BOX INLETS

Each of the drawings, ES-90, ES-91, ES-92, and ES-93, pages 2.31, 2.55, 2.79, and 2.95, pertains to a different variation of box inlets. Nomenclature is given on the drawings.

On developing the spillway crest onto a plane (i.e., unfolding the sidewalls into the same plane as the endwall) a rectangular weir having a crest length of (2 B + W) will be obtained for the box inlets illustrated by ES-90 and the corresponding value for ES-91 is (2 B + W + 1). The weir crest of the type illustrated by ES-91 has a six-inch radius rounding on the downstream edge. The development, onto a plane, of the weir crests of box inlets illustrated by ES-92 and ES-93 yields a trapezoidal weir with a level crest length of (2 B + W) and 3 to 1 sloping sides and the corresponding value for ES-93 is (2 B + W + 1). For convenience in presentation, the variations of box inlets are classified in the following manner.

Drawing No.	Classification of variations of box inlets	Page
ES-90	flat-rectangular weir box inlet	2.31
ES-91	rounded-rectangular weir box inlet	2.55
ES-92	flat-trapezoidal weir box inlet	2.79
ES-93	rounded-trapezoidal weir box inlet	2.95

Box inlets are usually used in association with large embankments or excavations when wave freeboard requirements are small. In some instances, they are also used because a physical condition requires the head over the crest to be restricted to a small value. Elsewhere they may be used to facilitate drainage of perched water or to provide an outlet for a subsurface pipe.

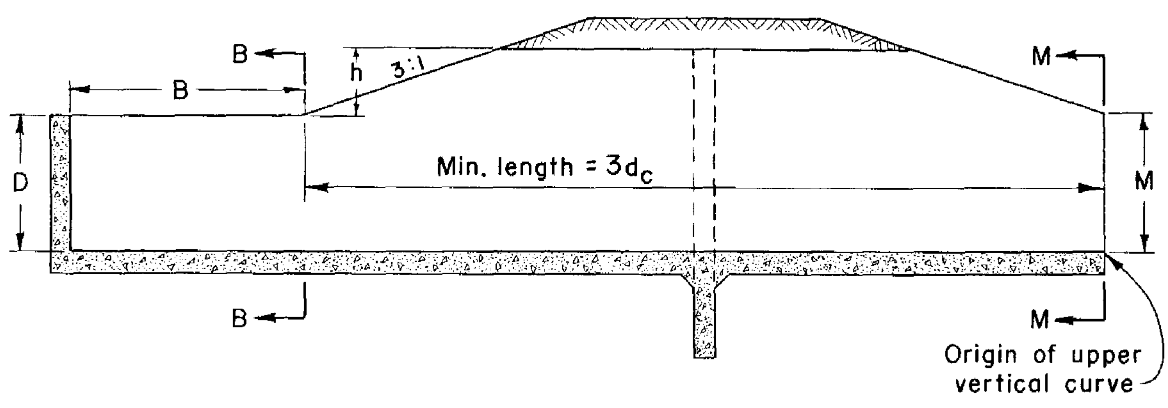

FIGURE 5A

Design Criteria of Box Inlets. The nappe over the box inlet crest falls free of the sidewalls and endwall. The space between the nappe and its sidewall is partly or wholly filled with water having a helical motion about a horizontal axis. There is considerable disturbance in the water surface and uneven distribution of velocities and discharges in the basin immediately downstream from section B. (See Fig. 5A.) The flow will have acceptable velocities and discharge distribution at the entrance to the steep channel, section M, if that portion of the inlet from section B to section M has

a. a prismatic rectangular channel cross section with a level floor

b. a minimum length of 3 d_c

This critical depth d_c is associated with the capacity without freeboard Q_{mi} in this prismatic portion of the inlet. These two criteria are based on preliminary model studies.[1]

The head-discharge relationship is dependent on the type of flow condition which exists for the discharge conveyed by the box inlet. An understanding of flow conditions which exist for a given head H_e over the crest is important in determining head-discharge relationship. Flow through a box inlet is either of two flow conditions, both of which may be subdivided into two subcategories. A qualitative description of these flow conditions follows the brief outline.

I. A free-flow condition exists at the crest of the box inlet. In other words, the discharge through the box inlet is not dependent on the depth of the box D. This discharge may be determined by only the crest dimensions B, W, and H_e; i.e., the discharge is controlled by the crest.

1. The discharge over the crest of the inlet is dependent only on the length of the developed weir (2 B + W) or (2 B + W + 1) as the case may be, and the head over the weir H_e and is determinable by the weir formula. Here only two dimensions, H_e and the total length of the developed weir, are required to determine the discharge.

2. The discharge over the crest of the inlet is not determinable by the weir formula but is dependent on the values of H_e, W, and B. The discharge is less than that which would be predicted by the weir formula. This situation arises because the head over the crest H_e is so great that the flow over the crest behaves more as an orifice flow and the flow in the opening between the sidewalls above the crest may be loosely compared to flow through a weir with a length W. Three dimensions, H_e, B, and W, are required to determine the discharge for this flow condition.

II. Submerged flow conditions exist at the crest of the inlet. This makes the discharge through the box inlet dependent on the value of D. Submerged flow conditions exist if the water-surface elevation downstream from the crest influences the discharge.

[1]Conducted by Mr. Fred W. Blaisdell, Hydraulic Engineer, ARS, St. Anthony Falls Hydraulic Laboratory.

1. The discharge is dependent, in part, on a high tailwater which results from a shallow box (i.e., small D) when the outflow from the downstream end of the box inlet is unsubmerged. The submergence at the crest is caused by a shallow basin in which the water-surface elevation at the upper end of the basin is sufficiently high to affect the discharge over the crest. In this case, if the depth of the box were increased sufficiently, free-flow conditions at the crest would be obtained. The four dimensions B, W, H_e, and D are required to determine the discharge of this flow condition.

2. The discharge is dependent, in part, on a high tailwater caused by channel conditions or obstructions downstream from the structure. This condition does not exist in a properly designed inlet for a chute spillway. It may occur in a box drop spillway.

Free-flow conditions exist at the crest of a box inlet whenever the tailwater downstream from the crest has no effect on the discharge. The tailwater in the basin will have no effect on the discharge when it has a sufficiently low surface elevation. When free-flow conditions exist at the crest of a box inlet, the dimension D can be increased without influencing the discharge Q; such a change would merely lower the elevation of the tailwater. Both subcategories of free-flow conditions have discharges dependent only on the values of the head over the crest H_e and the dimensions of the crest B and W. Thus, the crest of the box inlet is said to control the discharge when free-flow conditions exist at the crest. As the head over the crest H_e increases from zero, the discharge for free-flow conditions is defined by the weir formulas, Eq. 3.7, 3.8, 3.9, and 3.10, until the head H_e becomes large compared to W. Only the total value of $(2B + W)$ or $(2B + W + 1)$, as the case may be, and the value of H_e are the two values required to determine the discharge Q for free-flow conditions for subcategory 1 in which the weir formula is applicable.

When the head over the crest H_e is large compared to W, the weir formula predicts the discharge over the crest greater than the actual discharge Q. This actual discharge Q is dependent only on the three variables H_e, B, and W for free-flow conditions of subcategory 2 in which the weir formula is not applicable. The demarcation between the subcategories of free-flow conditions is given by the empirical relations Eqs. 3.7b, 3.8b, 3.9b, and 3.10b when the value of B/W is small.

Submerged flow conditions at the crest exist in a box inlet whenever the tailwater has an effect on the discharge over the crest of the inlet. Submergence is caused by a tailwater elevation about equal to or greater than the elevation of the crest of the inlet. The high tailwater may be caused by either a shallow box (i.e., a small value of D) or by channel conditions downstream from the inlet. The discharge of a box inlet with a submerged-flow condition at the crest but with a free-flow condition at its outlet is a function of the head over the crest H_e, the dimensions of the crest B and W, and the depth of the box inlet D. Thus four variables are required to define the discharge of a box inlet having a submerged flow condition caused by a shallow box depth D.

When the submerged flow condition is the result of a high tailwater caused by conditions other than a shallow depth D, the five variables H_e, B, W, D, and t, are required to determine the discharge Q. The variable t is the depth of the tailwater above the floor at the outlet section of the box inlet. Observe that the classification of flow conditions through a box inlet has been divided into categories according to the number of variables required to determine the head-discharge relationship. The determination of a discharge in a box inlet requires two to five variables (dimensions) according to the category of existing flow conditions.

