PAP-340

A BAFFLED APRON AS A SPILLWAY ENERGY DISSIPATOR

By
T. J. Rhone

UNITED STATES
DEPARTMENT OF THE INTERIOR
Bureau of Reclamation
Engineering and Research Center
Denver, Colorado

ABSTRACT

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KEY WORDS: Hydraulics : Spillways : Terminal facilities : Water flow : Dissipation (energy) : Chute blocks : Energy gradient : Hydraulic models : critical depth : chute spillways : Tailwater.

Hydraulic model investigations were performed to determine basic design criteria for a baffled apron spillway as an energy dissipator. Described are the effects of baffle block heights and spacing of the hydraulic efficiency of the system. Impact pressures were measured on the upstream faces of the blocks to determine impact forces. Pressures on the side, top, and back of the blocks were also measured to determine the possibility of cavitation damage.

Special consideration was given to develop alternative entrances to the baffled spillway. Three entrance configurations are proposed, two of which will not increase the upstream water level. The third entrance is similar to the conventional type used in contemporary designs.

Typical design procedures are outlined. Included are the determination of ideal design discharge criteria which might be less than the expected maximum and how to modify the structure to handle discharges greater than the design.

Reference: Rhone, Thomas J., "A Baffled Apron as a Spillway Energy Dissipator." Journal of the Hydraulics Division, ASCE DEC 1977

A BAFFLED APRON AS A SPILLWAY ENERGY DISSIPATOR[A.]

THOMAS J. RHONE[1] M. ASCE

INTRODUCTION

Baffled apron drops or chutes have been used on canal structures for many years. Their satisfactory performance has been proven by this extensive use. Primarily, a baffled chute is used to dissipate the energy in the flow at a wasteway or drop. In a canal structure they require no initial tailwater, although channel bed scour at the base of the chute is less extensive if the tailwater forms a pool into which the flow discharges.

Basically, the baffled apron or chute consists of a sloping apron, usually on a 2:1 or flatter slope, with multiple rows of blocks or baffle piers equally spaced along the chute. The flow passes over, around, and between the baffle piers and appears to slow down at each baffle pier and accelerate after passing the pier. The extent of acceleration and ultimate velocity at the base of the chute depends on the discharge and height, width, and spacing of the baffle piers.

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1. Head, Applied Hydraulics Section, Hydraulics Branch, Division of General Research, U.S. Bureau of Reclamation, Denver, Colo.

This type of drop has been used in a wide variety of structures from long, narrow canal drops to short, wide wasteways, Figure 1. The smaller structures are also found in highway drainage structures and urban flood control structures.

The development of the canal-type structures was brought about by the use of hydraulic model studies to verify a prototype design and observing prototype operation to verify the model studies and improve on the basic concept. As a result of this ideal combination, the presently used design standards were established.(1) A minimum of design limitations was placed on this type of structure. These were a maximum unit discharge of 60 $(ft^3/s)/ft$ width (5.6 $(m^3/s)/m$), and an approach velocity of less than the critical velocity of the design flow based on the design discharge. These criteria related to block or pier height are presented in graphical form Figure 2. The other details such as block width and spacing are standardized as a function of the block height.

Many prototype operating experiences have been reported, all of them generally favorable. The adverse comments such as excessive splash and channel bank erosion at the water surface were easily corrected by minor modifications such as the use of rip-rap. Some of the reports on prototype operation indicated that the structures operated at as much as twice the design discharge for short periods without adverse effect. Because of this favorable operation, it was questioned whether this concept could be used for a spillway design where foundation conditions might not be favorable for a flip bucket or conventional hydraulic jump energy dissipator and a moderate unit discharge in the vicinity of 100 (ft^3/s)/ft width (9.3 (m^3/s)/m width) could be expected.

DEVELOPMENT TESTS

The first spillway design to use the concept of a baffled apron was for a spillway rehabilitation project in Oregon. The Conconully spillway was designed for a unit discharge of 78 (ft^3/s)/ft (7.2 (m^3/s)/m), a width of 150 ft (45.7 m), and a fall of 65 ft (19.8 m). The dimensions of the structure were based on the same criteria as used for canal structures by extrapolating the design curves. The structure was studied with a sectional hydraulic model and subsequently constructed, Figure 3.(2)

The Conconully spillway has operated at small discharges every year since its completion. It was at this structure that a side benefit of a baffled apron was discovered which had to do with nitrogen supersaturation in the river downstream from the dam. Measurements indicated that the flow from a slide gate controlled outlet works adjacent to the spillway had an excess of dissolved nitrogen gas greater than permitted by the Oregon Department of Fish and Game, while flow at the base of the baffled spillway was well below allowable limits and after the two flows merged the gas supersaturation was well within permissible standards.

The Bonneville Hydraulic Laboratory of the Corps of Engineers subsequently performed extensive model investigations to develop spillway baffle blocks specifically shaped to provide the turbulence necessary to reduce nitrogen supersaturation.

A second Bureau of Reclamation spillway using the baffled apron concept was for the Marble Bluff Diversion Dam in Nevada. This structure has a unit discharge of 113 $(ft^3/s)/ft$ (10.5 $(m^3/s)/m$) with a 150 ft (45.7 m) width and a 70 ft (21.3 m) fall, Figure 4. Hydraulic model studies were also made of this structure prior to construction.

HYDRAULIC MODEL INVESTIGATIONS

Because of the apparent need for this type of structure, a hydraulic testing program was initiated to generalize the design criteria for large unit discharges. The test facility consisted of a large tank or head box to contain the approach flow, a sloping apron that could be adjusted for width, and an erodible sand bed in a tail box. The baffle blocks were constructed of wood except for one row which consisted of metal blocks equipped with piezometers so that impact pressures could be recorded on the upstream face and, if present, the extent of subatmospheric pressures in critical areas.

A model scale of 1:33 was selected to take full advantage of the laboratory water supply capacity. The design unit discharge was

300 $(ft^3/s)/ft$ (27.8 $(m^3/s)/m$). The intial configuration was obtained by extrapolating the criteria used for canal structures. A 2:1 slope was used for all tests. It had been suggested that a steeper slope was not practical for field construction and if the steeper slope was necessary for a specific design, the suitability of the structure could be confirmed by hydraulic model studies. Previous experience had shown that a baffled apron installed on a slope flatter than 2:1 performed as good or better than the standard design.

Tests with the basic design indicated that flow conditions were essentially the same as had been found with smaller unit discharges, Figure 5. Typically, there was no increase in the impact pressures after the third row of baffles, Figure 6; discharges near the design flow produced less splash and spray and an apparently smoother water surface than the smaller flows. Erosion at the base of the structure was moderate for all tests. No subatmospheric pressures were measured in the side and top piezometer. Actually, they were near atmospheric for all flows, indicating full aeration. Some test runs were made with discharges greater than design and in all cases the flow appearance was improved, mainly less splash and spray, although bottom erosion was moderately greater.

Many tests were made with the standard blocks used at different block and row spacing. The results were usually poorer flow conditions on the chute such as excessive splash or an increase in velocity down the chute. Also tried were undersize baffles, oversize baffles, and several combinations of sizes. Only rectangular shaped baffles were used in these tests. It seemed conclusive that this was a near optimum design with the only restriction being structural considerations or what could be built as far as size and stability are concerned.

One feature of the design that seemed to lend itself to some improvement was the entrance. The row of blocks near the top of the structure caused a significant increase in the water surface elevation, Figure 7. This row could also become clogged with large debris causing the upstream water level to encroach on the freeboard. The next phase of the investigation was directed toward obtaining alternate entrance configurations.

Three types of entrances were developed after many tests. The first is the standard entrance, Figure 8, which gives the best flow conditions at the upstream end of the chute and is recommended if an increase in upstream water level is not objectionable.

The second entrance, called entrance XVI, eliminates the top row of blocks but substitutes a sloping or triangular block adjacent to each sidewall, Figure 9. A larger fin of water forms on the sidewall near the second row of blocks but does not overtop the sidewall if the design height is used, Figure 10. This entrance does not cause excessive acceleration before impinging on the first row of blocks, Figure 11.

