

5. TYPE B DROP SPILLWAY

General. Minimum layout and hydraulic design criteria for a type B drop spillway are given on drawing ES-67 (page 5.3) and in the following discussion. These criteria are patterned after those suggested by Messrs. B. T. Morris and D. C. Johnson in a paper entitled "Hydraulic Design of Drop Structures for Gully Control" which was published in the Trans. of the American Society of Civil Engineers, Vol. 108 (1943). Study of this paper will disclose the differences between the criteria proposed by Morris and Johnson and those proposed herein.

The type B drop spillway is not recommended for sites where easily eroded soils exist in channel bottoms or banks, or at sites where prolonged flow will occur as in irrigation channels. The scour in these sites is apt to be so severe that it will endanger the stability of the structure. Drop structures in such locations require a longer apron and more effective energy dissipation. Pending availability of results of research now underway on drop spillways for such conditions, it is suggested that Field Engineers present such problems to the Washington Engineering Division for assistance.

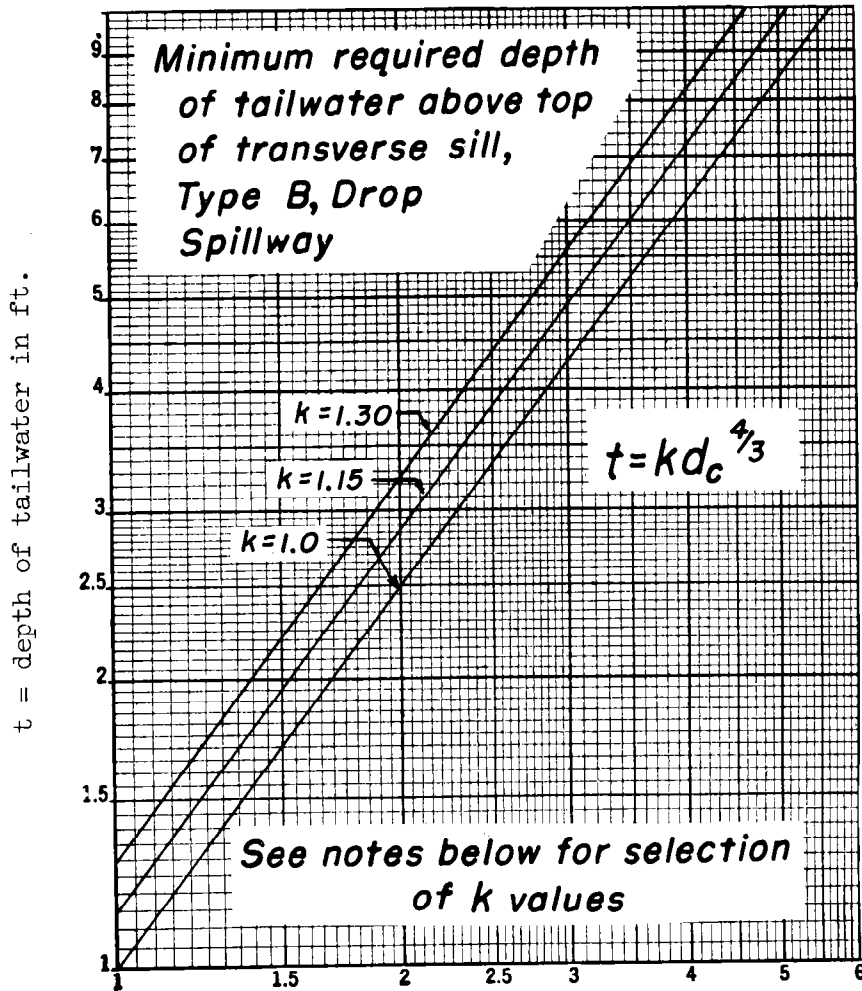
On dense firm clays, dense well-graded and compacted glacial tills, and dense well-graded and compacted mixtures of silt, sand and clay, the type B drop spillway should give satisfactory performance. On silts and sandy silts, riprap will probably be required to protect the channel bottom and banks just below the spillway. Where the need of riprap is anticipated, it should be placed during the original construction, especially if systematic maintenance of the structure is doubtful. The type B drop spillway should not be used where the channel bottom and banks below it are composed of loose or easily eroded materials such as sand.

As the ratio $h + F$ increases, the tendency for scour to occur also increases. For this reason, and because the most economical spillways for a given discharge tend toward low values of the $h + F$ ratio, it is recommended that this ratio be kept lower than 0.50 with an absolute maximum of 0.75.

The ratio of $L + h$ should always be equal to, or greater than, 2. This criterion applies to all rectangular weirs.

As will be seen later, the longitudinal sills become an important element in the structural design of the apron. In long weirs, where the value of $F + h$ is approximately 12 feet or more, it is structurally advantageous to shorten the horizontal span in the headwall by the use of buttresses; such buttresses should be placed so that the horizontal length of headwall is divided into equal spans. For practical construction and design reasons, the location of buttresses and longitudinal sills should coincide. Hence, it is recommended that the longitudinal sills be located so that the distance between center lines of the sidewalls will be divided into approximately equal spans of practical length, and that the location of longitudinal sills and buttresses be made to coincide where buttresses are used.

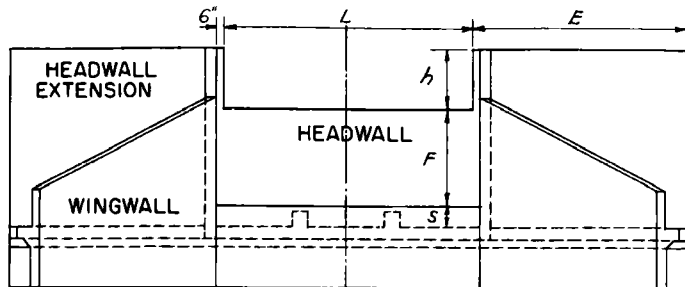
Tailwater. A minimum tailwater elevation is required to reduce the scour of the channel bottom and banks just below the spillway to tolerable limits. A significant amount of model testing and field observation show that a low tailwater permits the jet of water, cast upward by the transverse sill, to strike the channel bottom with serious scour effects and that strong side eddies which attack the channel banks are created. With a high tailwater, the velocity of the jet off the transverse sill is reduced and the jet merges with the downstream flow with less serious results. The proper amount of tailwater for a type B drop spillway has not been definitely established. Pending additional research, the recommended minimum required tailwater depth above the top of the transverse sill, t in feet, is given in fig. 5.1. A tailwater depth $t = 2d_c$ is desirable and should be obtained where practicable.



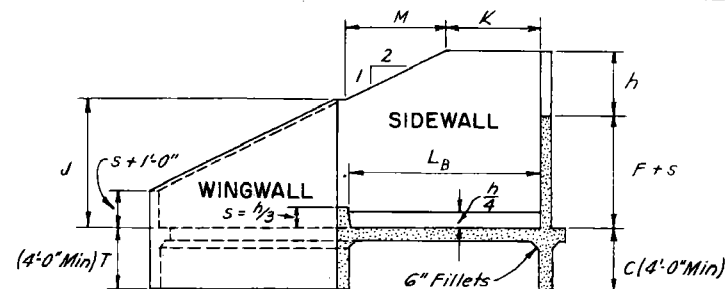
$d_c = \text{critical depth at weir, ft.}$

FIGURE 5.1

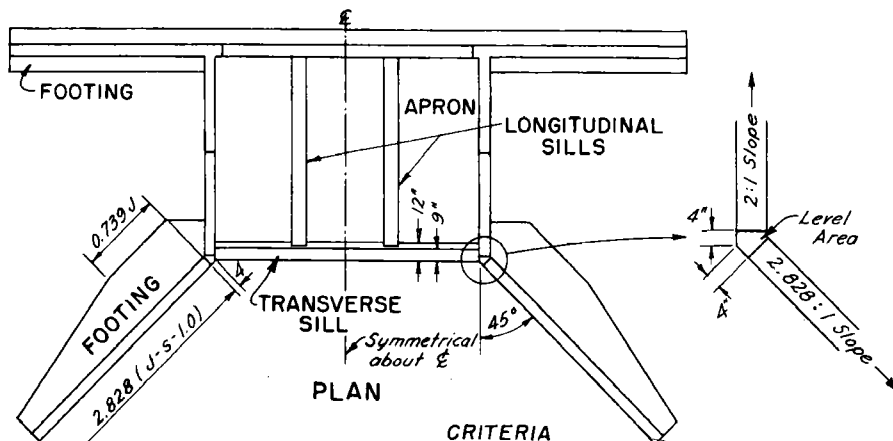
DROP SPILLWAYS: LAYOUT AND HYDRAULIC DESIGN CRITERIA - TYPE B



DOWNSTREAM ELEVATION



SECTION ON CENTER LINE



PLAN

CRITERIA

$E =$ Minimum length of headwall extension (in feet) = $[3h + 2]$ or $[1.5F]$ whichever is greater.

$J =$ Height of wingwall and sidewall at junction (in feet) = $[2h]$ or $[F + h + s - (\frac{L_B + 0.42}{2})]$ or $[t + 1]$ whichever is greater.

$L_B =$ Length of basin (in feet) = $[F(2.28 \frac{h}{F} + 0.52)]$

$M = [2(F + \frac{4}{3}h - J)]$

$K = [(L_B + 0.42) - M]$

NOTE: 1.- See Engineering Handbook, Section 11, Drop Spillways, for criteria on placement of longitudinal sills, tailwater requirements, hydraulic capacity, structural design, etc.

2.- All dimensions in foot units.

Minimum Length of Apron

$$\frac{L_B}{F} = [2.041 + 0.599(\frac{h}{F}) + 0.169(\frac{h}{F})^3] (\frac{h}{F})^{\frac{1}{2}}$$

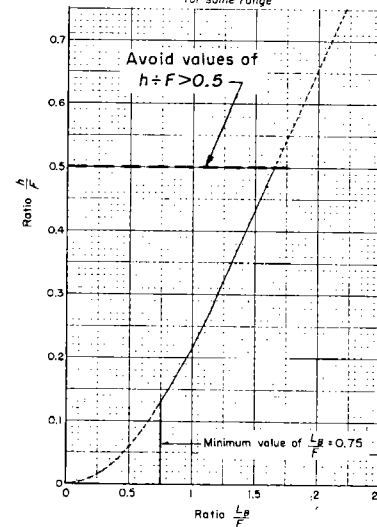
for range of values

$$\frac{L_B}{F} \geq 0.75 - 2.22$$

or use

$$\frac{L_B}{F} = 2.28 \frac{h}{F} + 0.52$$

for same range



REFERENCE

Revised 12-16-53

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN SECTION

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Use $k = 1.0$, fig. 5.1 (page 5.2)

Where flow is intermittent, the periods of high discharges are of short duration, and the channel below the structure is highly resistant to scour, such as a tight clay or glacial till.