Generally, if submergence at the crest occurs as a result of a shallow box, the various categories of flow will appear in the following order as the head over the crest is increased from zero: First, crest control in which the head-discharge relationship is determined by the weir formula; second, crest control in which the head over the crest H_e is large compared to the width W and the head-discharge relationship is not determinable by the weir formula; third, submergence at the crest as a result of a shallow box. Very often the flow will pass directly from the first to the third flow condition because the head H_e has not become great compared to W before the submergence of the crest occurs. This can happen when the dimension D is small.

When the approach channel to the box inlet is narrow, the discharge of the approach channel and box inlet is less than that of a wide channel and box inlet. Likewise, whenever the toe of the dike over the headwall of a rectangular inlet is near the crest, the head-discharge relationship is materially changed from that relationship for discharge-head having no dike effect.

Capacities. Box inlets to chutes should be proportioned to produce free-flow conditions at the crest. Therefore only the head-discharge relationship of box inlet having free-flow conditions are considered. The discharge-head relationship for the four variations of box inlets with various approach channel conditions are given in drawings ES-90, ES-91, ES-92, and ES-93. These values are based on the experimental model results of Fred W. Blaisdell and Charles A. Donnelly, Hydraulic Engineers, ARS, St. Anthony Falls Hydraulic Laboratory. The discharge-head relationship shown by these charts are only for free-flow conditions at the crest of the box inlet. The values of D_r as given by these charts are minimum values of the depth of the box inlet required to insure crest control. The value D_r may be increased from that shown without affecting the discharge Q. Decreasing the value of D_r from that shown will decrease the discharge and submergence at the crest will occur at the discharge Q shown by the chart.

The following weir formulas give the discharge-head over the crest relationship for only those box inlets having wide approach channels and no dike effect. Sheets 5, 6, and 7 of drawings ES-90, ES-91, ES-92, and ES-93 are a graphical solution of Eqs. 3.7, 3.8, 3.9, and 3.10, respectively. The weir formula for a flat-rectangular weir box inlet is

$$Q = 3.1\ (2\ B + W)\ H_e^{3/2} \quad \text{when} \quad 3.7a$$

$$0 < H_e \leqq 0.49\ W + 0.04\ B \quad \text{and} \quad 3.7b$$

$$0 < Q \leqq 5.5\ W^{5/2} \quad \text{and} \quad 3.7c$$

$$\psi^3 - 3\ \psi + 2 \left[\frac{W}{2\ B + W}\right]^2 = 0 \quad \text{where} \quad 3.7d$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi \geqq 1 \quad 3.7e$$

3.7

The weir formula for a 6-inch radius rounded-rectangular weir box inlet is

$$Q = 3.1\ (2\ B + W + 2)\ H_e^{3/2} \quad \text{when} \quad 3.8a$$

$$0 < H_e \leqq 0.49\ W + 0.04\ B + 0.51\ ; \quad (W \geqq 4\ \text{ft}) \quad \text{and} \quad 3.8b$$

$$0 < Q \leqq 5.5\ (W + 1)^{5/2} \quad \text{and} \quad 3.8c$$

$$\psi^3 - 3\ \psi + 2 \left[\frac{W + 1}{2\ B + W + 2}\right]^2 = 0 \quad \text{where} \quad 3.8d$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi \geqq 1 \quad 3.8e$$

3.8

The weir formula for flat-trapezoidal (z_o:1 side slopes) weir box inlets is

$$Q = 3.1\ (2\ B + W + 0.8\ z_o\ H_e)\ H_e^{3/2} \quad \text{when} \quad 3.9a$$

$$0 < H_e \leqq \frac{0.49\ W}{1 - 0.016\ z_o} + \frac{0.04\ B}{1 - 0.016\ z_o} \quad \text{and} \quad 3.9b$$

$$0 < Q \leqq 5.5\ W^{5/2} \quad \text{and} \quad 3.9c$$

$$\psi^3 - 3\ \psi + 2 \left[\frac{W}{2\ B + W + 0.8\ z_o\ H_e}\right]^2 = 0 \quad \text{where} \quad 3.9d$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi \geqq 1 \quad 3.9e$$

3.9

The weir formula for a 6-inch radius rounded-trapezoidal (z_o:1 side slopes) weir box inlet is

$$
\left.
\begin{aligned}
&Q = 3.1\ (2\ B + W + 2 + 0.8\ z_o\ H_e)\ H_e^{3/2} && \text{when} && 3.10a \\
&0 < H_e \leq \frac{0.49\ W}{1 - 0.016\ z_o} + \frac{0.04\ B}{1 - 0.016\ z_o} + \frac{0.51}{1 - 0.016\ z_o} \\
&\qquad\qquad\qquad\qquad (W \geq 4\ \text{ft}) && \text{and} && 3.10b \\
&0 < Q \leq 5.5\ W^{5/2} && \text{and} && 3.10c \\
&\psi^3 - 3\ \psi + 2 \left[\frac{W + 1}{2\ B + W + 0.8\ z_o\ H_e + 2}\right]^2 = 0 && \text{where} && 3.10d \\
&\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi \geq 1 && && 3.10e
\end{aligned}
\right\} 3.10
$$

where Q = the discharge for free-flow condition at the crest of the box inlet in cfs

H_e = the head over the crest of the box inlet in ft

W = inside width of the box inlet (distance between the sidewalls) in ft

B = inside length of the level portion of the crest on one side of the box inlet in ft

D_r = required depth of box inlet, distance from the crest to the floor, causing impending submerged-flow conditions at the crest in ft

z_o = side slope of crest of weir of the box inlet

Only Eq. 3.7 and ES-90 will be discussed, but the same discussion is applicable to Eqs. 3.8, 3.9, and 3.10 and ES-91, ES-92, and ES-93. Equations 3.7b and 3.7c give the intervals of values of H_e and Q in which the weir formula Eq. 3.7a for box inlets is applicable when D is chosen sufficiently large. The upper limit of H_e given by Eq. 3.7b is the greatest value of H_e for which the weir formula is applicable. Values of H_e greater than this upper limit of H_e represent a flow condition of the second subcategory listed under free-flow conditions at the crest. The limitation of the discharge Q imposed by Eq. 3.7c is the result of lack of experimental data to confirm the validity of Eq. 3.7a for the larger values of H_e associated with the large values of B/W. The depth D_r required to cause impending submergence at the crest of the box inlet is determinable by the cubic equation 3.7d. Equation 3.7e gives the root of Eq. 3.7d which is to be used.

The graphical solution of Eq. 3.7 is given on sheets 5, 6, and 7 of ES-90. The region represented by the graph is for free-flow conditions at the crest. Another type of graph would be required to represent flow conditions involving submergence at the crest. The clear portion of this graph defines the discharge in accordance with the weir formula Eq. 3.7a. The stippled region is for free-flow conditions for which the weir formula does not predict the proper discharge. Formulas for this region have not been included because of their complexity.

The validity of Eqs. 3.9 and 3.10 is partially confirmed by experimental results obtained by Mr. Neal E. Minshall[1] and the results obtained under the direction of Dr. Arno T. Lenz at the University of Wisconsin.[2]

Capacity. The capacity without freeboard Q_{mi} of a box inlet having free-flow conditions at the crest, a wide approach channel, and no dike effect is determined by the dimensions h, B, D, W, and M of the inlet. The values of h, D, B, and W will determine the capacity without freeboard at the crest Q_{mh}. The value of D is to be sufficiently large to insure free-flow conditions at the crest (i.e., $D \geqq D_r$) as given by sheets 5, 6, or 7 of ES-90, pages 2.35, 2.36, and 2.37. The capacity without freeboard at the crest Q_{mh} is equal to the discharge Q of the box inlet when the head over the crest H_e is equal to h. The value of M and W will determine the capacity without freeboard Q_{mM} at the downstream section of the box inlet. The lower value of Q_{mh} or Q_{mM} is the capacity of the inlet without freeboard Q_{mi}.