The third entrance is called the Fujimoto entrance and consists of a serrated horizontal broad crested weir, Figure 12. The weir is at the top of the chute in place of the first row of blocks. The second row of blocks used with the standard entrance and the XVI entrance are omitted. The configuration of the short and long sections is important, a long section even thought it is not full width should be placed next to the sidewalls. This entrance provides an acceptable flow condition at the top of the chute, Figure 13, and fully retarded acceleration by the third row of blocks, Figure 14.

Neither entrance XVI nor the Fujimoto entrance increases the elvation of the approaching flow. It should be emphasized that the design criteria requiring the velocity of the flow approaching the drop to be less than critical velocity should be followed regardless of the entrance configuration selected.

DESIGN EXAMPLE

As an illustration of the use of a baffled apron spillway consider the design used for a comparatively small watershed with an intense runoff. The watershed is approximately 63 mi^2 (163 km^2) with the upper end heavily developed and criss-crossed with numerous roads. The design operating criteria require that a detention reservoir be able to hold the 100-year flood at the crest of the emergency spillway and to pass the freeboard hydrograph (FBH) flood at the crest of the dam.

For this project, a vertical drop inlet is the service spillway and a baffled apron spillway is planned for emergency use or the FBH spillway, Figure 15.

The freeboard hydrograph shows a maximum inflow of 60,000 ft^3/s (1700 m^3/s), Figure 16. Arbitrarily, a design discharge of 40,000 ft^3/s (1133 m^3/s) plus a surcharge of 20,000 ft^3/s (567 m^3/s) and a unit discharge based on the design discharge of 150 $ft^3/s/ft$ (13.9 $m^3/s/m$).

This unit discharge has a critical depth of 8.88 ft (2.71 m) or a block height of 7.0 ft (2.13 m), Figure 17. Using the design criteria, the block width and spacing will be 10.5 ft (3.20 m). The sidewall height on the chute is 21.0 ft (6.40 m) plus 5.6 ft (1.71 m) for the critical depth of the surcharge flow or a total of 26.6 ft (8.11 m). The width of the chute will be 267 ft (81.4 m). The height from the crest of the chute to the top of the dam is one and one-half times the critical depth of the FBH flow or 17.45 ft (5.32 m). If a standard entrance is used, the 17.45 ft (5.32 m) dimension will have to be increased by 8 percent or to 18.85 ft (5.75 m). If a type XVI or Fujimoto entrance is used, no additional height need to be provided.

CONCLUSIONS

1. Extended experience with baffled apron chutes has proved their reliability and efficiency.

2. Model tests of specific projects showed that the concept could be used in lieu of spillway energy dissipators at larger unit discharges.

3. Further model studies were made to generalize the design criteria for unit discharges up to 300 $(ft^3/s)/ft$ (27.9 $(m^3/s)/m$).

4. These studies indicated that this type of structure was satisfactory for any discharge but structural and size-of-block limitations might control the quantity of the design unit discharge.

5. Three alternative entrances were developed, two of which will not increase the elevation of the approaching flow.

6. As with all new concepts, a design based on this example should be confirmed by hydraulic model studies.

APPENDIX 1

(1) Peterka, A. J., "Hydraulic Design of Stilling Basins and Energy Dissipators," Engineering Monograph No. 25, U. S. Department of Interior, Bureau of Reclamation, 1964, pp. 154-188

(2) Rhone, T. J., "Studies to Determine the Feasibility of a Baffled Apron Drop as a Spillway Energy Dissipator - Conconully Dam Spillway - Okanogan Project, Washington," U. S. Bureau of Reclamation, Report REC-ERC-71-29, 1972

H-1798-3

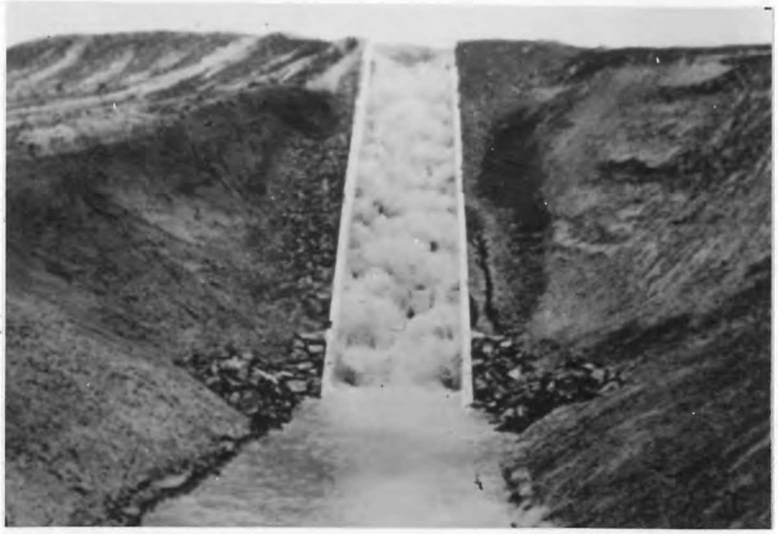

Figure 1

Canal Baffled
Apron Drop

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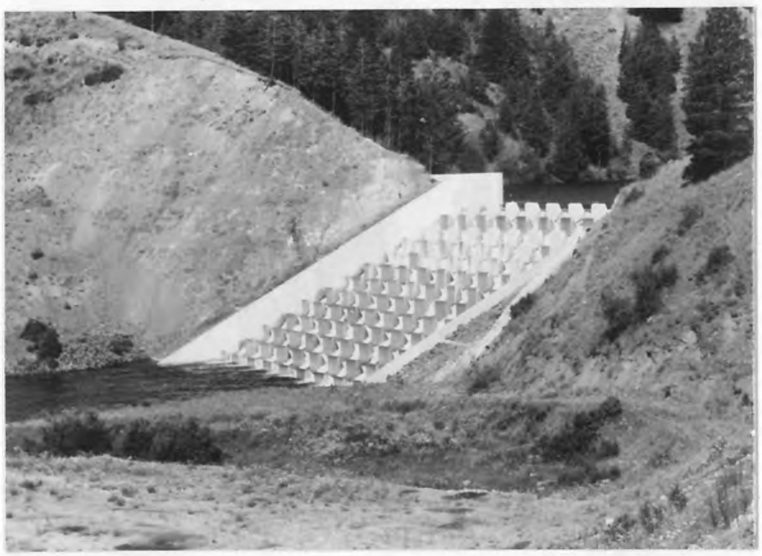