Use $k = 1.15$

- (a) Where flow is intermittent, the periods of high discharge are of short duration, and the channel below the structure is resistant to scour. (This covers most average conditions.)
- (b) Where flow is intermittent, but the periods of high discharge are relatively long and the channel below the structure is highly resistant to scour.

Use $k = 1.30$

Where flow is intermittent, periods of high discharge are relatively long, and the channel below the structure is resistant to scour.

It may be necessary to set the elevation of the top of the transverse sill below the elevation of the stable grade line of the downstream channel in order to provide the required tailwater.

In addition to the above requirements for minimum tailwater, there are limitations of maximum permissible tailwater for the type B drop spillway. Tailwater depths above maximum permissible values cause the jet of water coming through the weir to be deflected upward and outward to such an extent that a considerable part of the discharge may not hit the apron but falls on the unprotected stream bed in front of the apron. To avoid this situation and prevent the excessive scour associated with it, the tailwater depth above the top of the transverse sill, t , should not be greater than $0.5 (F + h)$.

Then the range in value of tailwater depth, t , is given by the following formula.

$$kd_c^{4/3} \leq t \leq \frac{F + h}{2} \quad 5.1$$

Volumes of Concrete and Steel. The volume of reinforced concrete required to construct certain sizes of type B drop spillways with minimum dimensions is given in drawing ES-66 (page 5.7). Drawing ES-74 (page 5.9) gives the weir dimensions and concrete volume of the type B drop spillway that requires the minimum volume of concrete for a given design discharge, Q , and net drop, F . These quantities are based on the use of class B concrete as defined in the Engineering Handbook, Section 6 on Structural Design, and a working stress for reinforcing steel, $f_s = 20,000$ psi. Load assumptions were:

1. Weight of concrete = 150 lbs/ft³
2. Weight of earth fill = 100 lbs/ft³
3. Weight of equivalent fluid against headwall = 62.4 lbs/ft³
4. Weight of equivalent fluid against sidewalls = 35 lbs/ft³
5. Weight of equivalent fluid against wingwalls = 35 lbs/ft³
6. Weight of equivalent fluid against headwall extensions = 5 lbs/ft³
7. Allowable soil bearing pressure = 2000 lbs/ft²

In some cases, for stability reasons, it will be necessary to increase the length of the headwall extensions and increase the depth of the cutoff wall beyond the minimum values indicated on drawing ES-67 (page 5.3). Such changes will require additional concrete above the amount indicated in the tables of drawing ES-66 (page 5.7). The amount of additional concrete can be estimated with reasonable accuracy from drawing ES-48 (page 5.10) with $b = 8$ in.

The amount of reinforcing steel required, as measured in terms of pounds of reinforcing steel per cubic yard of concrete, will vary considerably with the height of the structure and to a smaller extent with the length of the weir. Approximate amounts of reinforcing steel to be used for estimating purposes only are given in fig. 5.2.

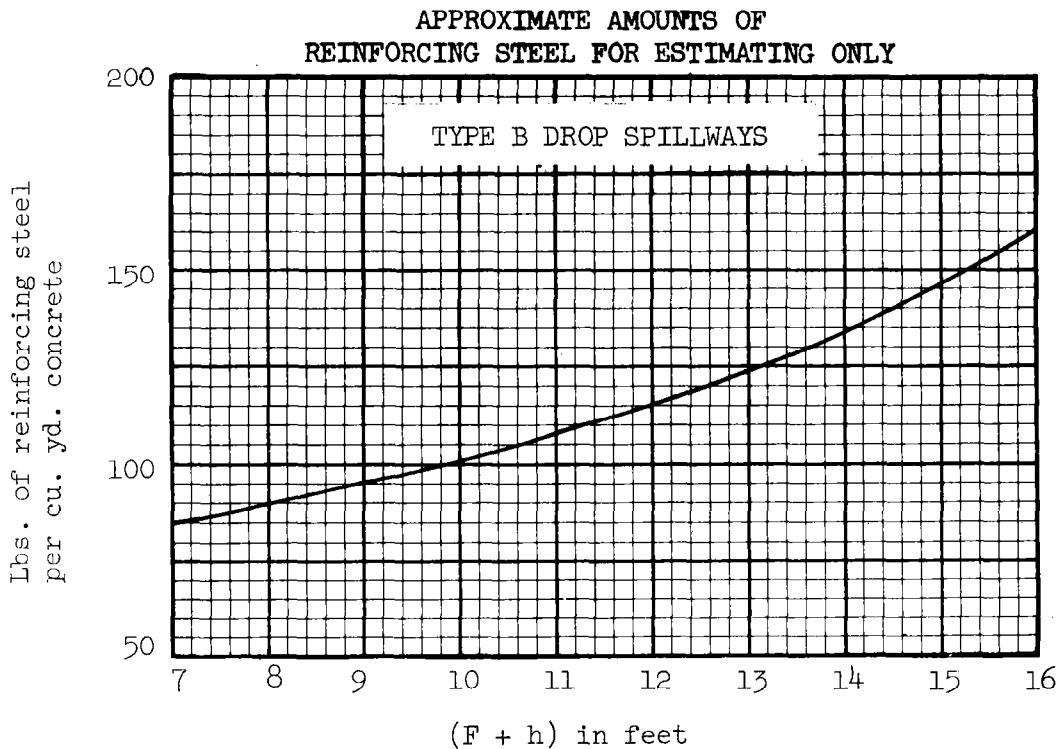


FIGURE 5.2

Example 5.1

- Given:
1. Required discharge capacity, $Q = 200$ cfs
 2. Net drop, $F = 7$ ft
 3. Free flow condition (no submergence)
 4. Use drawing ES-74 (page 5.9)

- Find:
1. The length L and depth h of a weir of a type B drop spillway that will carry the required discharge and contain a minimum amount of concrete.
 2. The estimated amount of reinforcing steel required for each structure considered.

Solution: Drawing ES-74 (page 5.9) shows that for a Q of 200 cfs and F of 7.0 ft, a drop spillway having weir dimensions of $L = 20'-0''$ and $h = 2'-6''$ requires the minimum volume of concrete, namely 34.9 cubic yards.

Figure 5.2 (page 5.5) shows that for $F + h = 7 + 2.5 = 9.5$ ft the estimated reinforcing steel requirement is 98 pounds per cubic yard of concrete. Therefore, the total estimated steel requirement is $34.9 \cdot 98 = 3420$ pounds.

Comment: Drawing ES-74 (page 5.9) also shows there is only 0.5 cubic yard difference in concrete volume required by the 2.5 x 20 weir and the 3 x 16 weir. As pointed out previously, final selection of weir proportions should be based on site requirements and comparative cost estimates that include costs of excavation, fill, drainage, etc.

Example 5.2

Given: A type B drop spillway with $F = 7$ ft, $h = 3$ ft, and $L = 16$ ft of minimum dimensions as indicated on drawing ES-67 (page 5.3) and a wall thickness, $b = 8$ inches.

Find: The increase in concrete yardage if the length of each headwall extension is increased 4.0 ft and the depth of cutoff wall is increased 2.0 ft.

Solution: Reference to drawings ES-48 (page 5.10) and ES-67 (page 5.3) should make the following computations self-evident: $s = h \div 3 = 3 \div 3 = 1$; then $Y = F + h + s = 7 + 3 + 1 = 11$ ft. For $b = 8$ in, and $Y = 11$ ft, X as taken from the curve = 0.8 ft, but use $X = 1.0$ ft; $b + 1 = 9$ in = 0.75 ft; $b + 2 = 10$ in = 0.833 ft. Now compute added volume in headwall extension without increase in cutoff wall depth.

$$\begin{aligned} 11 \cdot 0.667 &= 7.34 \\ 2.667 \cdot 0.75 &= 2.00 \\ 3.25 \cdot 0.833 &= 2.71 \\ 2 \cdot 0.5 \cdot 0.5 \cdot 0.5 &= \underline{0.25} \\ 12.30 \cdot 2 \cdot 4 &= 98.40 \text{ ft}^3 \end{aligned}$$

Now compute added volume due to increase in depth.

Original length of cutoff wall = $L + 2(3h + 2)$ or $L + 2(1.5F)$, whichever is greater.

$$L + 2(3h + 2) = 16 + 2(9 + 2) = 38 \text{ ft} \quad (\text{Use})$$

$$L + 2(1.5F) = 16 + 2(1.5 \cdot 7) = 37 \text{ ft}$$

Final length of cutoff wall = $38 + 8 = 46$ ft; increase in volume of cutoff wall = $46 \cdot 2 \cdot 0.833 = 76.64 \text{ ft}^3$; total increase in volume = $(98.40 + 76.64) \div 27 = 6.5$ cu yd.

Comment: In actual practice, a sketch should be made to facilitate such computations.