Head-discharge Relationship for Box Inlet with Narrow Approach Channel. When the approach channel to the box inlet is narrow, the discharge-head relationship of the channel and box inlet is changed from the discharge-head relationship of the box inlet alone as given by sheets 5, 6, and 7 of ES-90, or Eq. 3.7. The discharge Q_K of a box inlet having a narrow channel and a given head over the crest is less than the discharge Q for the same box inlet located in a wide channel or reservoir and operating with the same given head over the crest. Further, the discharge Q_K of a box inlet having a narrow approach channel is not greater than that discharge of the narrow channel terminating with a free overfall. The relationship of Q_K and Q is

$$Q_K = K\,Q$$

where
- Q_K = the free-flow discharge of a given box inlet in a narrow channel and a head over the crest of H_e in cfs
- Q = the discharge of the given box inlet as given by sheets 5, 6, or 7 of ES-90 (pages 2.35, 2.36, and 2.37) with the same head over the crest H_e in cfs
- K = correction factor as given by sheets 9 and 10 of ES-90 (pages 2.39 and 2.40). The value of K is a measure of the efficiency of the narrow approach channel and box inlet compared with the box inlet alone.

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[1]Minshall, Neal E., Evaluation of Wisconsin Gully Control Structures, Agricultural Engineering, January 1955.

[2]Bastian, R. K., Olson, E. G., and Plautz, F. L., Model Test of Head Spillway, Thesis No. 463, June 1953.

When the values of W_c, B, H_e, and W are given, the value of $\frac{Q_K}{W\ H_e^{3/2}}$ may be read from either sheet 9 or 10 of ES-90. The actual discharge Q_K may be calculated since $\frac{Q_K}{W\ H_e^{3/2}}$, H_e, and W are all known. Also the value of K may be read instead of $\frac{Q_K}{W\ H_e^{3/2}}$ and from sheets 5, 6, or 7 the value of Q determined. Then it is possible to determine the value of $Q_K = K\ Q$. Either method of solving for the value of Q_K will give the same results.

Along the curve K = 0.97, a scale of values $\kappa = \frac{W_c + 0.8\ z_s\ H_e}{W}$ has been given. These values are associated with values of W_c which have the effect of a three percent decrease on the discharge, since K = 0.97 and the discharge of the box inlet with the approach channel width considered Q_K becomes equal to 0.97 times the discharge of the box inlet with no narrow channel effect Q. Theoretically the value of W_c would need to be infinitely great to have no effect on the discharge.

Since it would be possible to obtain the discharge of a box inlet when the weir formula is applicable from sheets 9 and 10 if the line K = 1 were drawn the purpose of sheets 5, 6, and 7 appear at first glance to be a repetition of data. Quite to the contrary, sheets 5, 6, and 7 defined the depth of the box inlet D_r at which impending submergence of the crest occurs and also showed by the stippled region the values of B, W, and H_e for which the weir formula is not applicable in defining discharge. Sheets 9 and 10 are applicable for only box inlets having values of W, B, H_e, and D with free-flow conditions at the crest in which the weir formula is applicable.

With the same head over the crest H_e, a box inlet having a narrow approach channel does not require as great a depth of the box inlet D_r to prevent submergence of the crest as does the same box inlet located in a wide approach channel. The value $\frac{D_r}{W}$ which would cause impending submergence of the crest at a given head H_e for box inlets located in narrow approach channels may be determined at the point of intersection of the $\frac{Q_K}{W^{5/2}}$ line and the $\frac{B}{W}$ line of sheets 5, 6, or 7 of ES-90.

<u>Box Inlet with Dike Effect</u>. Whenever the toe of the dike covering the headwall of the rectangular weir box inlet is a small distance X from the crest of the drop inlet, the discharge-head relationship is changed from that given by sheets 5, 6, or 7 of ES-90 or Eq. 3.7.

The actual discharge Q_λ of a flat-rectangular weir box inlet having a dike and narrow channel which influences the discharge may be found by use of the graph given by ES-90, pages 2.41 through 2.43. Only rectangular weir box inlets would have dikes near weir crest; a trapezoidal weir box inlet has its weir projecting upstream from the embankment through which the water is conveyed. The trapezoidal weir box inlet has an anti-seep collar near the center of the structure instead of a headwall, which is used in the rectangular weir box inlet as an anti-seep collar and end of the weir section. A good way to calculate the discharge Q_λ is to draw a plan view of the weir crest and the first approximation of the effective toe line of the dike. (See sheet 20, ES-90.) The crest of a flat-rectangular weir box inlet in plan view is coincident with the downstream face of the vertical walls forming the box. The crest of a rounded-rectangular weir box inlet in plan view is a line upstream a distance equal to the radius of rounding from the downstream face of the vertical walls forming the box. (See ES-91, page 2.74.) The effective toe location of the dike covering the headwall is dependent upon the head over the crest H_e and lies between the actual toe of the dike and the water line on the dike corresponding to the head H_e. The actual toe of the dike is the line formed by the intersection of the horizontal plane at crest elevation and the dike. The effective toe line for a dike having a z_s to 1 slope is located a distance $0.4\ z_s\ H_e$ from the toe of the dike. (See ES-90, page 2.50.) The symbol η is used to designate the distance from the crest of the box inlet to the effective toe of the dike. This distance is measured in a direction perpendicular to the crest. This distance is $\eta = X + 0.4\ z_s\ H_e$. The symbol β is used to designate the incremental distance parallel to the sidewalls of the weir between successive values of η. The incremental lengths β are numbered by subscripts in an upstream direction. The subscripts of η pertain to end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The bar over η, i.e., $\bar{\eta}$, designates an average value of η for the particular incremental length β under consideration and the subscript of $\bar{\eta}$ equals the subscript β when $\bar{\eta}$ is associated with the same incremental length β. The value of $\bar{\eta}_i$ is the average of η_{i-1} and η_i. For the incremental distance β_i the associated average distance to the effective toe of the dike from the crest of the box inlet $\bar{\eta}$ is

$$\bar{\eta}_i = \frac{\eta_{i-1} + \eta_i}{2}$$

The value of β_i is to be selected as a small value when $\eta_i - \eta_{i-1}$ is large. The subscripts of $\bar{\eta}$'s and β's are equal when the $\bar{\eta}$ and β values are associated with the same incremental portion of the inlet. Therefore the average distance to the effective toe of the dike from the crest of the box inlet $\bar{\eta}$ are also numbered by subscripts in an upstream direction from the headwall.

Determination of the value of Q_λ. Values of H_e, B, W, X's and β's are given when the value of Q_λ is to be determined. The values of $\bar{\eta}_i$ corresponding to the values of β_i are determined when the head over the crest through each incremental distance is assumed to be H_e. The value of Q_λ for this assumption is determined in the following manner:

1a. Find the values of T_1 and μ_1 corresponding to $\frac{\bar{\eta}_1}{W}$ and $\frac{\beta_1}{W} = \tau_1$ from ES-90, pages 2.41 to 2.43, where

$$\bar{\eta}_1 = \frac{\eta_o + \eta_1}{2}$$

b. Find the values of $\tau_{1,2}$ and $\mu_{1,2}$ corresponding to T_1 and $\frac{\overline{\eta}_2}{W}$

iia. Find the values of T_2 and μ_2 corresponding to $\frac{\overline{\eta}_2}{W}$ and τ_2 where

$$\tau_2 = \frac{\beta_2}{W} + \tau_{1,2}$$

b. Find the values of $\tau_{2,3}$ and $\mu_{2,3}$ corresponding to T_2 and $\frac{\overline{\eta}_3}{W}$

Repeat steps iia and iib increasing the subscripts by unity for as many times as is required to reach the subscript n where

$$\beta_1 + \beta_2 + \cdot \cdot \cdot + \beta_n = B$$

When the last value β_n is used in step iia, it will not be necessary to perform step iib; that is, the value of $\tau_{n,n+1}$ is not required nor is it possible to obtain since no value of $\frac{\overline{\eta}_{n+1}}{W}$ is given. If the assumption that H_e remains constant is valid, the actual discharge Q_λ of the rectangular-weir box inlet is

$$Q_\lambda = (3.09 + T_n)\ W\ H_e^{3/2}$$

The head over the crest at the upstream section i of the incremental length β_i varies throughout the length B of the box inlet if the dike causes and effect on the discharge through the box inlet. Since it is impossible to determine this head without first knowing the discharge, which is also being determined, an approximate Q_λ is first determined by assuming the head at each section i to be constant. After determining this approximate Q_λ the heads at the upstream section i of each incremental length β_i are determined. The section n has the given head over the crest H_e. The head H_{ei} over the crest at any section i is

$$H_{ei} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdot \cdot \cdot \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The effective toe line of the dike covering the headwall is relocated using the values of H_{ei} at each upstream section of the incremental lengths β_i. The new values of $\overline{\eta}_i$ are calculated and steps ia, ib, iia, and iib are performed again for these new values of $\overline{\eta}_i$. (See Ex. 7, page 2.49, ES-90.)