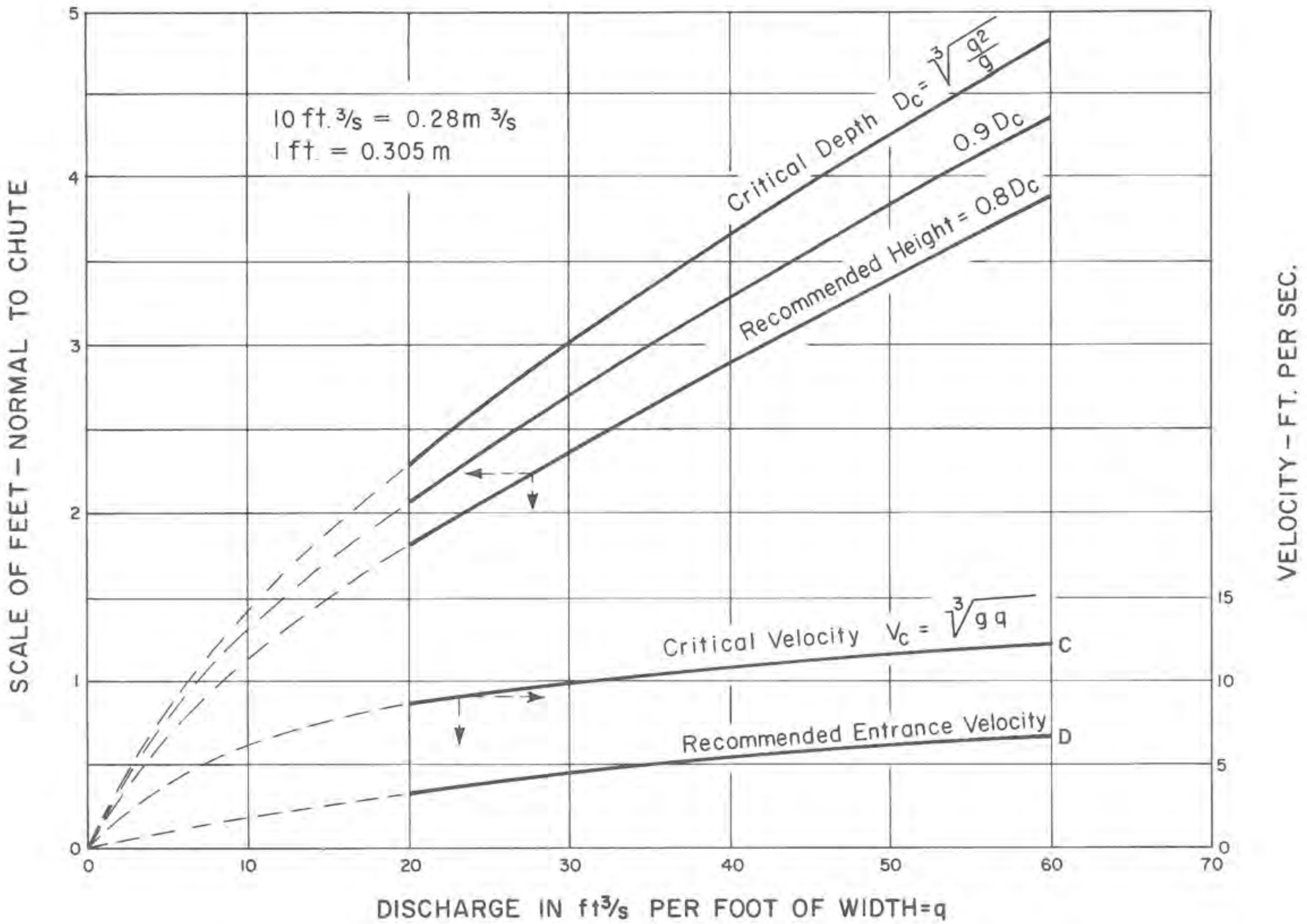
Figure 3

Conconully Dam
Baffled Spillway

H-1798-2

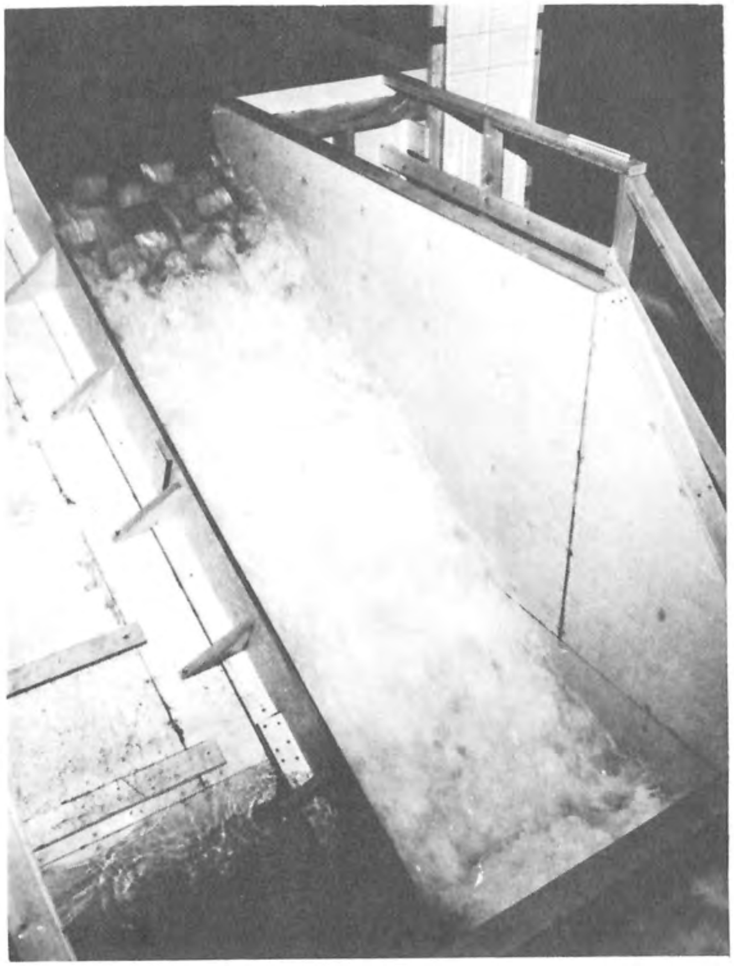
Figure 4

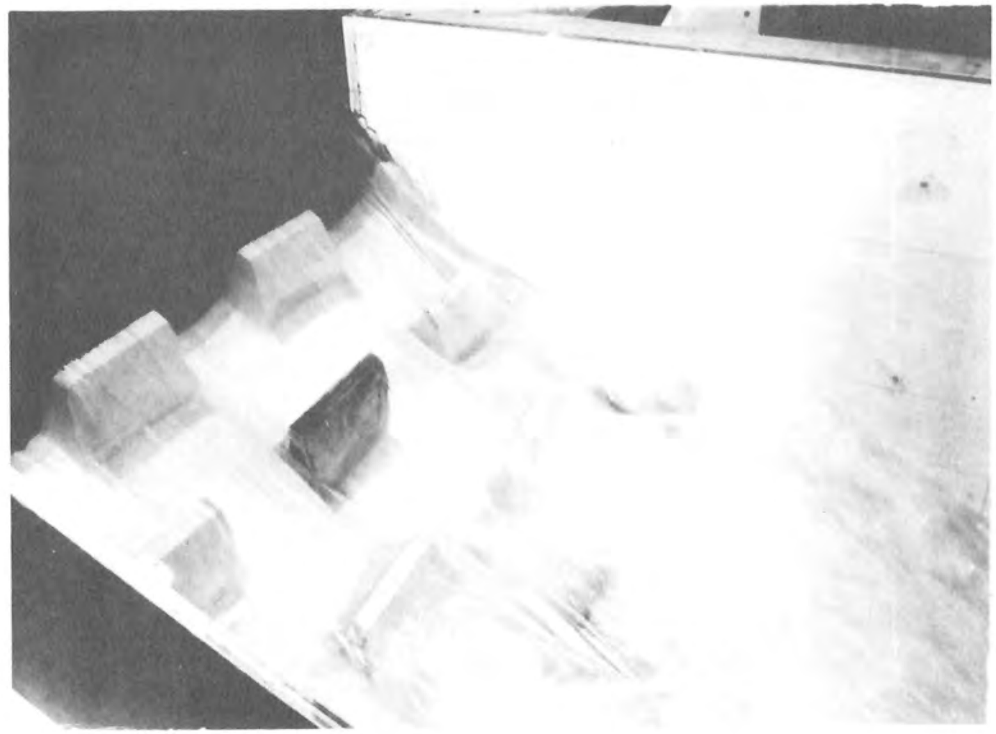
Marble Bluff
Diversion Dam
Baffled Spillway