DROP SPILLWAYS: APPROXIMATE VOLUMES OF REINFORCED CONCRETE IN CUBIC YARDS - TYPE B

F	L														
	h		6	8	10	12	14	16	18	20	22	24	26	28	30
3	2-0		14	15	16	18	19	20	21	22	23	24	25	26	27
4	2-0		15	16	18	19	20	21	22	24	25	26	27	28	29
	2-6		19	20	22	23	24	26	27	28	29	31	32	33	34
	3-0		23	25	26	28	29	30	32	33	34	36	37	38	40
5	2-0		16	17	19	20	21	23	24	25	26	28	29	30	31
	2-6		20	22	23	25	26	27	29	30	31	33	34	35	37
	3-0		25	26	28	29	31	32	33	35	36	38	39	41	42
	3-6		30	31	33	34	36	37	39	40	42	43	45	46	48
6	2-0		19	20	22	23	24	26	27	28	30	31	32	34	35
	2-6		21	23	24	26	27	29	30	32	33	34	36	37	39
	3-0		26	28	29	31	32	34	35	37	38	40	41	43	44
	3-6		32	33	35	37	38	40	41	43	45	46	48	49	51
	4-0		37	39	40	42	44	46	47	49	51	52	54	56	57
	4-6		43	45	47	49	51	52	54	56	58	59	61	63	65
7	2-0		23	24	26	27	29	30	31	33	34	36	37	38	40
	2-6		25	26	28	29	31	32	34	35	37	38	40	41	43
	3-0		28	29	31	33	34	36	37	39	41	42	44	45	47
	3-6		33	35	36	38	40	42	43	45	47	48	50	52	53
	4-0		39	41	43	45	47	48	50	52	54	55	57	59	61
	4-6		45	47	49	51	53	55	57	59	61	62	65	67	69
	5-0		52	54	56	58	60	62	64	66	68	70	72	74	76
8	2-0		27	29	30	32	33	35	36	38	39	41	43	45	46
	2-6		29	31	32	34	35	37	39	40	42	43	46	47	49
	3-0		30	32	34	36	37	39	41	42	44	46	47	50	52
	3-6		35	36	38	40	42	44	46	47	49	51	53	55	57
	4-0		41	43	44	47	48	50	52	54	56	58	60	62	64
	4-6		47	49	51	53	55	57	59	61	63	66	68	70	72
	5-0		54	56	58	61	63	65	67	69	72	74	76	78	80

DROP SPILLWAYS: APPROXIMATE VOLUMES OF REINFORCED CONCRETE IN CUBIC YARDS - TYPE B

F	h \ L														
		6	8	10	12	14	16	18	20	22	24	26	28	30	
9	2-0	32	33	35	37	38	40	41	43	45	47	49	50	52	
	2-6	34	36	37	39	41	43	44	46	49	50	52	54	55	
	3-0	35	37	39	41	43	44	46	48	51	53	54	56	58	
	3-6	37	39	41	43	45	47	49	51	53	55	57	59	61	
	4-0	42	44	46	48	50	52	54	57	59	61	63	65	67	
	4-6	49	51	53	56	58	60	62	65	67	69	71	73	75	
	5-0	56	58	61	63	65	67	69	73	75	77	79	81	83	
10	2-0	37	39	41	42	44	46	47	50	52	54	55	57	59	
	2-6	39	41	43	44	46	48	50	53	54	56	58	60	61	
	3-0	40	42	44	46	48	50	53	55	57	59	60	62	64	
	3-6	43	45	47	49	51	53	56	58	60	62	64	66	68	
	4-0	45	47	50	52	54	56	59	61	63	65	67	69	71	
	4-6	51	53	55	58	60	62	65	68	70	72	74	76	78	
	5-0	59	61	63	66	68	70	74	76	78	80	83	85	87	

- Note: (1) These volumes apply only to drop spillways designed in accordance with criteria set forth in drawing ES-67, page 5.3, and on page 5.4 of the Engineering Handbook, Section 11, Drop Spillways.
- (2) F = net drop from crest of weir to top of transverse sill in feet.
 h = total depth of weir in feet.
 L = length of weir in feet.

REFERENCE

Revised 7-9-53

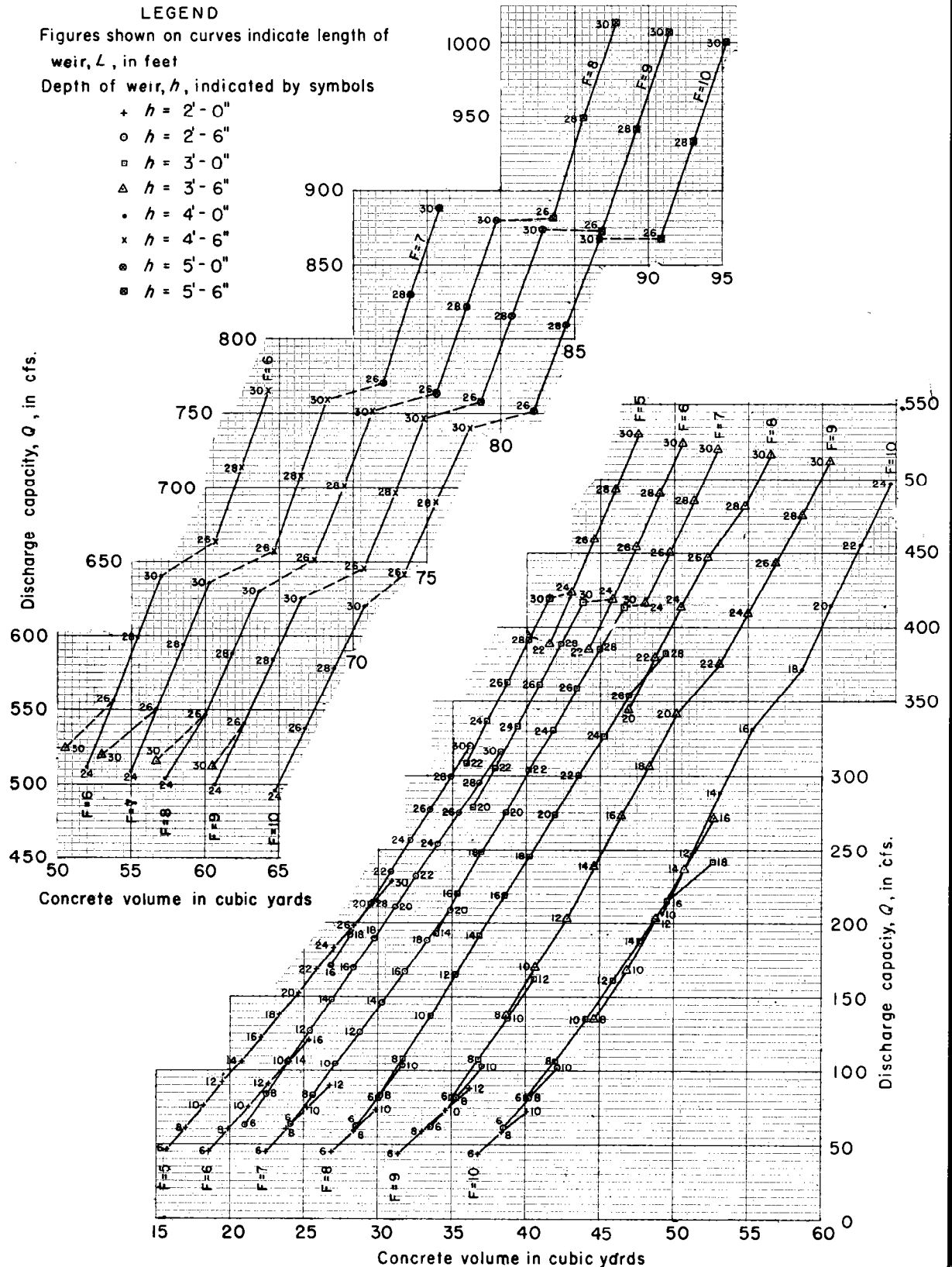
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ES-66

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DROP SPILLWAYS - TYPE B - MINIMUM CONCRETE VOLUME FOR VARIOUS DISCHARGES FOR NET DROPS, F, OF 5 TO 10 FEET AND WEIR LENGTHS, L, UP TO 30 FEET.



REFERENCE

U.S. DEPARTMENT OF AGRICULTURE
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ENGINEERING DIVISION - DESIGN SECTION

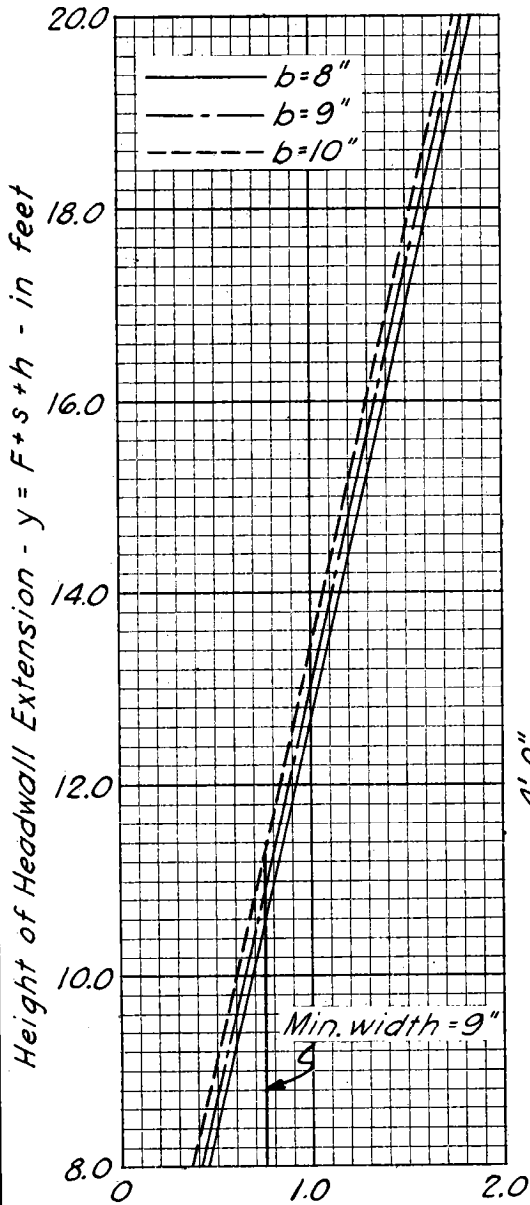
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SHEET 1 OF 1

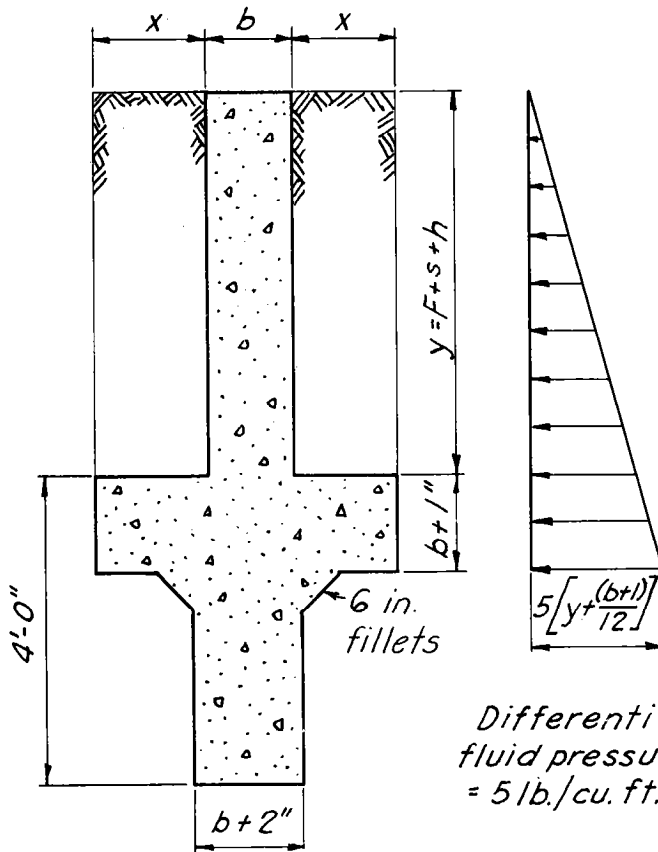
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DROP SPILLWAYS: REQUIRED WIDTH OF HEADWALL EXTENSION FOOTINGS FOR TYPE B



Minimum width of footing - x - in feet.