Determination of the value of B. Design problems will generally have the dike size given; that is, values of $\overline{\eta}$'s and β's along with Q_{fr}, W, and h. The value of B is determined which will convey the discharge Q_{fr} when the head over the crest $H_e = h$.

The effective toe of the dike is determined corresponding to the head h as illustrated by the drawing ES-91, page 2.74. The calculations for the value of B for a flat-rectangular box inlet are performed by the following step procedure.

i. Determine the value of Υ_n. This is the final value of Υ_n required.

$$\Upsilon_n = \frac{Q_{fr}}{W\ h^{3/2}} - 3.09$$

iia. Find the values of Υ_1 and μ_1 corresponding to $\frac{\bar{\eta}_1}{W}$ and $\tau_1 = \frac{\beta_1}{W}$ by pages 2.41 to 2.43. If $\Upsilon_1 < \Upsilon_n$ then the required $B > \beta_1$; perform step iib and iiia. If $\Upsilon_1 > \Upsilon_n$ then the required $B < \beta_1$; perform step iv.

b. Find the values $\tau_{1,2}$ and $\mu_{1,2}$ corresponding to Υ_1 and $\frac{\bar{\eta}_2}{W}$.

iiia. Determine the value of τ_2

$$\tau_2 = \tau_{1,2} + \frac{\beta_2}{W}$$

and find the values of Υ_2 and μ_2 corresponding to τ_2 and $\frac{\bar{\eta}_2}{W}$. If $\Upsilon_2 < \Upsilon_n$ repeat steps iib and iiia increasing the subscript by unity for as many times necessary to attain a value of $\Upsilon_i > \Upsilon_n$ and perform step 4.

iv. Find the value of τ_i corresponding to $\frac{\bar{\eta}_i}{W}$ and Υ_n where

$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W}$$

The value of B becomes

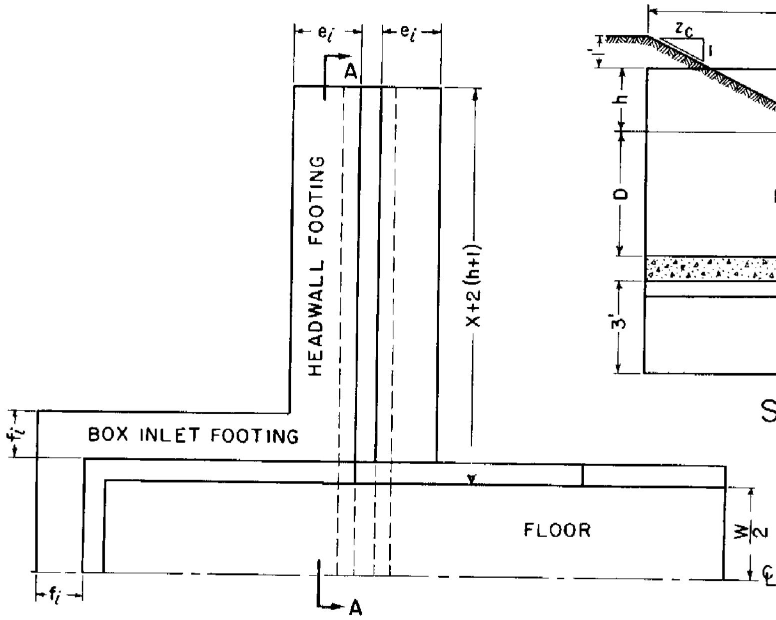
$$B = \beta_1 + \beta_2 + \cdot\ \cdot\ \cdot + \beta_i$$

The head over the crest varies throughout the length B of the box inlet. The head over the crest at any section i is

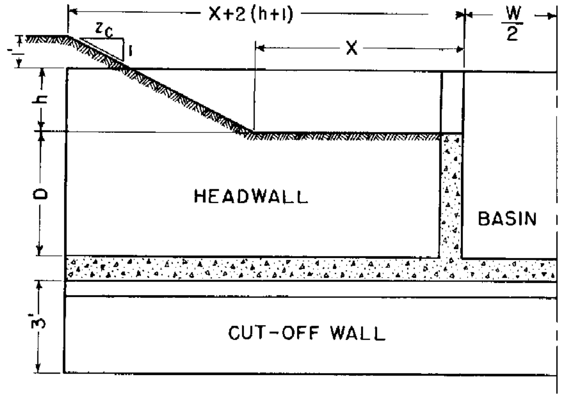
$$H_{ei} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdot\ \cdot\ \cdot \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The effective toe line is relocated using the corrected head over the crest for each incremental length β. New values of $\bar{\eta}$ are calculated and steps ii, iii, and iv are performed again. See Ex. 7, page 2.73, ES-91.

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLET; General layout.



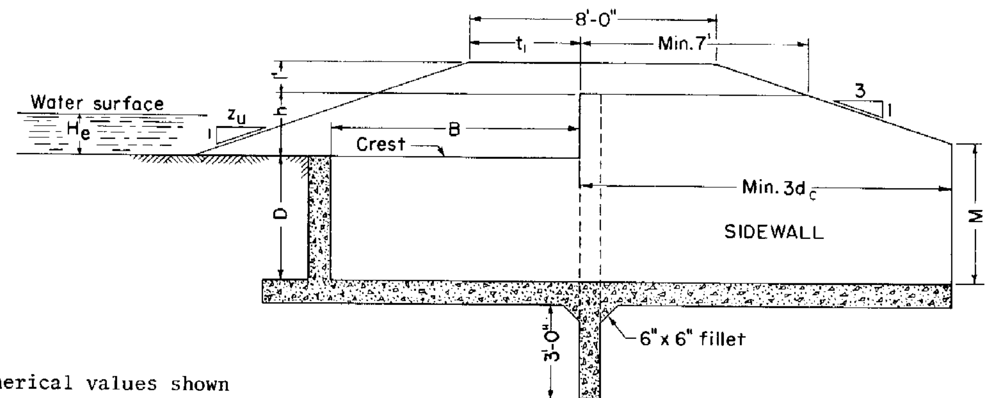
HALF-PLAN



SECTION A-A

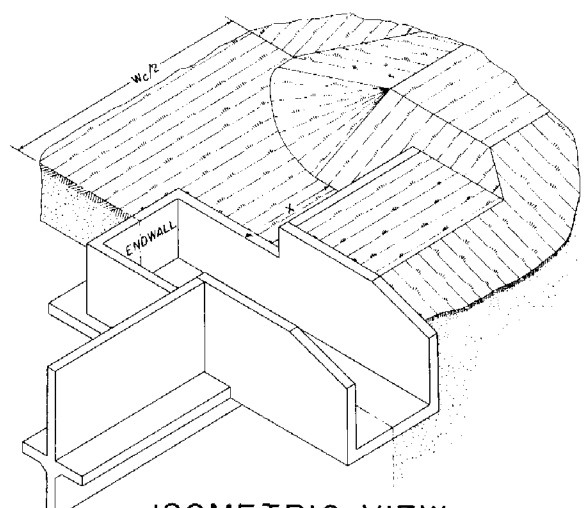
Note—
Hydraulic formulas are given on sheet 4

Capacities for this structure with a wide approach channel and no dike effect are given on sheets 5, 6, and 7.



Numerical values shown are suggested minimums.

SECTION ALONG CENTER LINE



ISOMETRIC VIEW

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 90 SHEET 1 OF 24 DATE 3-1-55

Revised 10/77

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLET; Effect of narrow channel and dike on discharge.