BAFFLED CHUTE STUDIES
RECOMMENDED BAFFLE PIER HEIGHTS AND ALLOWABLE VELOCITIES

Figure 2





STANDARD ENTRANCE

Unit Q = 300 ft ^{3}/s
8.5 m ^{3}/s

Figure 5

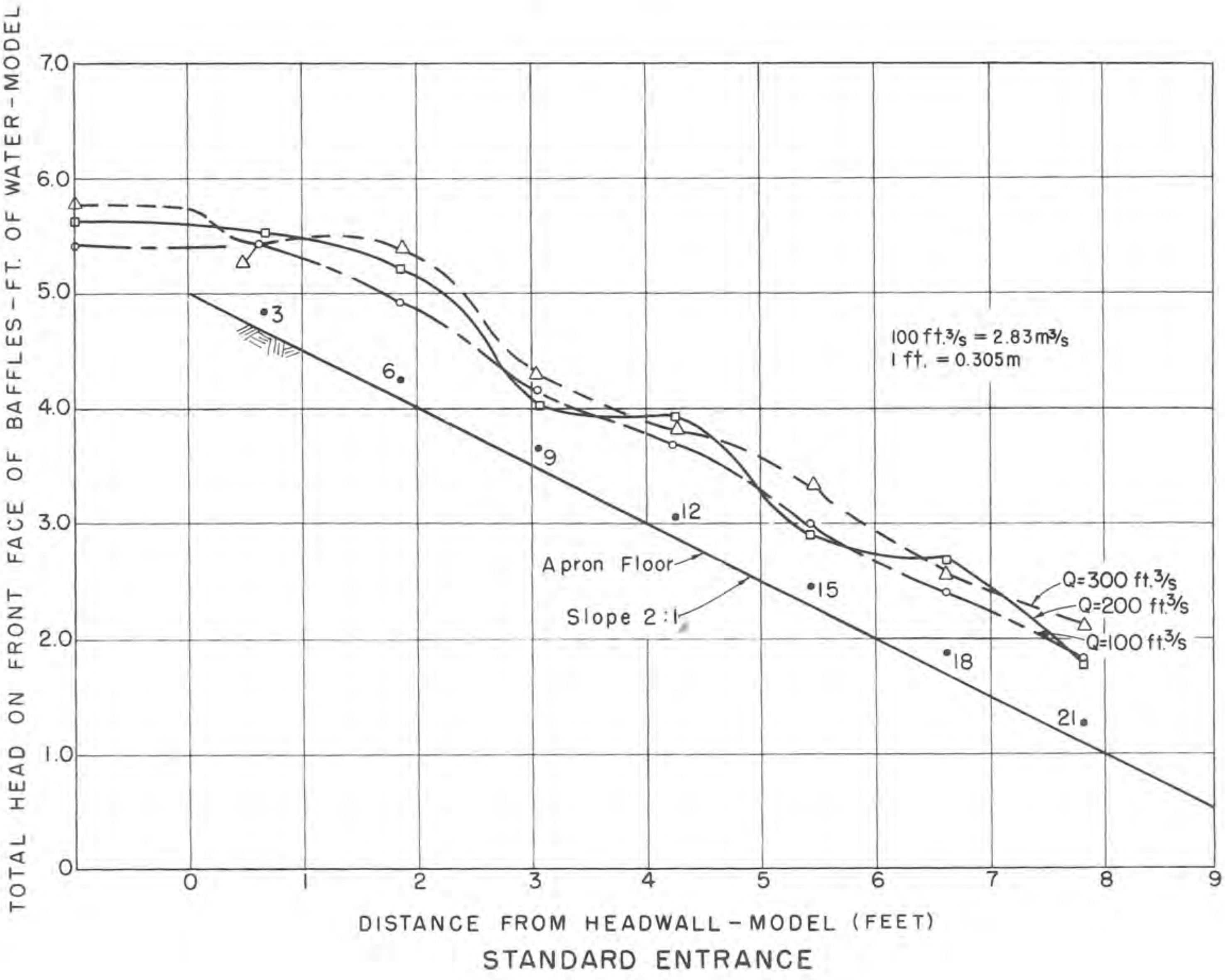
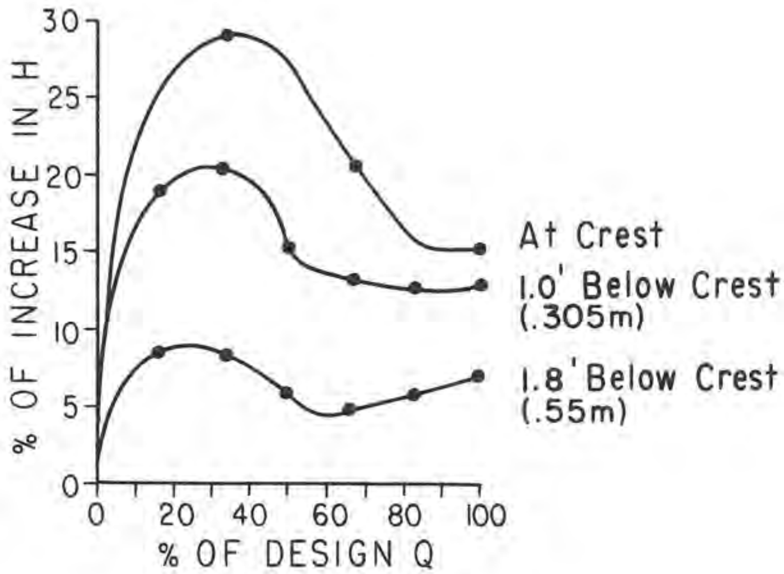
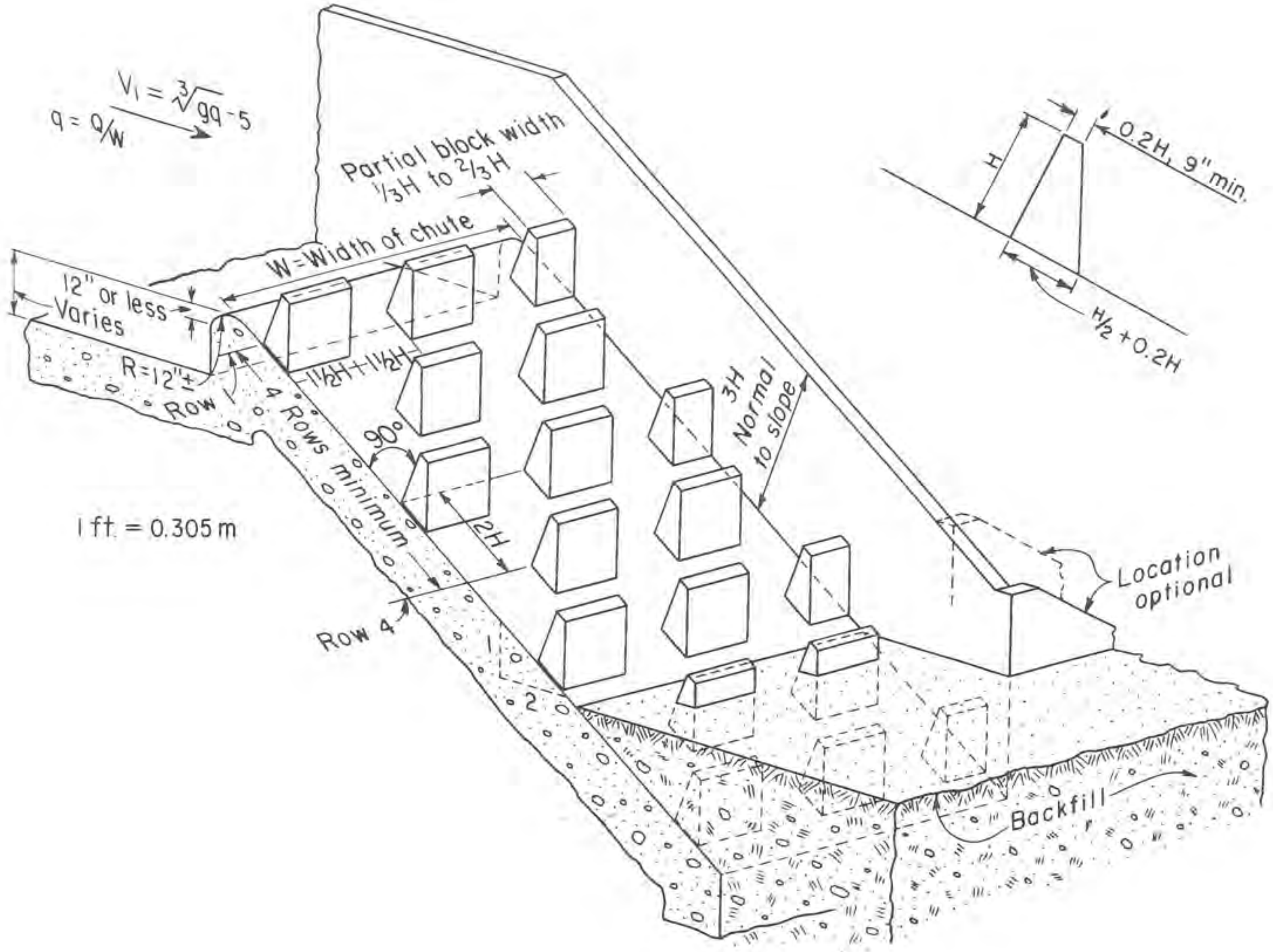