Note: Use values of x of 0.75, 1.00, 1.25 etc. (i.e. in even increments of 0.25 ft.)



Differential fluid pressure = 5 lb./cu. ft.

HEADWALL EXTENSION

REFERENCE

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ES-48

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Hydraulic Design of Type C Drop Spillways

The nomenclature associated with the type C drop spillway is given in ES-111, page 5-18. The hydraulic design is illustrated by examples beginning on page 5-23.

The type C drop spillway was developed for use in locations where type B drop spillways are considered inadequate. These locations include the following situations:

1. Continuous flow;
2. Long durations of flow at discharges nearly equal to design discharge;
3. High tailwater; and
4. Values of h/F greater than 0.5.

Limitations of Type C Drop Spillways

Type C drop spillways were developed by model studies.* These model studies were limited to a range of values of

1. $0.1 \leq \frac{h}{F} \leq 1.43$
2. $L \geq 1.5 d_c$
3. $t \geq 1.75 d_c$

where h is the design head over the crest, ft

F is the vertical distance from the crest of the spillway to the top of the end sill, ft

L is the length of spillway crest, ft

t is the tailwater depth above the transverse sill, ft

d_c is defined in the next paragraph

Values of d_c , ft

The parameter d_c is used in the determination of various dimensions of the drop spillway which are set by the hydraulic design. The critical depth d_c is that critical depth corresponding to the capacity-without-freeboard Q_s in the weir notch of the drop spillway. The value of d_c corresponding to various discharges for rectangular sections are given on the line charts of ES-111, page 5-19.

Design Discharge Q_r , cfs

Design discharge Q_r is that discharge the structure is required to convey with a freeboard. It is determined from hydrologic data, reservoir routing, and economic considerations. The hydrologic aspect of this determination is given in the National Engineering Handbook, Section 4, Hydrology.

* St. Anthony Falls Hydraulic Laboratory, Technical Paper No. 15, Series B, Straight Drop Spillway Stilling Basin, by Charles A. Donnelley and Fred W. Blaisdell.

Required-Capacity-Without-Freeboard Q_{fr} , cfs

The required-capacity-without-freeboard Q_{fr} is that discharge the structure must convey without freeboard. Knowing this required capacity Q_{fr} will enable the designer to select the structure with sufficient capacity-without-freeboard Q_s .

$$Q_{fr} = (1.10 + 0.01 F)Q_r$$

where Q_r = design discharge, cfs

F = vertical distance between the crest of the spillway and the top of transverse sill, ft

Capacity-Without-Freeboard Q_s , cfs

The capacity-without-freeboard Q_s of any hydraulic structure is equal to the maximum discharge the structure is capable of conveying without overtopping. It is determined solely by the size of the structure and its operating conditions. The capacity-without-freeboard Q_s must be equal to or greater than the required-capacity-without-freeboard Q_{fr} .

$$Q_s \geq Q_{fr}$$

The capacity-without-freeboard $Q_s = q_s L$ with and without high tailwater is given on ES-111, page 5-20. The effect of submergence of the crest on the capacity-without-freeboard is reflected in the graph and is in accordance with Figure 3.4, page 3.17. Thus, the capacity-without-freeboard Q_s sometimes depends on the tailwater depth.

Required Tailwater Depth $t \geq 1.75 d_c$

Tailwater depths over the transverse sill are determined by computing water surface profiles.

The tailwater depth over the transverse sill t must be greater than or equal to $1.75d_c$ to prevent excess scour in the downstream bed and banks. Sufficient tailwater depth over the transverse end sill can always be obtained by increasing the value of F; that is, by lowering the apron and transverse sill.

Length of Stilling Basin Apron L_B

The tailwater depth t , the value of F, and the values of h are the parameters required in the determination of apron length L_B . The minimum length of the stilling basin L_B is given graphically by ES-111, page 5-21.

Values along the right side of the graph represent submergence of the crest of $0.7d_c$. For submergence of the crest greater than $0.7d_c$, use a value of L_B equal to that L_B obtained for a submergence of the crest of $0.7d_c$. Thus, increasing the tailwater depth over the crest of the spillway greater than $0.7d_c$ does not require that L_B be increased more than that computed for $0.7d_c$.

Values of $\frac{h}{t} > 0.857$ (Note that $\frac{h}{t} = \frac{1.5d_c}{1.75d_c} = 0.857$) are impermissible because they represent tailwater depths which are smaller than that which is required.

It is required that the value of $\frac{h}{F} < 1.43$. The value of $\frac{h}{F} = 1.43$ is a maximum value of $\frac{h}{F}$ tested by models. When $\frac{h}{F} = 1.43$, the minimum tail-water depth $1.75d_c$ causes a submergence of the crest of $0.7d_c$. Because of this, the minimum value of F is $1.05d_c$.

The length of the stilling basin may be increased from the minimum.

Location of Floor Blocks L_f

The distance L_f between the headwall and the floor blocks is given graphically by ES-111, page 5-22. The distance L_f is required to assure that the trajet of the nappe will be upstream from the floor blocks. When this distance is too small, a high boil occurs because of the floor blocks and the floor blocks are ineffective in the dissipation of kinetic energy.

If, for some reason, the length of the apron L_B is increased above the minimum amount, the distance L_f from the headwall to the floor block should not be increased.

The minimum distance between the floor block and the transverse sill, $L_B - L_f = 1.75d_c$, may be increased. This distance permits the reduction of turbulence downstream from the floor blocks.

Height of Floor Blocks $0.8d_c$

The heights of the floor blocks and the end sill are significant in the performance of the stilling basin. The primary function of the floor blocks is to control bank or lateral erosion of the channel downstream from the spillway. The recommended height of floor blocks is $0.8d_c$. This may be varied slightly to permit the use of even dimensions.

Floor Block Width $(0.4 \pm 0.15)d_c$

The floor block width and the spacing of the floor blocks are important parts of the design. Floor blocks which are too wide do not function properly in dissipating the kinetic energy and require high sidewalls. The recommended width of floor blocks (in a direction transverse to the flow) is $0.4d_c$. This may be varied slightly to permit the use of even dimensions but the floor block width should be within the interval $(0.4 \pm 0.15)d_c$.

Floor Block Length $(0.4 \pm 0.15)d_c$

The recommended length (in the direction of flow) of floor blocks is $0.4d_c$. This dimension effects the required dimension between the floor blocks and the end sill. This distance is required for energy dissipation of the flow which has been divided by the floor blocks. The length may be varied slightly to permit the use of even dimensions.

Floor Block Spacing

Floor blocks which occupy over 60 percent of the transverse length of the stilling basin tend to function like a solid sill. If they occupy less than 50 percent of the transverse length of the stilling basin, they function less efficiently. A half space ($0.2d_c$) shall be allowed adjacent to the sidewalls, thus, no floor block will be placed adjacent to the sidewalls.

Longitudinal Sills

Longitudinal sills may be used for structural purposes. Their width will be equal to or less than the floor block width, and their height is determined from structural requirements. They are not to be spaced between the floor blocks. Longitudinal sills are neither beneficial nor harmful hydraulically.

Transverse Sill Height $0.4d_c$

The transverse sill prevents erosion in the channel bed immediately downstream from the drop spillway. The lowest height of the transverse sill was selected from model study to reduce the tailwater requirement. The recommended height of the transverse sill is $0.4d_c$. This height may be increased slightly to permit the use of even dimensions.

Sidewall Height ($t + 0.85d_c$)

The sidewall must extend above the tailwater to prevent overtopping of the sidewalls. The water surface in the stilling basin fluctuates considerably. The floor blocks and end sills cause boils and standing waves. The highest boils are $0.60d_c$ above the tailwater. The recommended minimum height of the sidewall at the end sill is $t + 0.85d_c$, but not greater than $F + h$. From the standpoint of hydraulics, the top of the sidewalls may be level and have the recommended height.

Wingwalls

Wingwalls are set at an angle of 45° with the centerline of the basin. The top of the wingwall should have a slope not steeper than 1 to 1. The length of the wingwall is usually controlled by the backfill slope and should be sufficient to intersect the backfill slope in the horizontal plane at the top of the transverse sill.

Approach Channel

Certain approach channel conditions are necessary for this type of drop spillway to function properly. These conditions are

1. The bottom of the approach channel must be level and have the same elevation as the crest of the drop spillway for a minimum distance of $6d_c$ upstream from the crest. When the bottom of the approach channel is below the crest of the nappe, it will not have the same trajectory and trajet as that used in the model study. This could cause the nappe to strike the floor too close to the floor blocks. Lowering the approach channel bottom a distance of $0.1d_c$ will cause a significant and unsatisfactory change in the position of the nappe trajectory.

2. The dikes covering the upstream face of the headwalls are essential for the proper functioning of this structure. See ES-111, page 5-18. It is preferable hydraulically, that the slope of the dike along the face of the headwall be steeper than a 2:1 slope. When this slope is flatter than 2:1, the discharge over the weir is concentrated in the central portion of the stilling basin.

When dikes are omitted in wide channels or when the toe of dike at the upstream face of the headwall is not at the weir notch corner, a significant end contraction of flow occurs in the weir section. This causes an unfavorable distribution of discharge in the stilling basin and poor stilling basin performance.

If, for some reason, the bottom width of the approach channel is equal to the length of the weir notch, no dikes will be required, provided the side slope of the channel at the structure is not flatter than 2:1.

