
.4
.6
.8
1.0
H
H-FEET
3-1-72

ENTRANCE TO STOPLOG BAY



EXIT FROM STOPLOG BAY

WEST CANAL STOPLOG BAY SIMULATION
WATER SYSTEMS AUTOMATION STUDIES