TOTAL HEAD ON FRONT FACE OF BAFFLES - FT. OF WATER - MODEL
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0
1
2
3
4
5
6
7
8
9
3
6
9
12
15
18
21
100 ft.³/s = 2.83 m³/s
1 ft. = 0.305 m
Apron Floor
Slope 2:1
Q=300 ft.³/s
Q=200 ft.³/s
Q=100 ft.³/s
DISTANCE FROM HEADWALL - MODEL (FEET)
STANDARD ENTRANCE

Figure 6



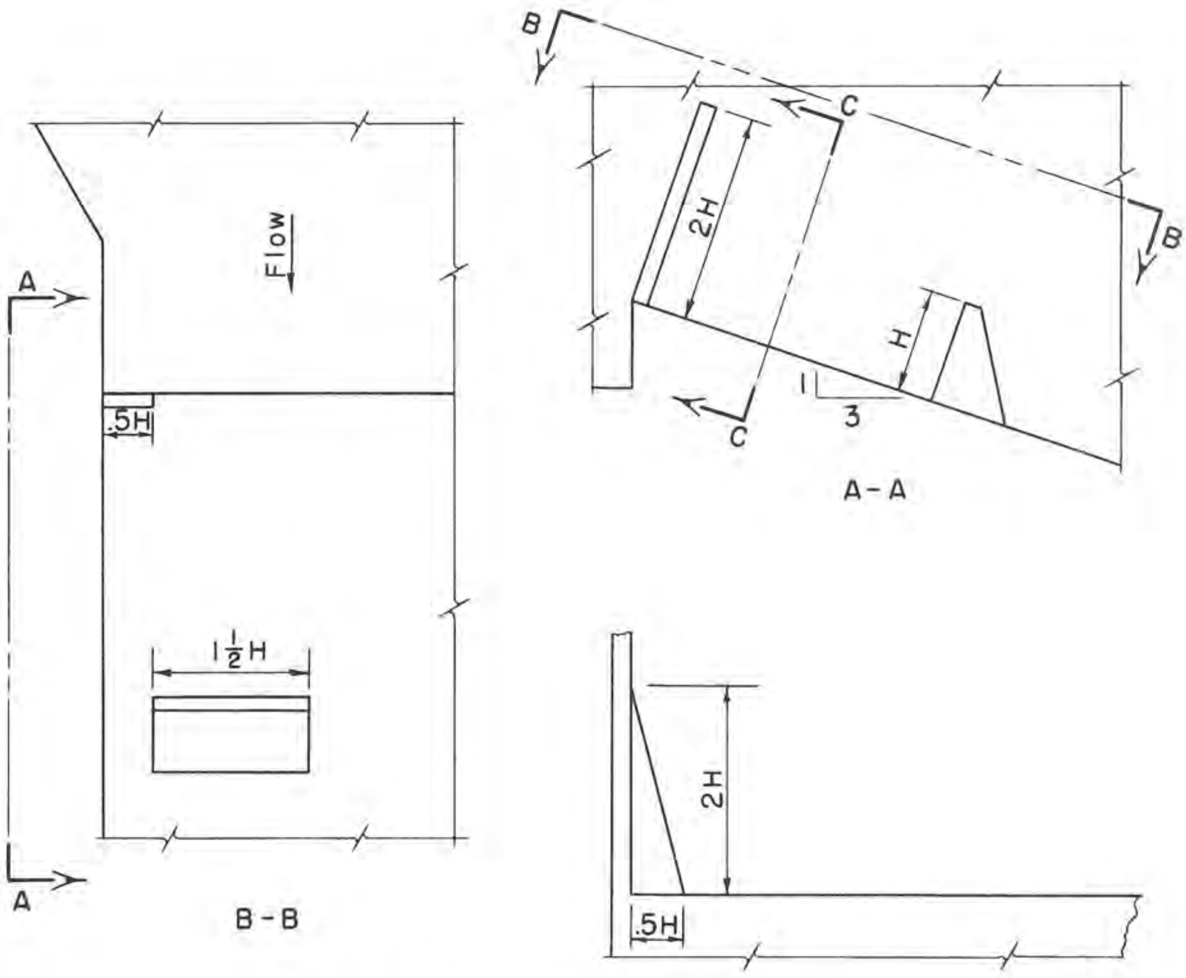
EFFECT OF BLOCK LOCATION
ON RESERVOIR LEVEL