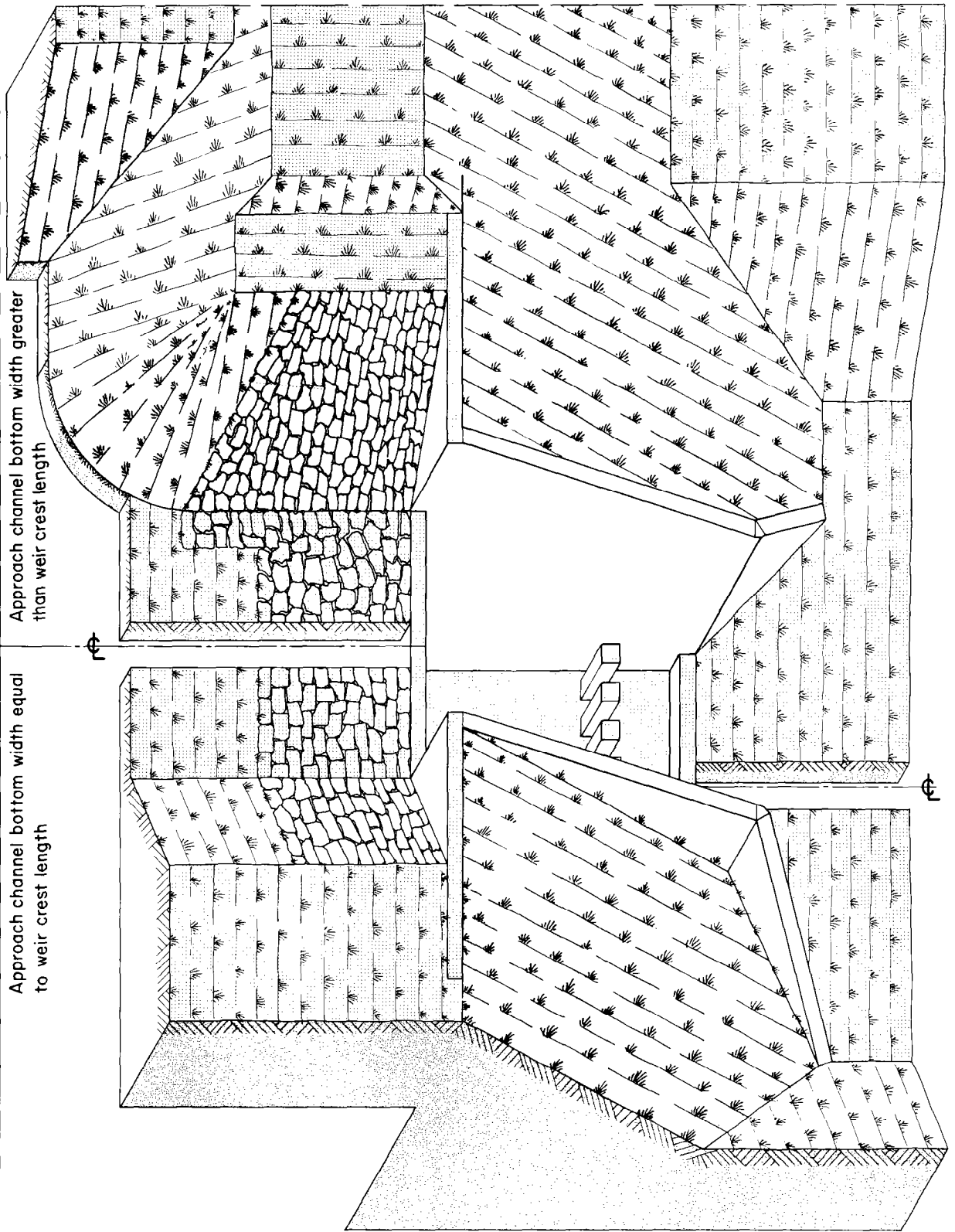
3. The channel bottom and the dikes covering the upstream face of the headwall require riprap to prevent their erosion. The recommended use of riprap and the specifications for riprap size and weight are given on pages 2.4, 2.5 and ES-79, page 2.6. Of course, concrete paving may be used in place of riprap.
4. The general channel alignment, both upstream and downstream from the drop spillway, is prescribed on pages 2.1 and 2.2.

Aeration Under Nappe

No provision for aeration of the nappe is required unless two or more headwall buttresses are used. The recommended approach channel conditions insure sufficient end contraction of the flow to permit ample aeration for ordinary weir lengths. The nappe over that portion of the weir sections supported by buttresses require provisions for aeration. Proper aeration can be provided by the construction of holes in the top of the buttresses. The determination of the size of these openings is given in ES-81, page 3.3. It is recommended that the top of buttresses be placed six inches below the crest of the weir.



DROP SPILLWAYS: HYDRAULIC DESIGN, STRAIGHT DROP SPILLWAY—Type C



Approach channel bottom width greater than weir crest length

Approach channel bottom width equal to weir crest length

REFERENCE

St. Anthony Falls hydraulic laboratory technical paper No. 5, series B Straight Drop Spillway Stilling Basin, by Charles A. Donnelly and Fred. W. Blaisdell.

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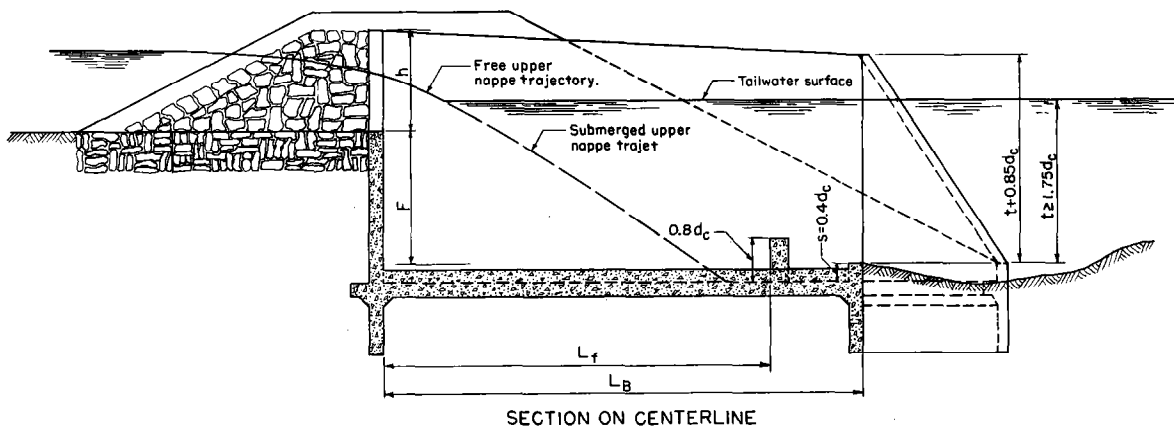
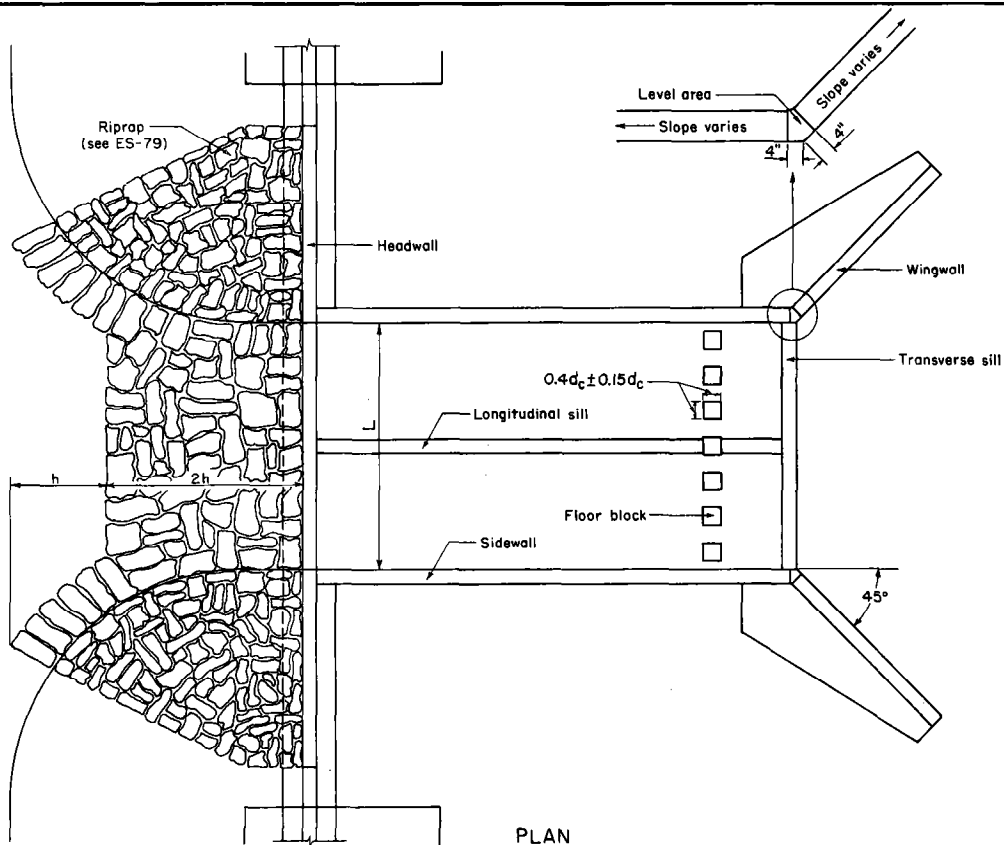
STANDARD DWG. NO.

ES-111

SHEET 1 OF 6

DATE 2-9-59

DROP SPILLWAYS: HYDRAULIC DESIGN, STRAIGHT DROP SPILLWAY STILLING BASIN—Type C.



Symbols :

- d_c = Critical depth for the weir section of the spillway
- F = Vertical distance from top of transverse sill to spillway crest
- h = Depth of weir
- L = Crest length = stilling basin width
- L_B = Minimum stilling basin length
- L_f = Distance from downstream face of headwall to upstream face of floor blocks
- Q_S = Maximum discharge structure is capable of conveying without overtopping: $Q_S = LQ_S$
- s = Height of transverse sill
- t = Vertical distance from tailwater surface to top of transverse sill

REFERENCE

St. Anthony Falls hydraulic laboratory technical paper No. 5, series B Straight Drop Spillway Stilling Basin, by Charles A. Donnelly and Fred W. Blaisdell.