Note –

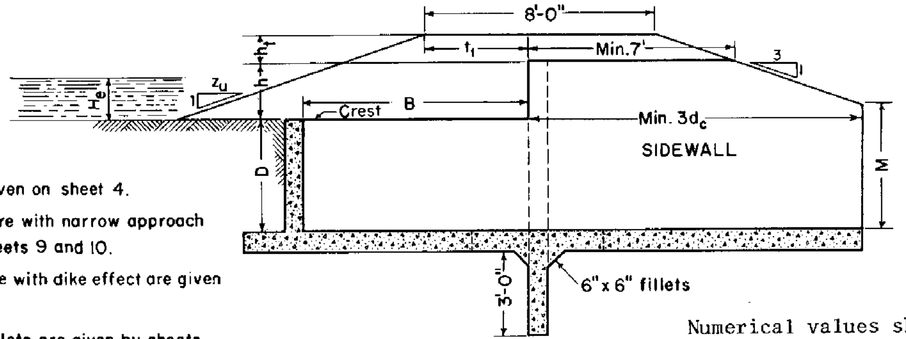
Hydraulic formulas are given on sheet 4.

Capacities for this structure with narrow approach channel are given by sheets 9 and 10.

Capacities of this structure with dike effect are given by sheets 11, 12, and 13.

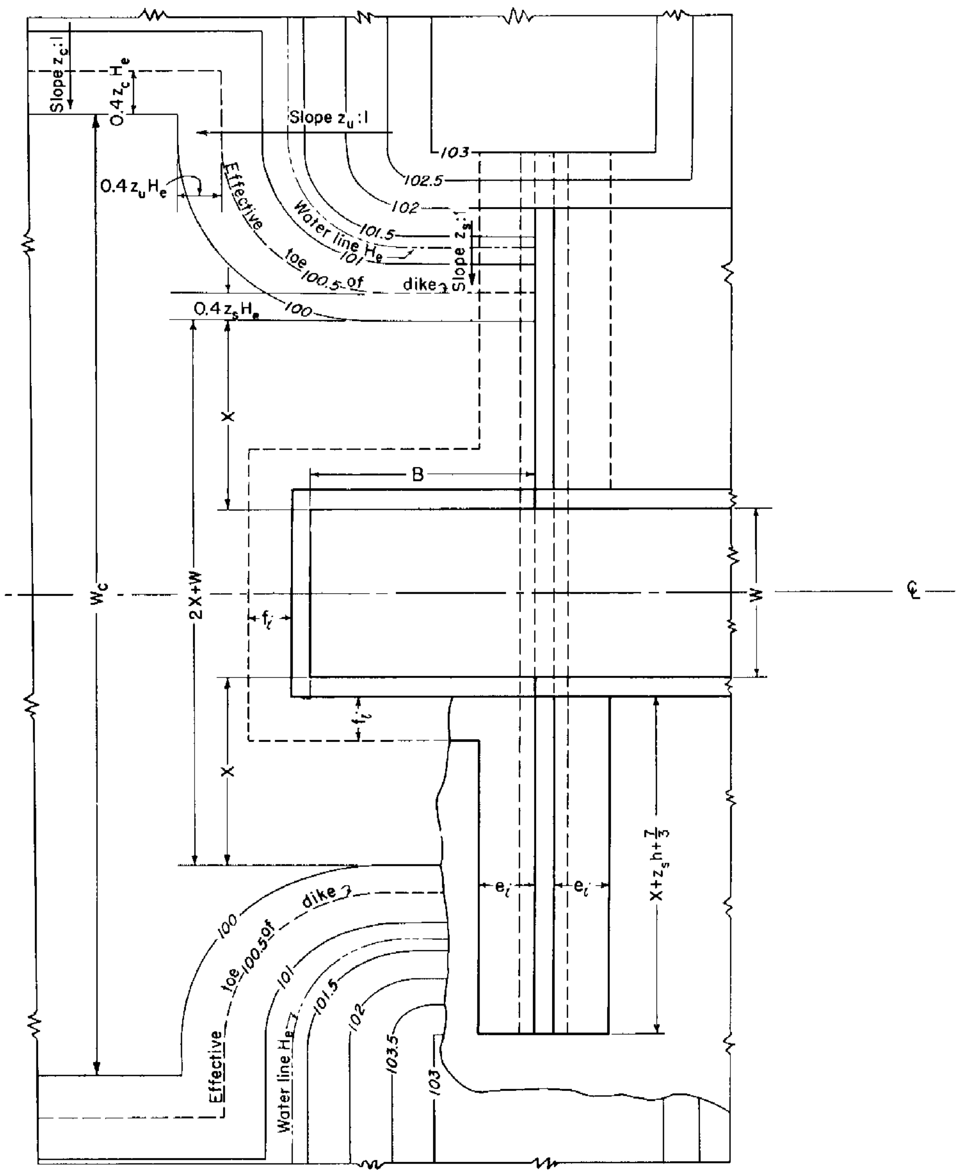
Required depths of box inlets are given by sheets 5, 6, and 7.

(See sheet 1 for isometric view)



Numerical values shown are suggested minimums.

SECTION ALONG CENTER LINE



PLAN

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 2 OF 24 DATE 3-1-55

Revised 10/77

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Definition of symbols

DEFINITION OF SYMBOLS

B = Inside length of the box inlet measured from the downstream face of the endwall to the upstream face of the headwall in ft
D = Depth (i.e., distance from the crest to the floor) of the box inlet in ft
D_r = Required depth of box inlet to prevent submergence at the crest when the discharge is Q in ft
h = Height of sidewalls above the crest of the box inlet in ft
h_t = Height of embankment above the top of sidewalls in ft
H_e = Specific energy head above the crest of the inlet corresponding to any discharge Q the inlet is capable of conveying in ft
i = Indices used for β, η, $\bar{\eta}$, τ, and T
K = $\frac{Q_K}{Q}$
L = Length of developed crest = 2B + W
M = Height of sidewall above the floor of the box inlet at the junction with the vertical curve section in ft
q = Discharge per unit width W or $q = \frac{Q}{W}$ in cfs/ft
Q = Discharge corresponding to the head H_e of a box inlet having no narrow approach channel or dike effect in cfs
Q_r = Design discharge in cfs
Q_{fr} = Required capacity without freeboard in cfs
Q_{si} = Capacity of inlet in cfs
Q_{mi} = Capacity of inlet without freeboard in cfs
Q_{mh} = Capacity of inlet without freeboard at the crest in cfs; discharge $Q = Q_{mh}$ when $H_e = h$
Q_{mM} = Capacity of inlet without freeboard at the origin of the upper vertical curve in cfs
$(Q_K)_{mh}$ = Capacity without freeboard of a box inlet at the crest when a narrow approach channel is considered in cfs. The discharge $Q = (Q_K)_{mh}$ when $H_e = h$.
Q_K = Discharge corresponding to the head H_e of a box inlet having a narrow approach channel in cfs
Q_λ = Discharge corresponding to the head of H_e of a box inlet having dike effect in cfs
$(Q_K)_{mi}$ = Capacity without freeboard of a box inlet and narrow approach channel of width W_c and downstream end section having a sidewall height M in cfs
$(Q_\lambda)_{mh}$ = Capacity without freeboard of a box inlet at the crest when a narrow channel and dike are considered in cfs. The discharge $Q_\lambda = (Q_\lambda)_{mh}$ when $H_e = h$.
$(Q_\lambda)_{mi}$ = Capacity without freeboard of a box inlet when a narrow channel and dike effects are both considered as well as the downstream section having a sidewall height M in cfs
t_1 = That portion of the top width of the embankment covering the headwall upstream from the upstream face of the headwall in ft
W = Width of inlet in ft
W_c = Bottom width of the approach channel for the box inlet in ft
z_c = Side slope (horizontal distance per vertical foot) of approach channel
z_s = Side slope (horizontal distance per vertical foot) of dike covering the headwall in the direction towards the crest of the box inlet. (See sheet 2)
z_u = Side slope (horizontal distance per vertical foot) of dike covering the headwall in an upstream direction. (See sheet 2)
X = Distance of the toe of the dike covering the headwall from the crest of the box inlet in ft
Z = Vertical drop from the crest of the inlet to the floor of the SAF outlet in ft
β = An incremental length of distance B in ft (see figure, sheet 20)
κ = Ratio $\frac{W_c + 0.8\, z_c\, H_e}{W}$
λ = $\frac{Q_\lambda}{Q}$
τ = See formula sheet 4 or sheets 11 and 13
T = Values read on chart of sheets 11, 12, and 13
η = Distance between effective toe of dike covering the headwall and the crest of the inlet in ft
$\bar{\eta}$ = Average distance of effective toe of dike covering the headwall from the crest of the box inlet in the incremental length β in ft
ψ = $\frac{1.2\, g^{1/3}\, W^{2/3}}{Q^{2/3}} D_r$ where $\psi > 1$ (see equations, sheet 4)
γ = Ratio $\frac{H_e}{W}$
δ = Ratio $\frac{D_r}{W}$
μ = Values read from graph of sheets 11, 12, and 13