Figure 7



BASIC PROPORTIONS OF A BAFFLED CHUTE

Figure 8

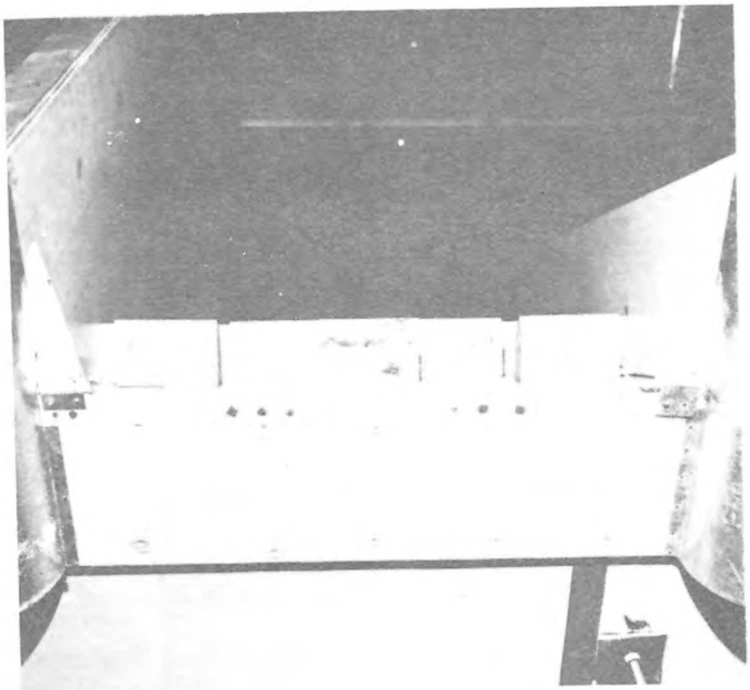


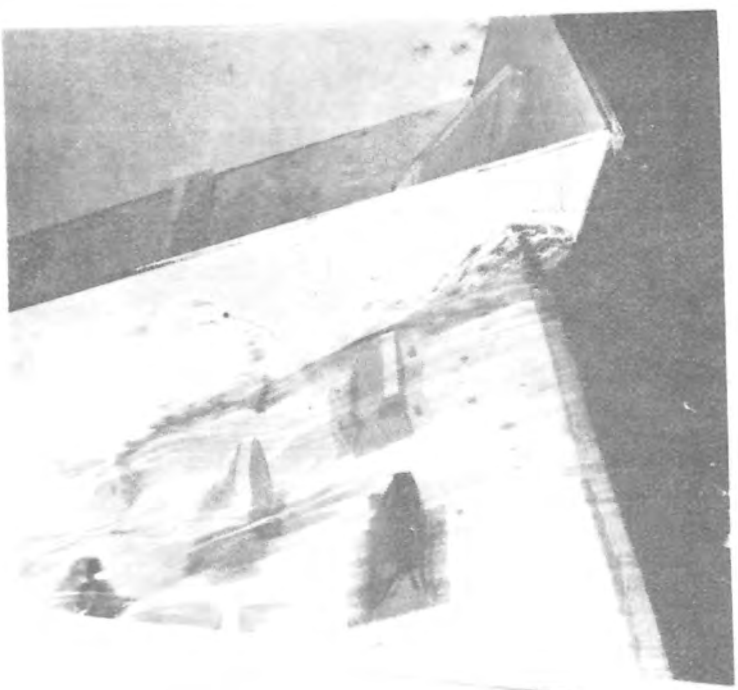
NOTE: $H = 0.8D_c$

D_c = CRITICAL DEPTH FOR DESIGN Q

ENTRANCE XVI

Figure 9

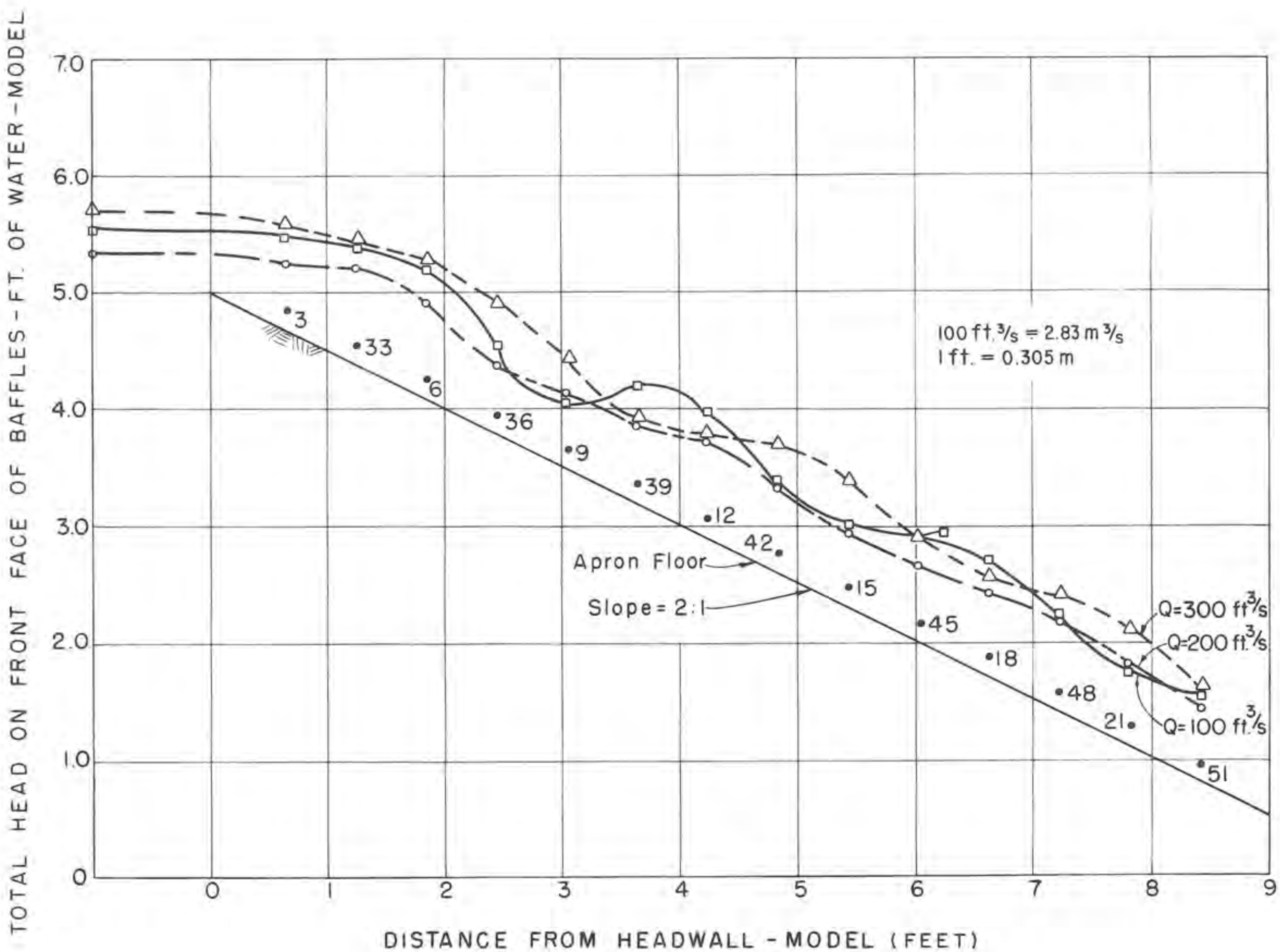




DESIGN XVI

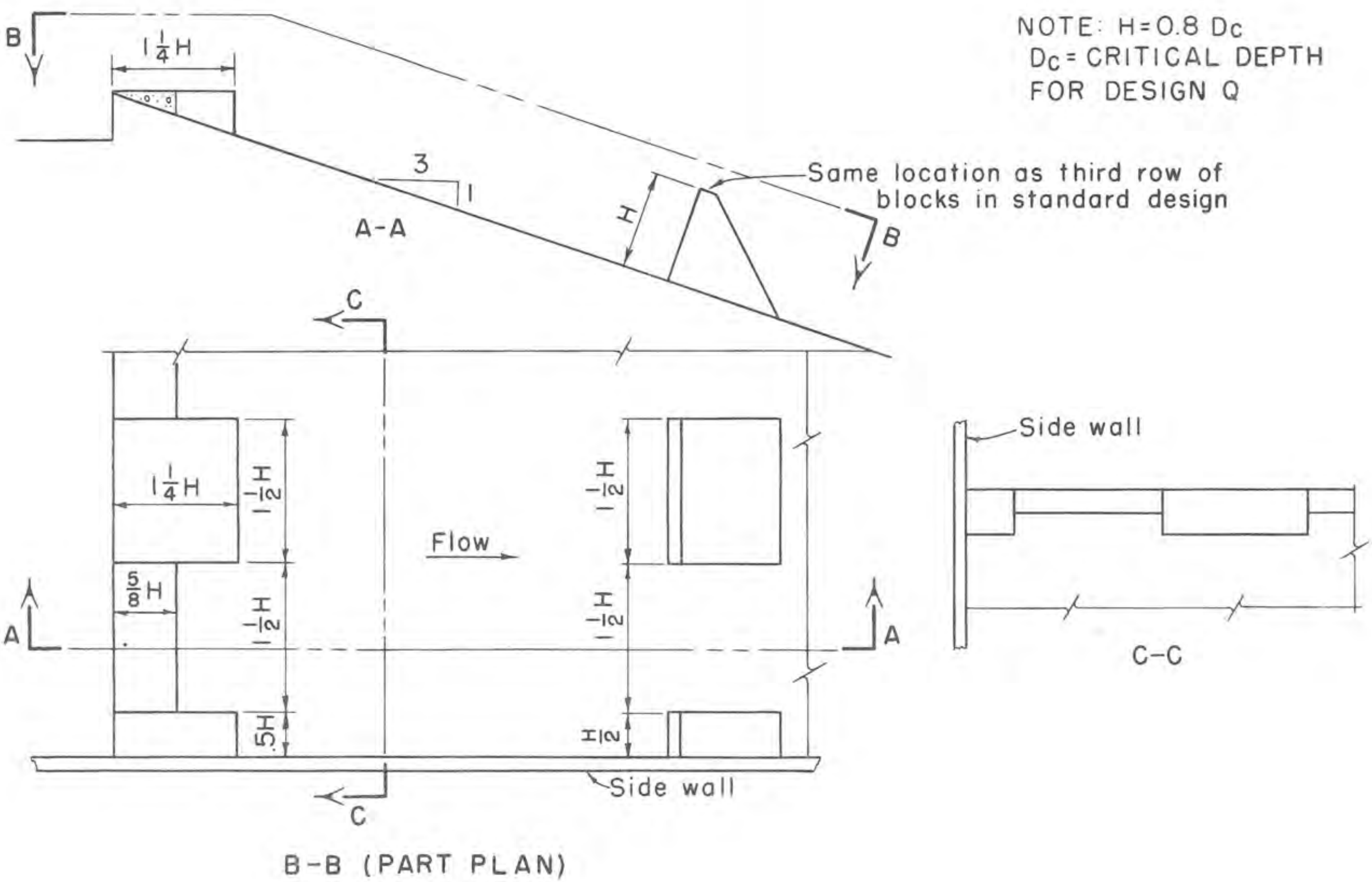
Unit Q = $\frac{300\ ft^3/s}{8.5\ m^3/s}$