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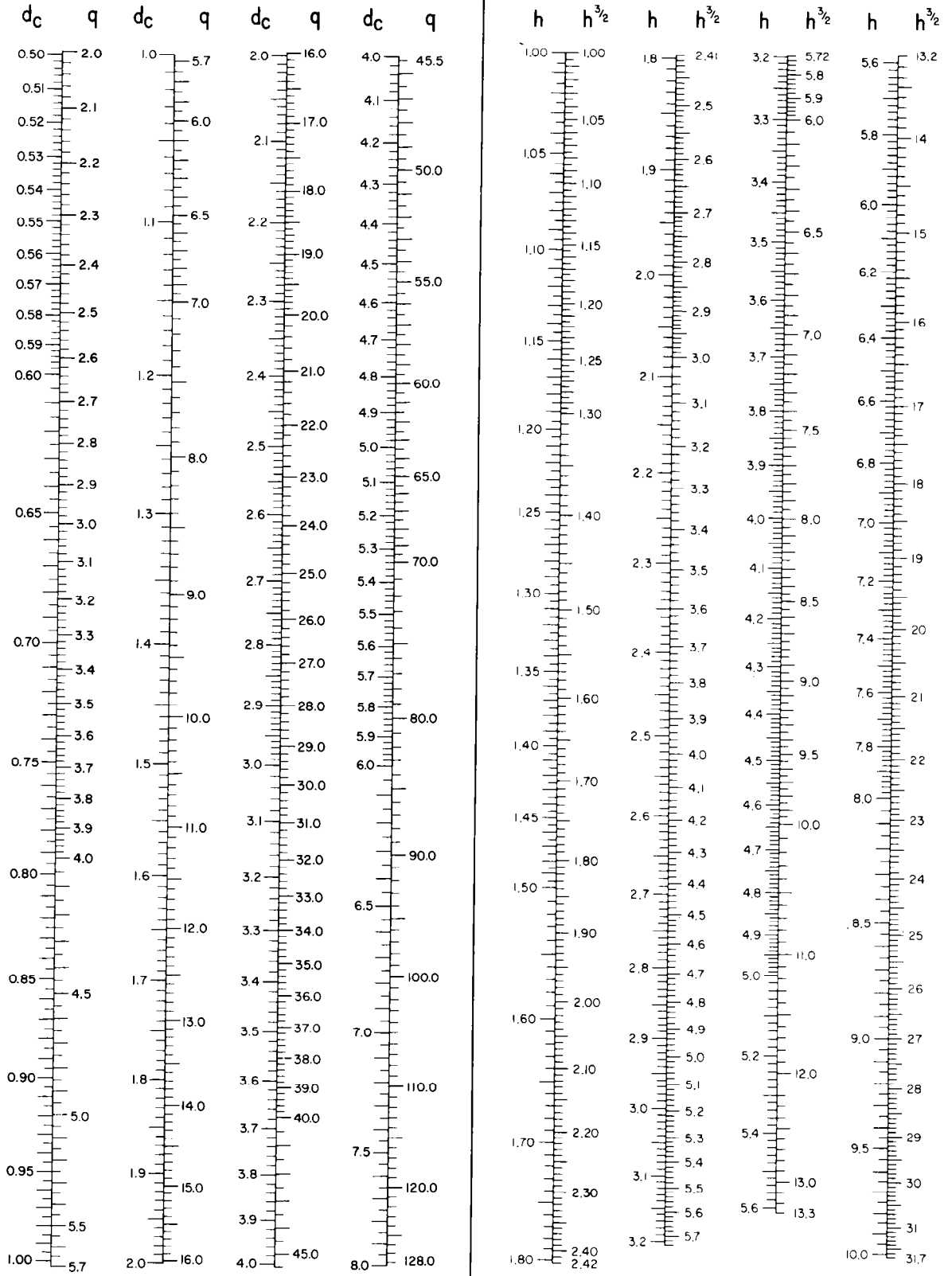
ES- 111

SHEET 2 OF 6

DATE 1-28-58

DROP SPILLWAYS:

TYPE C
 d_c vs. q and h vs. $h^{3/2}$



REFERENCE

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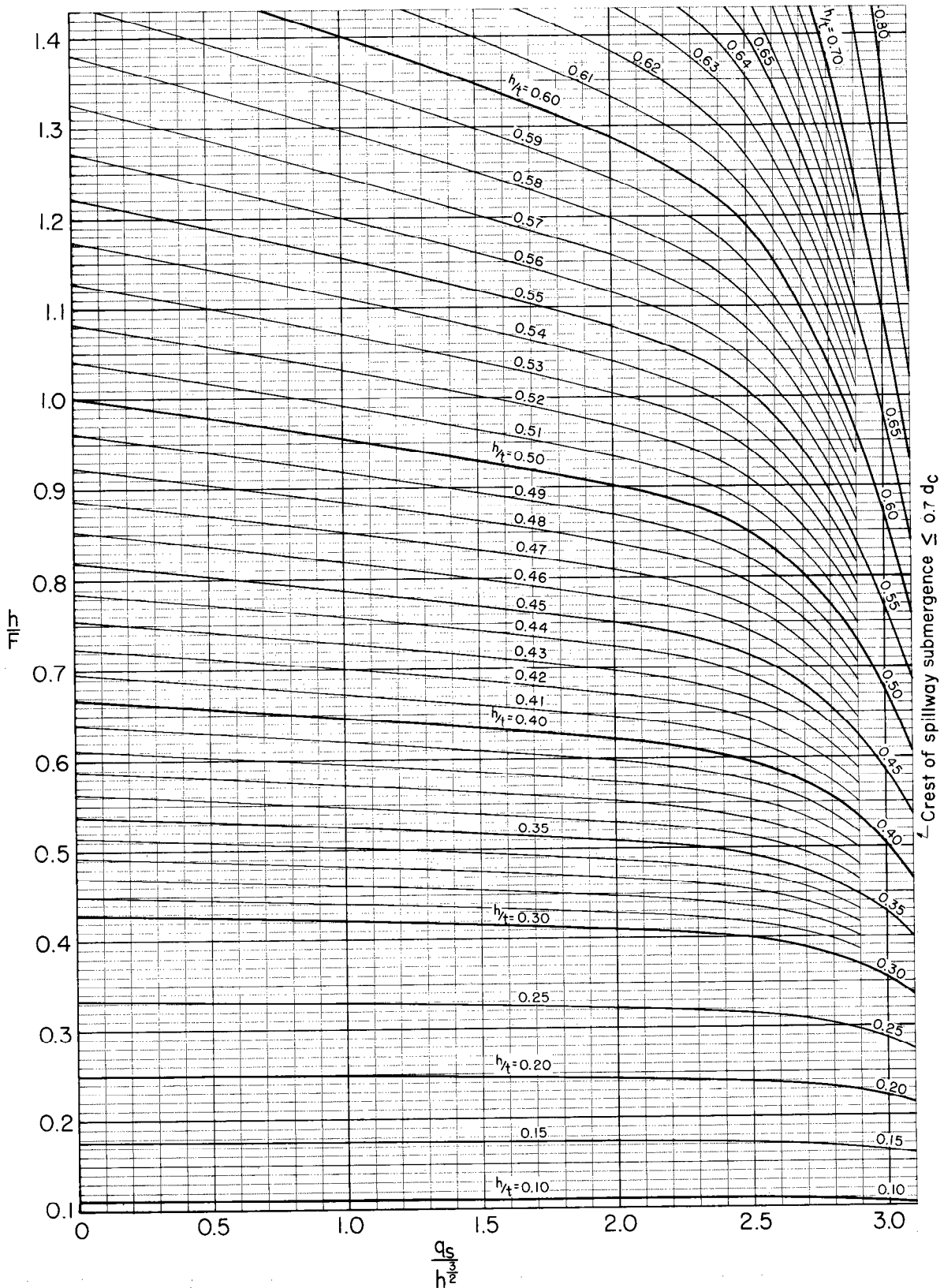
ES- 111

SHEET 3 OF 6

DATE 5-28-58

DROP SPILLWAYS: Type C

Capacity without freeboard per foot length of weir q_s

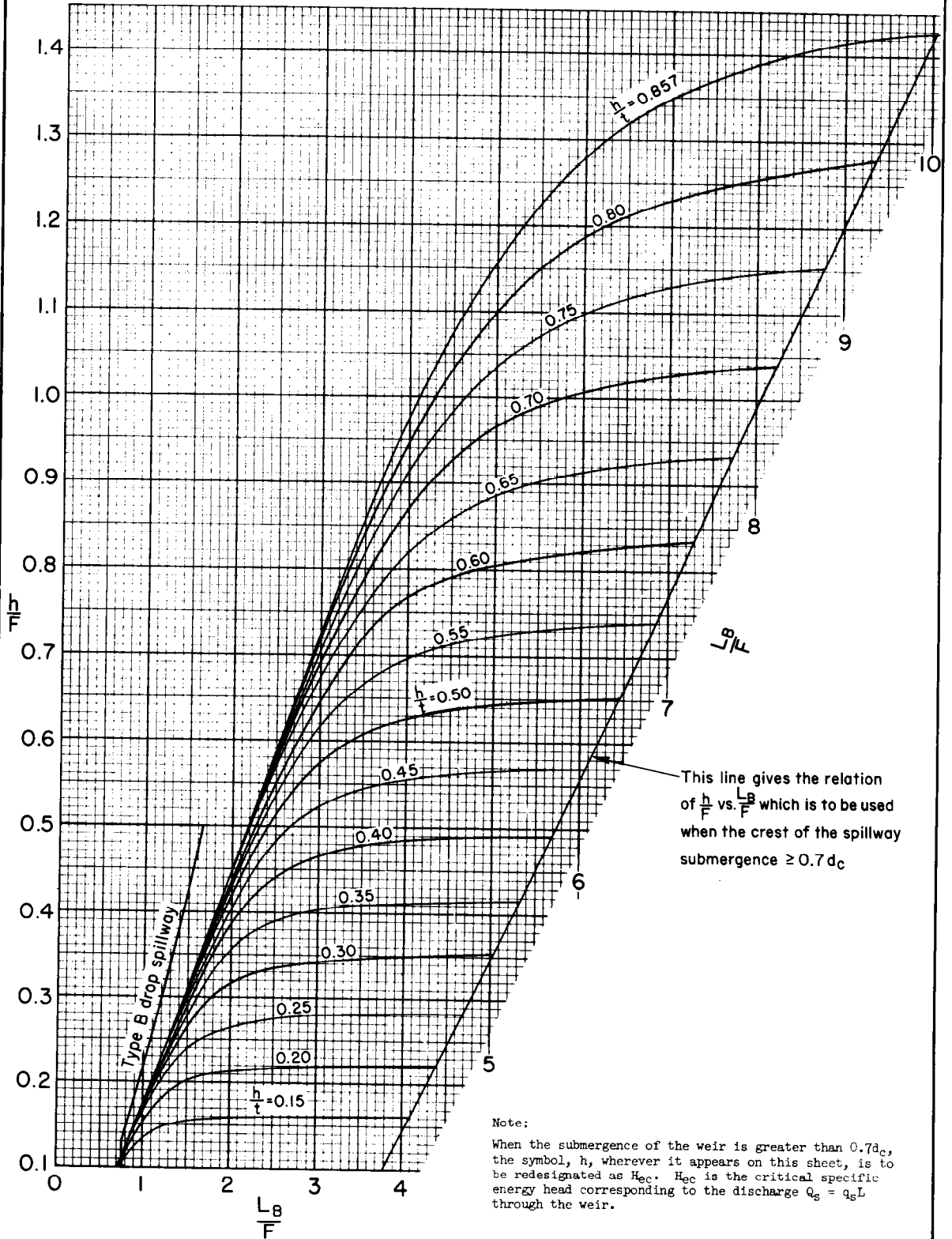


REFERENCE
Data taken from page 3.17
figure 3.4

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STANDARD DWG. NO.
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DROP SPILLWAYS: Type C—Apron length L_B



Note:
 When the submergence of the weir is greater than $0.7d_c$, the symbol, h , wherever it appears on this sheet, is to be redesignated as H_{ec} . H_{ec} is the critical specific energy head corresponding to the discharge $Q_c = q_c L$ through the weir.