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
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STANDARD DWG. NO. ES-90
SHEET 3 OF 24
DATE 6-4-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Formulas

FORMULAS

The relationship of the discharge-head over the crest for a flat-rectangular weir box inlet having a wide approach channel and no dike effect is

$$Q = 3.1\ (2\ B + W)\ H_e^{3/2} \qquad \text{when}$$

$$0 < H_e \leq 0.49\ W + 0.04\ B \qquad \text{and}$$

$$0 < Q \leq 5.5\ W^{5/2} \qquad \text{and}$$

$$\psi^3 - 3\ \psi + 2 \left[\frac{W}{2\ B + W}\right]^2 = 0 \qquad \text{where}$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi > 1$$

These relations are expressed in graphical form by sheets 5, 6, and 7 where

$$\delta = \frac{D_r}{W} \qquad \text{and} \qquad \gamma = \frac{H_e}{W}$$

values of $H_e^{3/2}$ and $W^{5/2}$ are given on sheet 8. When $H_e > 0.49\ W + 0.04\ B$, no algebraic relationship is given. The last two relations are a requirement of the value of D to prevent submergence of the crest. The relationship of the discharge-head over the crest for a flat-rectangular weir box inlet having a narrow channel effect but no dike effect is

$$Q_K = K\ Q$$

where the value of K is obtained from sheets 9 and 10. The value of Q_K may be obtained from sheets 9 and 10 without determining the value of K. The value of κ is

$$\kappa = \frac{W_c + 0.8\ z_c\ H_e}{W}$$

The discharge-head relationship of a flat-rectangular weir box inlet having a narrow channel and dike effect is given in graphical form by sheets 11, 12, and 13.

$$Q_\lambda = \lambda\ Q$$

The effective toe of the dike is a distance of $0.4\ z_s\ H_e$ (or $0.4\ z_u\ H_e$) from the toe of the dike. At the headwall the effective toe of the dike is a distance η_o from the crest of the spillway or

$$\eta_o = X + 0.4\ z_s\ H_e \qquad \text{and} \qquad \bar{\eta}_i = \frac{\eta_{i+1} + \eta_i}{2}$$

and

$$\beta_1 + \beta_2 + \cdot\cdot\cdot + \beta_i + \cdot\cdot\cdot + \beta_n = B$$

where the subscript n is equal to the integer designating the number of increments considered in the length B. The increments β are numbered by subscripts in an upstream direction. The subscripts of η pertain to the end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The subscript of $\bar{\eta}$ equals the subscript of β when $\bar{\eta}$ is associated with the same incremental length β.

$$\tau_1 = \frac{\beta_1}{W} \qquad \text{and} \qquad \tau_i = \tau_{i-1,i} + \frac{\beta_i}{W} \qquad \text{where} \qquad i \geq 2$$

The value of $\tau_{i-1,i}$ is read from sheets 11, 12, and 13 at T_{i-1} and $\frac{\bar{\eta}_i}{W}$. The values of μ are used to determine the head over the crest at the various sections along the length B and to determine the location of the effective toe of the dike. The head over the crest at section i is

$$H_{e,i} = H_e\ \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdot\cdot\cdot\ \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

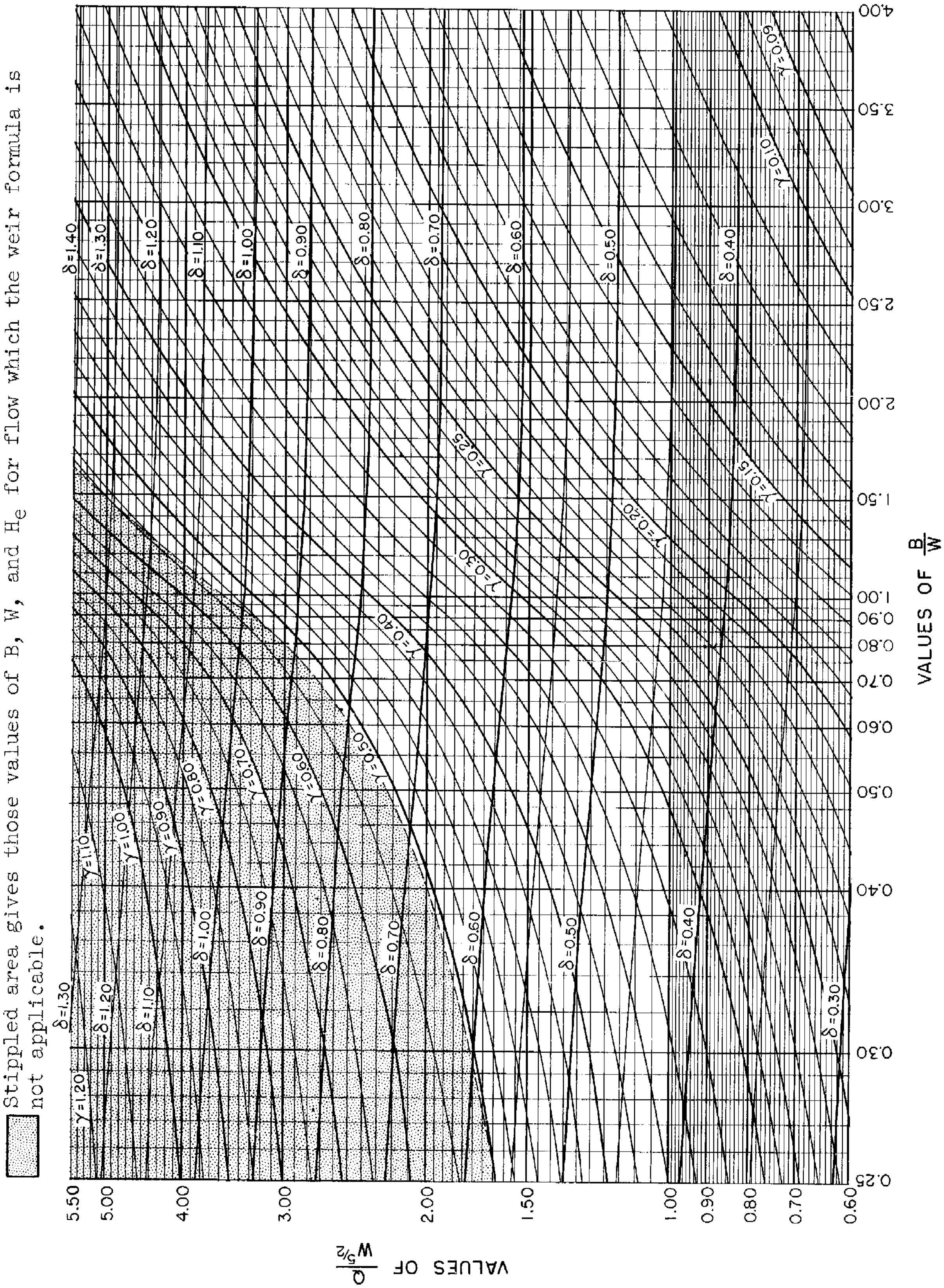
$$\tau_n + 3.09 = \frac{Q_\lambda}{W\ H_e^{3/2}}$$

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 90 SHEET 4 OF 24 DATE 6-4-56

CHUTE SPILLWAYS: The discharge-head relationship for a FLAT-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or channel effects.