Figure 10



DESIGN XVI

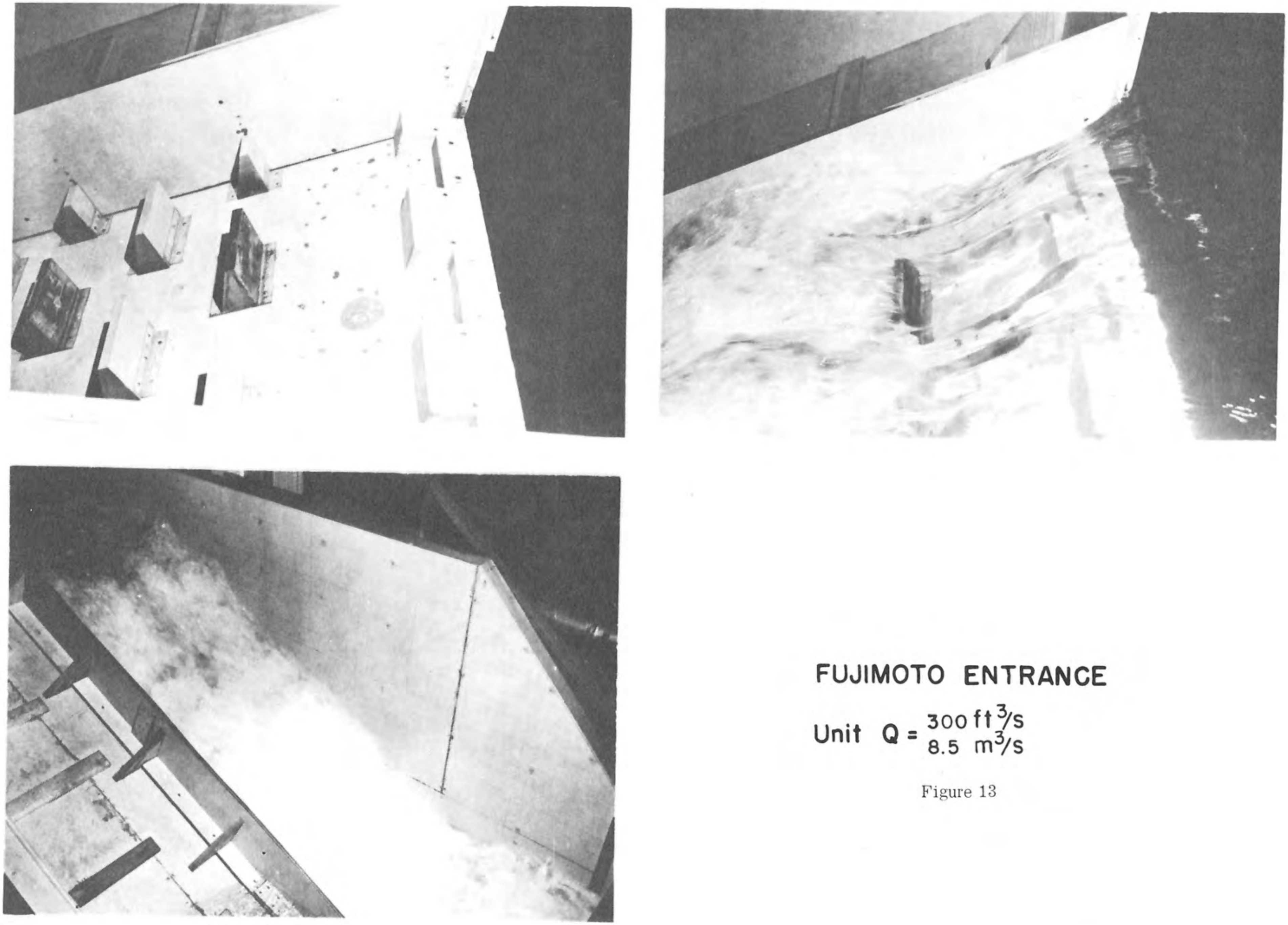
Figure 11



(NOT TO SCALE)