REFERENCE

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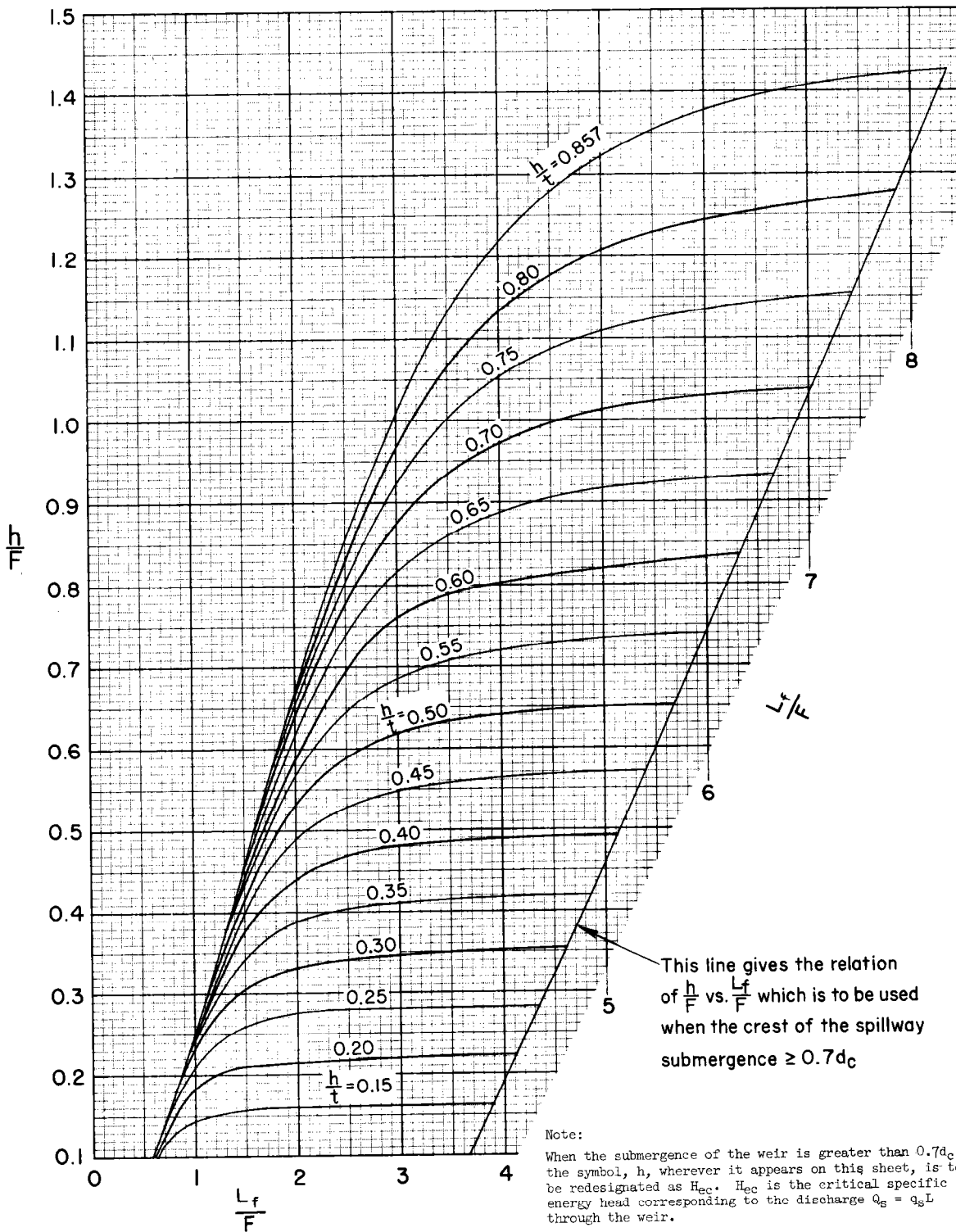
ES-111

SHEET 5 OF 6

DATE 5-28-58

Revised 4-68

DROP SPILLWAYS: Type C— Distance to floor blocks L_f



REFERENCE

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Design Examples

These are strictly academic examples and are only complete insofar as they illustrate the hydraulic design of the Straight Drop Spillway - Type C.

Given: The design discharge $Q_r = 745$ cfs. The approach channel is flat and has a bottom width of 44.0 ft. The maximum total energy head in the approach channel at the weir notch is limited to $H_e = 4.0$ ft. The drop to be controlled in the channel grade is 8.0 ft. The depth of flow in the downstream channel is 4.0 ft. Two buttresses and longitudinal sills are used in the design.

- Determine:
1. Weir notch depth.
 2. Vertical distance t from the top of the transverse sill to the tailwater surface.
 3. The vertical distance F from the top of the transverse sill to the crest.
 4. The required-capacity-without-freeboard Q_{fr} , the crest length L , and the capacity-without-freeboard Q_s .
 5. Approach channel hydraulic requirements.
 6. Minimum transverse sill height s .
 7. Stilling basin length L_B .
 8. Location, width, spacing, and height of floor blocks.
 9. Minimum sidewall height.
 10. Wingwall length.
 11. Size and location of aeration holes in buttresses.

- Solution:
1. Set the weir notch depth equal to the maximum allowable total energy head in the approach channel, or $h = 4.0$ ft. Then, $d_c = 2/3h = (0.667)(4.0) = 2.67$ ft.
 2. $t \geq 1.75 d_c = (1.75)(2.67) = 4.67$ ft
 3. If the controlled drop is 8.0 ft and the tailwater depth is 4.0 ft, the vertical distance from the tailwater to the crest is 4.0 ft. Then, $F = 4.0 + t = 4.0 + 4.67 = 8.67$ ft. The required tailwater depth places the top of the transverse sill 0.67 ft below the downstream channel grade.
 4. $Q_{fr} = (1.10 + 0.01F)Q_r$
 $= 1.10 + (0.01)(8.67)745 = 884$ cfs
 Since the weir is submerged less than $0.7 d_c$, the value of $\frac{q_s}{h^{3/2}} = 3.1$ (from ES-111, page 5-20).
 $q_s = 24.8$
 $L = \frac{884}{24.8} = 35.6$ ft -- use 36.0 ft
 $Q_s = (36.0)(24.8) = 893$ cfs

5. The bottom width of the approach channel must be reduced to 36.0 ft at the spillway crest. The channel side slopes at the headwall must be 2:1. This is accomplished by the addition of a conical shaped fill between the upstream face of the headwall and the side slope of the 44.0 ft approach channel. The approach channel is then riprapped in accordance with ES-79, page 2.6.

6. The minimum transverse sill height.

$$s = 0.4 d_c = (0.4)(2.67) = 1.07 \text{ ft} \quad \text{-- use } 1' - 0''$$

7. Stilling basin length L_B is determined from ES-111, page 5-21.

$$\frac{h}{F} = \frac{4.0}{8.67} = 0.461$$

$$\frac{h}{t} = \frac{4.0}{4.67} = 0.857$$

$$\frac{L_B}{F} = 2.04 ; L_B = (8.67)(2.04) = 17.76 \quad \text{-- use } 17' - 9''$$

8. The distance from the downstream face of the headwall to the upstream face of the floor blocks L_F is determined from ES-111, page 5-22.

$$\frac{h}{F} = 0.461$$

$$\frac{h}{t} = 0.857$$

$$\frac{L_F}{F} = 1.50 ; L_F = (8.67)(1.50) = 13.00 \text{ ft}$$

The blocks are square in plan. The width $w = 0.4 d_c = (0.4)(2.67) = 1.07 \text{ ft}$ (use 1' - 0"). Twenty blocks would occupy 20/36 or 55 percent of the basin width. The blocks are spaced 0' - 9 1/2" apart with the face of the outside blocks 0' - 5 3/4" from the sidewall.