$\delta = \frac{D_r}{W}$

$\gamma = \frac{H_e}{W}$

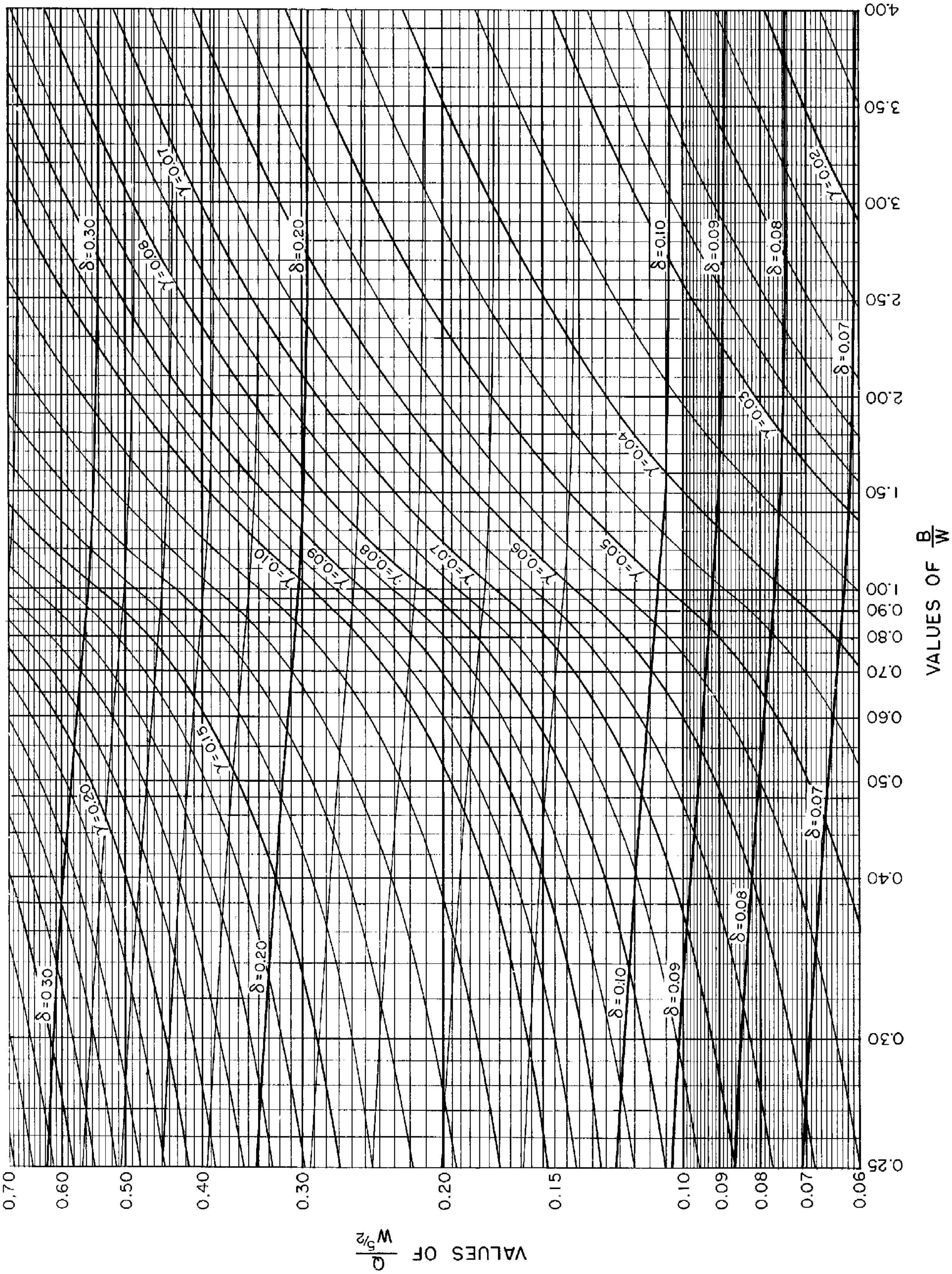


REFERENCE This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 5 OF 24 DATE 4-5-55

CHUTE SPILLWAYS: The discharge-head relationship for a FLAT-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or channel effects.

$\delta = \frac{D_r}{W}$

$\gamma = \frac{H_e}{W}$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

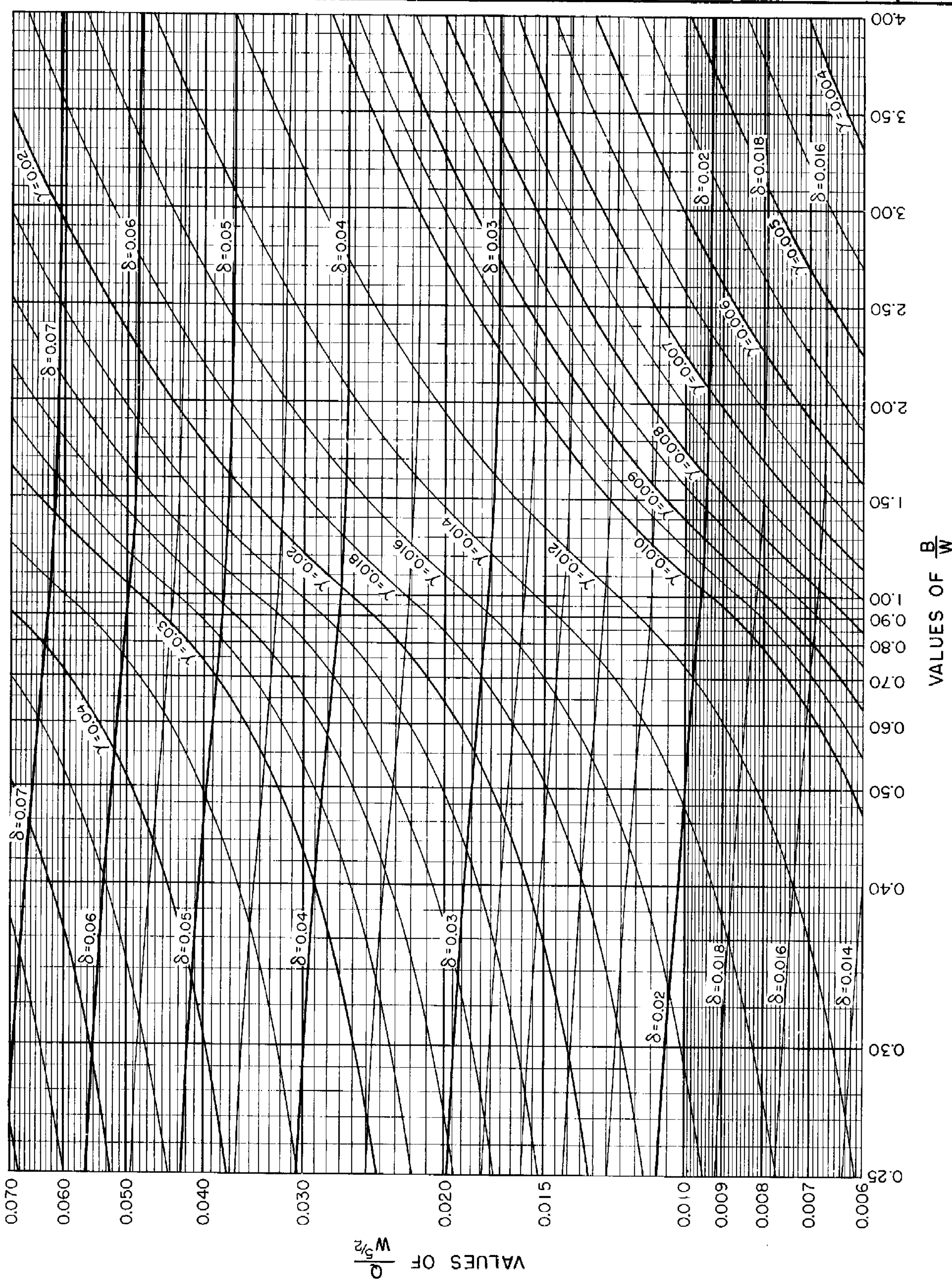
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-90
SHEET 6 OF 24
DATE 4-5-55

CHUTE SPILLWAYS: The discharge-head relationship for a FLAT-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or channel effects.