FUJIMOTO ENTRANCE

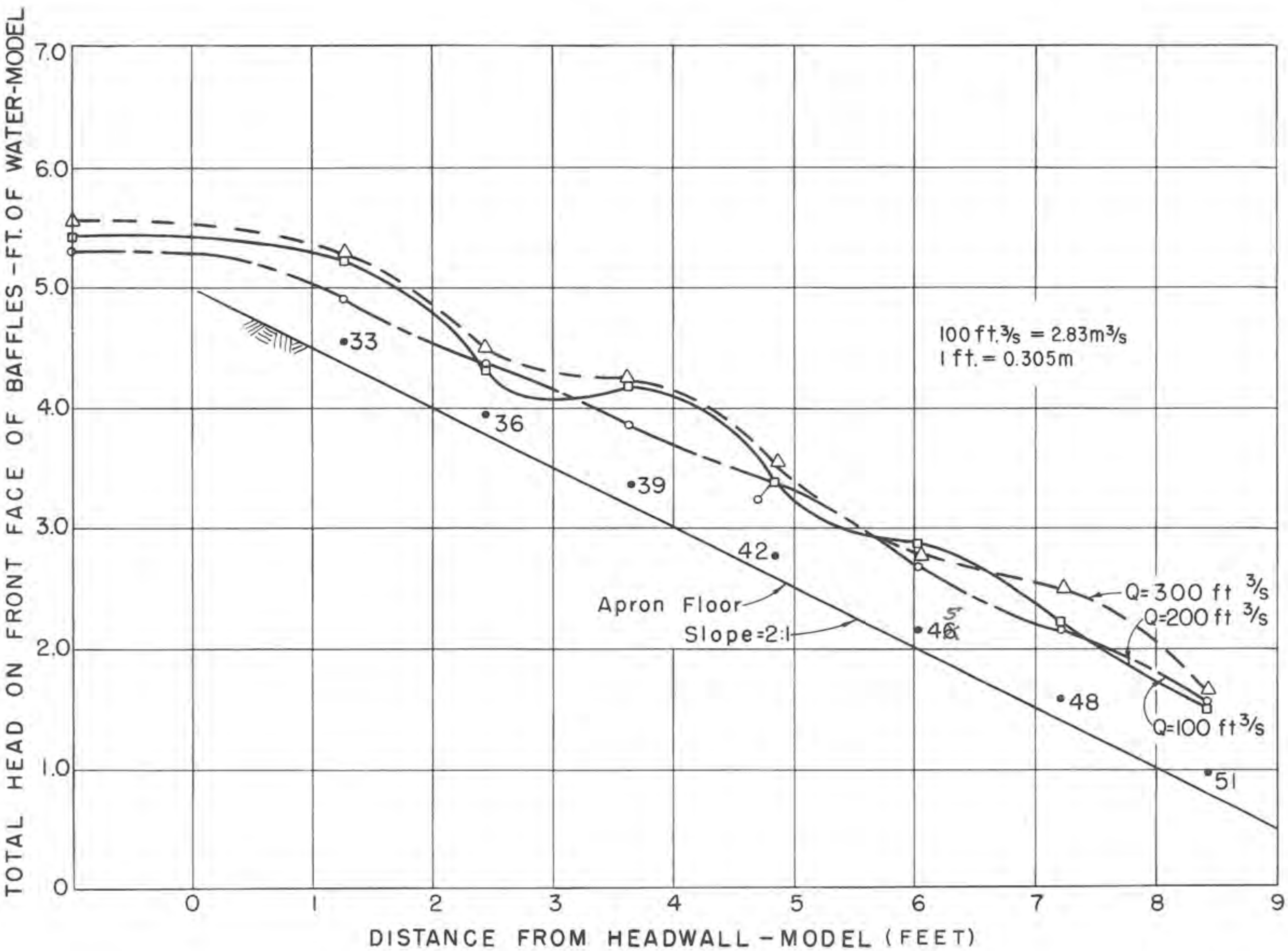
Figure 12



FUJIMOTO ENTRANCE

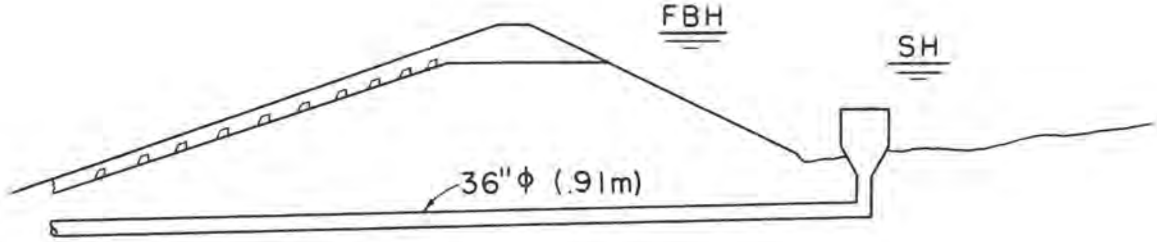
Unit Q = 300 ft³/s
8.5 m³/s

Figure 13



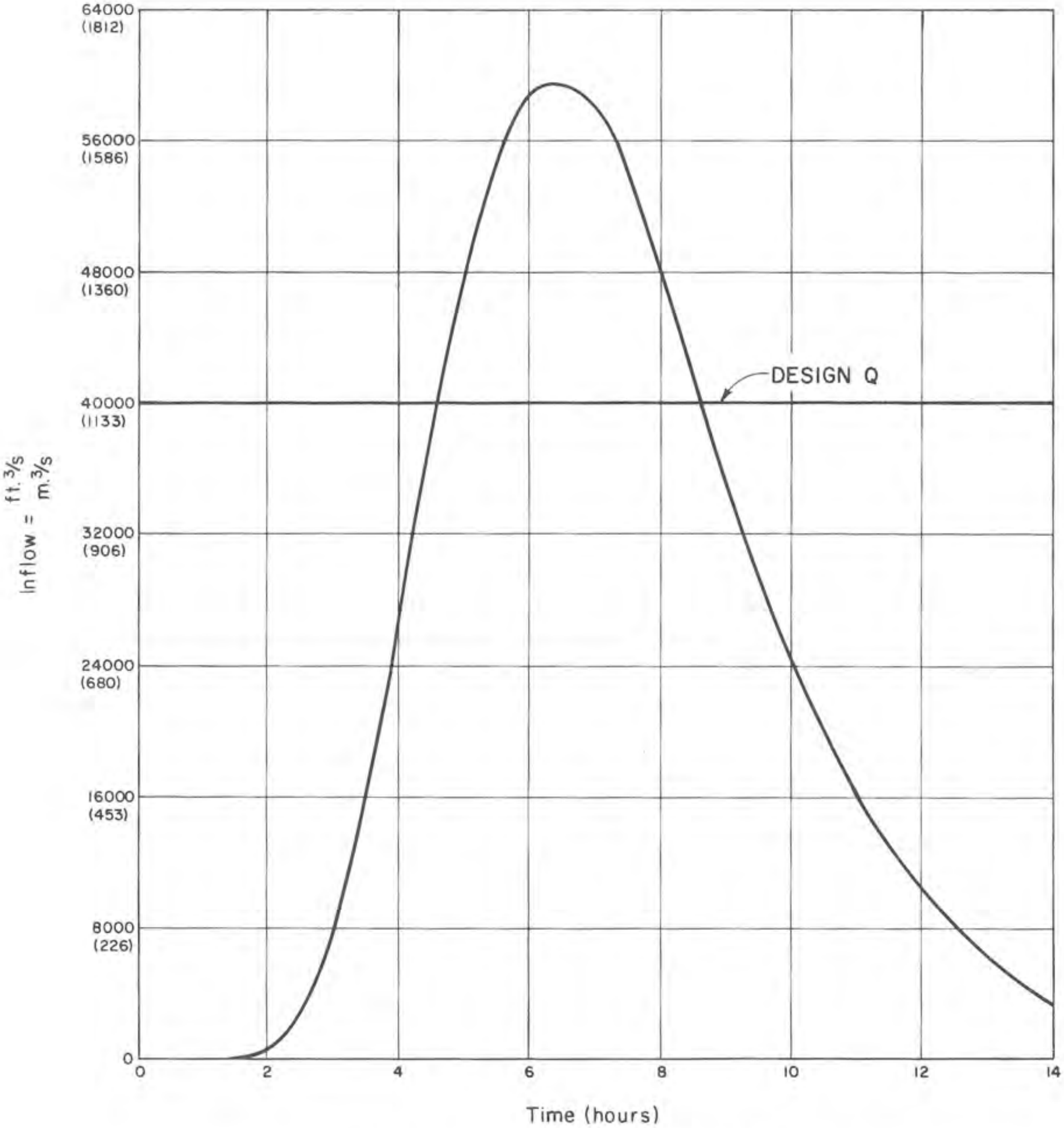
FUJIMOTO ENTRANCE

Figure 14



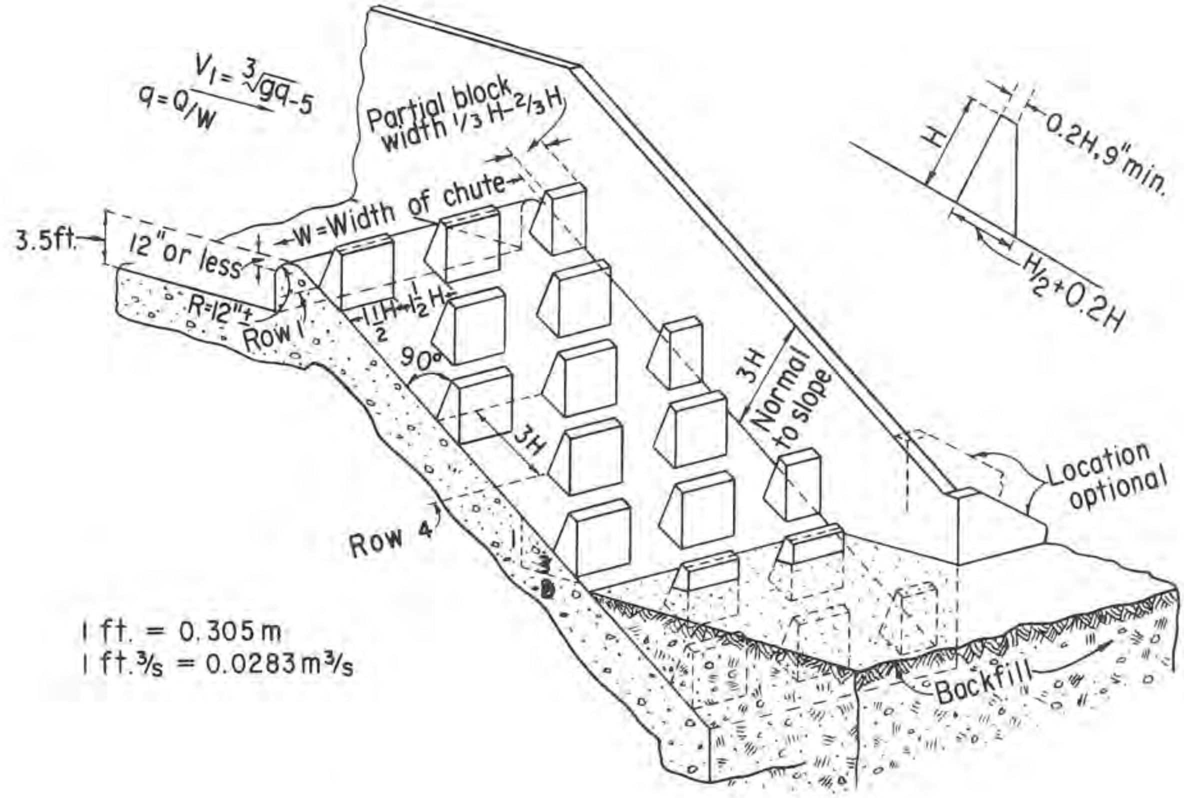
HYDRAULIC STRUCTURES

Figure 15



TYPICAL HYDROGRAPH

Figure 16



FBH Q = 60,000 cfs
Design for 40,000 cfs plus surcharge 20,000 cfs
Unit discharge = 150 cfs
Critical depth = 8.88 ft
H = 0.8 C_D = 7.1 ft. use 7.0 ft.
Block width and spacing = 10.5 ft.
Wall height = 3 H = 21.0 ft.
Surcharge 20,000 cfs C_D = 5.6 ft.
Side wall height = 21.0 + 5.6 = 26.6 ft.
Width chute = 266.67 ft.
Height crest to top of dam = 1.5 times C_D for
a unit discharge of 225 cfs = 17.45 ft.

Figure 17

GPO 847-659