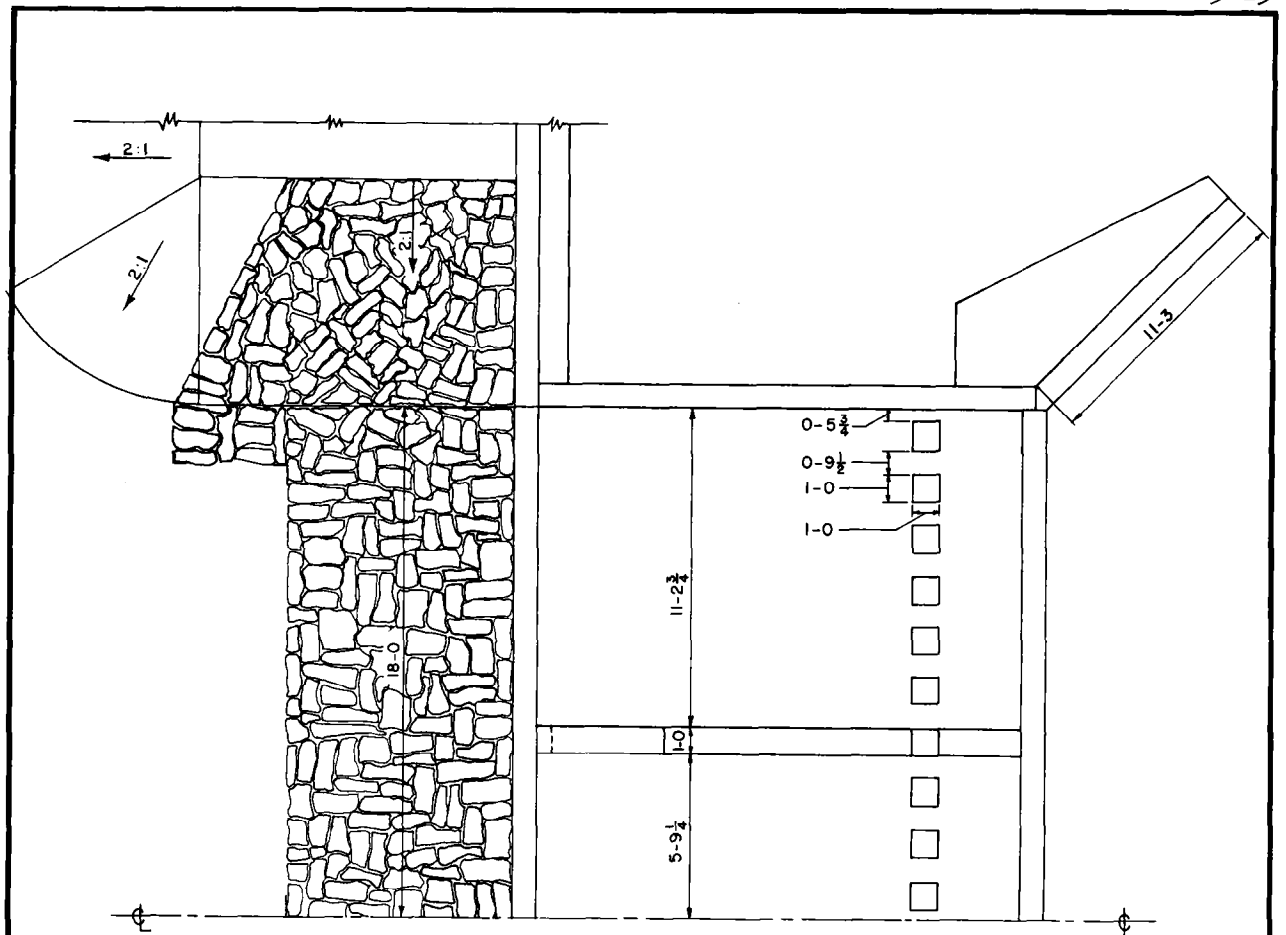
$$\text{Height of blocks} = 0.8 d_c = 2.14 \text{ ft.} \quad \text{-- use } 2' - 0''$$

9. The sidewall height above the top of the transverse sill is $t + 0.85 d_c = 4.67 + (0.85)(2.67) = 6.94 \text{ ft}$ (use 7' - 0").

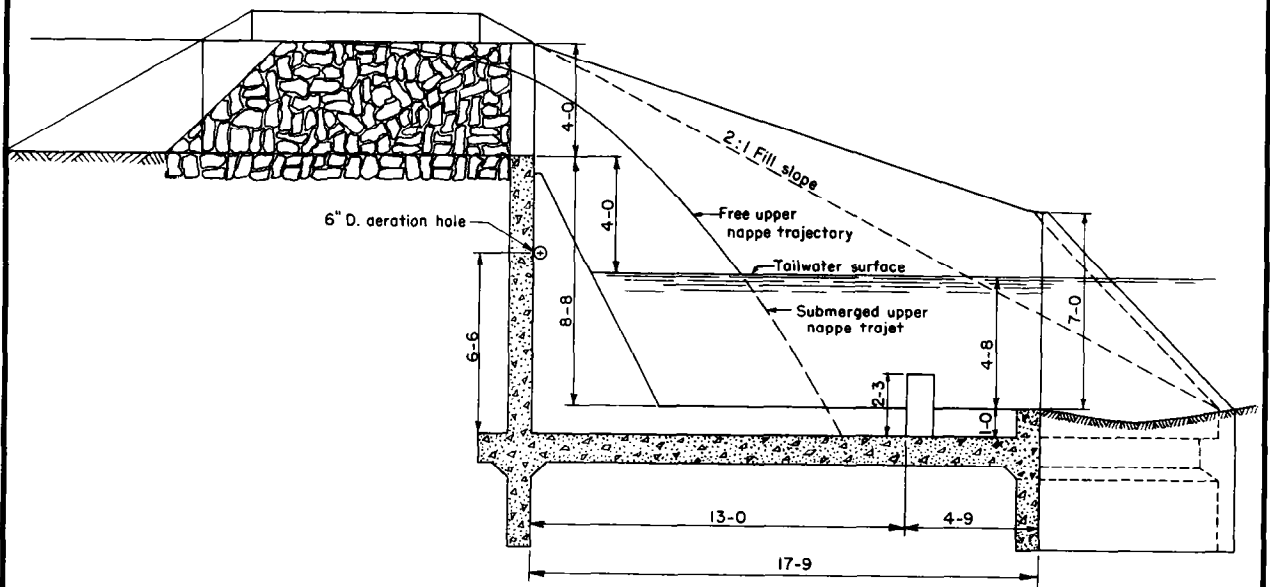
10. The 2:1 fill slope or the dike is 3.96 ft above the top of the transverse sill (end elevation of the top of the wingwall) at the junction of the wingwall and sidewall. The wingwall length is

$$\frac{(2)(3.96)}{0.707} = 11.20 \text{ ft (use } 11' - 3'')$$

11. The 12' - 6 1/2" weir length between the centers of the two buttresses is aerated by 6-inch diameter holes in each buttress. The 6-inch diameter holes will provide a differential pressure between atmospheric and pressure under the nappe of 0.17 ft (determined by ES-81, page 3.3). This does not influence the headwall design. The aeration holes are placed above the tailwater. (Use 6' - 6" above the floor of the stilling basin.)



HALF PLAN



SECTION ON CENTERLINE

Figure 1. — Design example: Straight drop spillway—Type C

Given: The required capacity-without-freeboard is $Q_{fr} = 1450$ cfs.
 The maximum total energy head in the approach channel at the weir, measured from the weir crest, cannot be greater than 5.0 ft. The controlled drop is $F = 5.0$ ft. and tailwater depth is $t = 9.0$ ft.

Determine:

1. Weir notch depth, h .
2. Crest length, L , and the capacity-without-freeboard Q_s .
3. The approach channel hydraulic requirements.
4. Minimum transverse sill height s .
5. Stilling basin length L_B .
6. Location, width, spacing and height of floor blocks.
7. Minimum sidewall height.

Solution: 1. Set the weir notch depth, h , equal to the maximum allowable total energy head in the approach channel at the weir, measured from the weir crest, thus, $h = 5.0$ ft.

2. a. Determine the crest length of weir, L , and critical depth, d_c .

$$\frac{h}{F} = \frac{5.0}{5.0} = 1.0 \text{ and } \frac{h}{t} = \frac{5.0}{9.0} = 0.556$$

From ES-111, page 5-20

$$\frac{q_s}{h^{3/2}} = 2.6$$

$$q_s = (5^{3/2})(2.6) = 29.07 \text{ cfs.}$$

From ES-111, page 5-19

$$d_c = 2.97 \text{ ft.}$$

$$L = \frac{Q_{fr}}{q_s} = \frac{1450}{29.07} = 49.88 \text{ ft. -- Use 50 ft.}$$

b. The capacity-without-freeboard, Q_s , when $L = 50$ ft. is

$$Q_s = q_s L = (29.07)(50) = 1453.5 \text{ cfs.}$$

3. The approach channel bottom width may be set at 50.0 ft. with side slope $z = 2$. (See Approach Channel, page 5-14).

4. Determine the minimum transverse sill height, s .

$$s = 0.4d_c$$

$$s = (0.4)(2.97) = 1.19 \text{ ft. -- Use 1' - 3"}$$

5. The stilling basin length L_B is determined from ES-111, page 5-21.

a. Ascertain if the submergence of the weir crest is greater than $0.7d_c$.
 The tailwater which causes submergence of the weir of $0.7d_c$ is

$$F + 0.7d_c = 5 + 0.7(2.97) = 7.08 \text{ ft.}$$

Since the tailwater is 9.0 ft., submergence is greater than $0.7d_c$.

When designing Type C drop spillways having greater than $0.7d_c$ submergence, the symbol, h , wherever it appears on sheets 5 and 6 of ES-111, should be redesignated as H_{ec} . H_{ec} is the critical specific energy head corresponding to the unit discharge, q_s , through the weir.

- b. Determine stilling basin length, L_B .

$$H_{ec} = \frac{3}{2}d_c = 4.46 \text{ ft.}$$

$$\frac{H_{ec}}{F} = \frac{4.46}{5.0} = 0.892$$

From ES-111, page 5-21, read at the $0.7d_c$ submergence curve, the values

$$\frac{L_B}{F} = 7.54 \text{ when } \frac{H_{ec}}{F} = 0.892$$

Since $\frac{H_{ec}}{t} = \frac{4.46}{9.0} = 0.496$ represents submergence greater than $0.7d_c$, the value of $\frac{L_B}{F} = 7.54$ is satisfactory,

(see Length of Stilling Basin Apron L_B , page 5-12).

$$L_B = 7.54(5) = 37.7 \text{ ft. -- Use } 37' - 9''$$

6. The distance from the downstream face of the headwall to the upstream face of the floor blocks L_f is determined from ES-111, page 5-22.

$$\frac{L_f}{F} = 6.52 \text{ when } \frac{H_{ec}}{F} = 0.892 \text{ at the } 0.7d_c \text{ submergence curve.}$$

$$L_f = 32.6 \text{ ft. -- use } 32' - 8''$$

The floor blocks are square in plan. The side width $w = 0.4d_c = (0.4)(2.97) = 1.19 \text{ ft. -- use } 1' - 3''$

Twenty-two blocks will occupy 55 percent of the basin width. The blocks are spaced $1' - 0''$ apart with the face of the outside blocks $0' - 9''$ from the sidewall. Height of blocks = $0.8d_c = 2.38 \text{ ft. -- use } 2' - 6''$

7. The sidewall height above the top of the transverse sill is

$$t + 0.85d_c = (9.0) + (0.85)(2.97) = 11.52 \text{ ft. -- use } 10' - 0'' \text{ (the maximum sidewall height is } F + h = 5 + 5 = 10' - 0'').$$