$\delta = \frac{D_r}{W}$

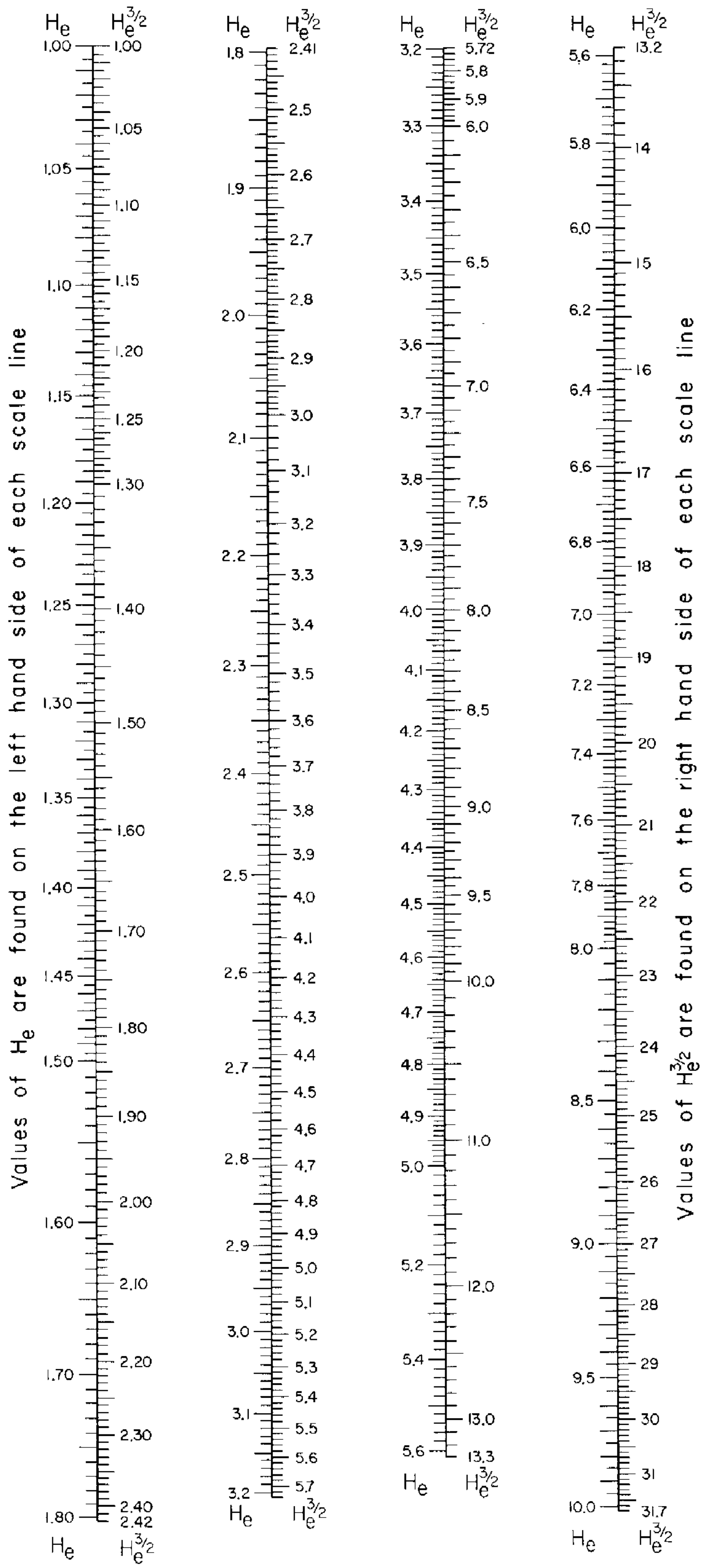
$\gamma = \frac{H_e}{W}$



REFERENCE		STANDARD DWG. NO.
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	ES-90 SHEET 7 OF 24 DATE 4-5-55

CHUTE SPILLWAYS : FLAT-RECTANGULAR WEIR BOX INLETS.

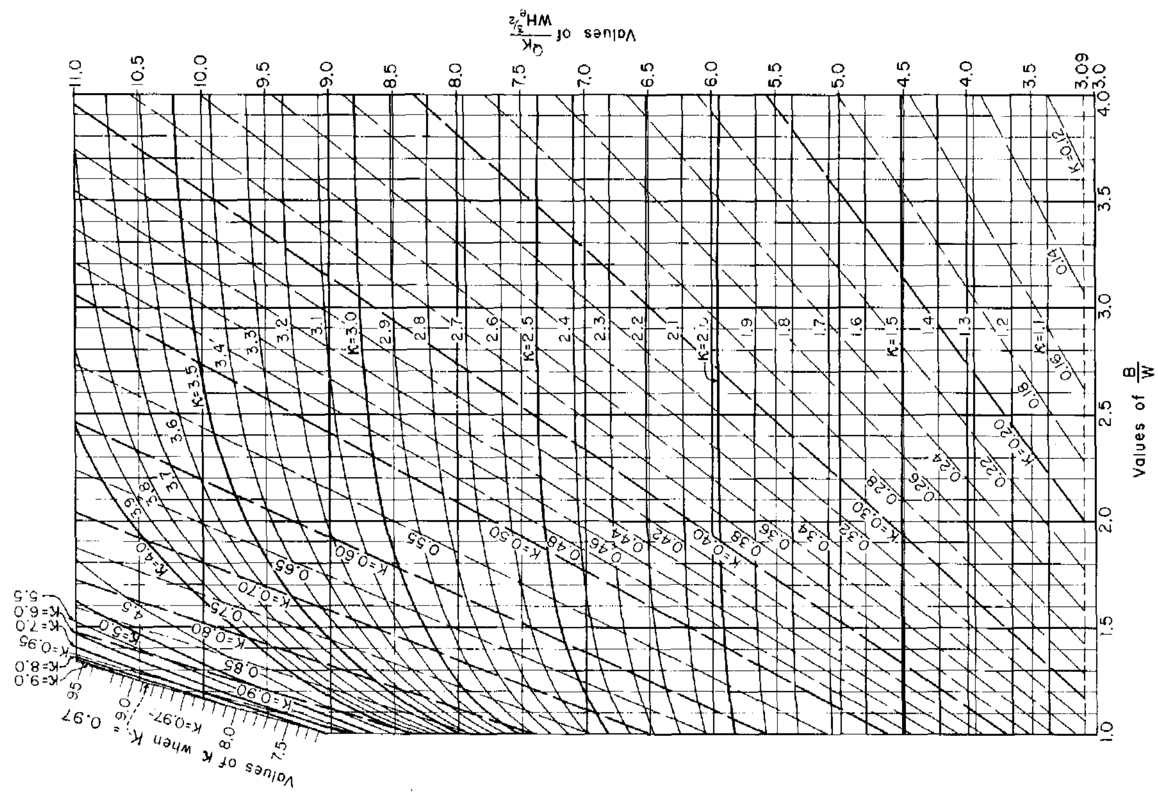
W-ft	$W^{5/2}$
3.0	15.588
3.5	22.918
4.0	32.000
4.5	42.957
5.0	55.902
5.5	70.943
6.0	88.182
6.5	107.72
7.0	129.64
7.5	154.05
8.0	181.02
8.5	210.64
9.0	243.00
9.5	278.17
10.0	316.23
10.5	357.25
11.0	401.31
11.5	448.48
12.0	498.83
12.5	552.43
13.0	609.34
13.5	669.63
14.0	733.36
14.5	800.61
15.0	871.42
15.5	945.87
16.0	1024.0
16.5	1105.9
17.0	1191.6
17.5	1281.1
18.0	1374.6
18.5	1472.1
19.0	1573.6
19.5	1679.1
20.0	1788.9
20.5	1902.8
21.0	2020.9
21.5	2143.4
22.0	2270.2
22.5	2401.4
23.0	2537.0
23.5	2677.1
24.0	2821.8
24.5	2971.1
25.0	3125.0
25.5	3283.6
26.0	3446.9
26.5	3615.1
27.0	3788.0
27.5	3965.8
28.0	4148.5
28.5	4336.2
29.0	4528.9
29.5	4726.7
30.0	4929.5
30.5	5137.5
31.0	5350.6
31.5	5569.0
32.0	5792.6
32.5	6021.6
33.0	6255.8
33.5	6497.2
34.0	6740.6
34.5	6991.1
35.0	7247.2
35.5	7508.8
36.0	7776.0
36.5	8048.8
37.0	8327.3
37.5	8611.5
38.0	8901.4
38.5	9197.1
39.0	9498.6
39.5	9806.0
40.0	10,119

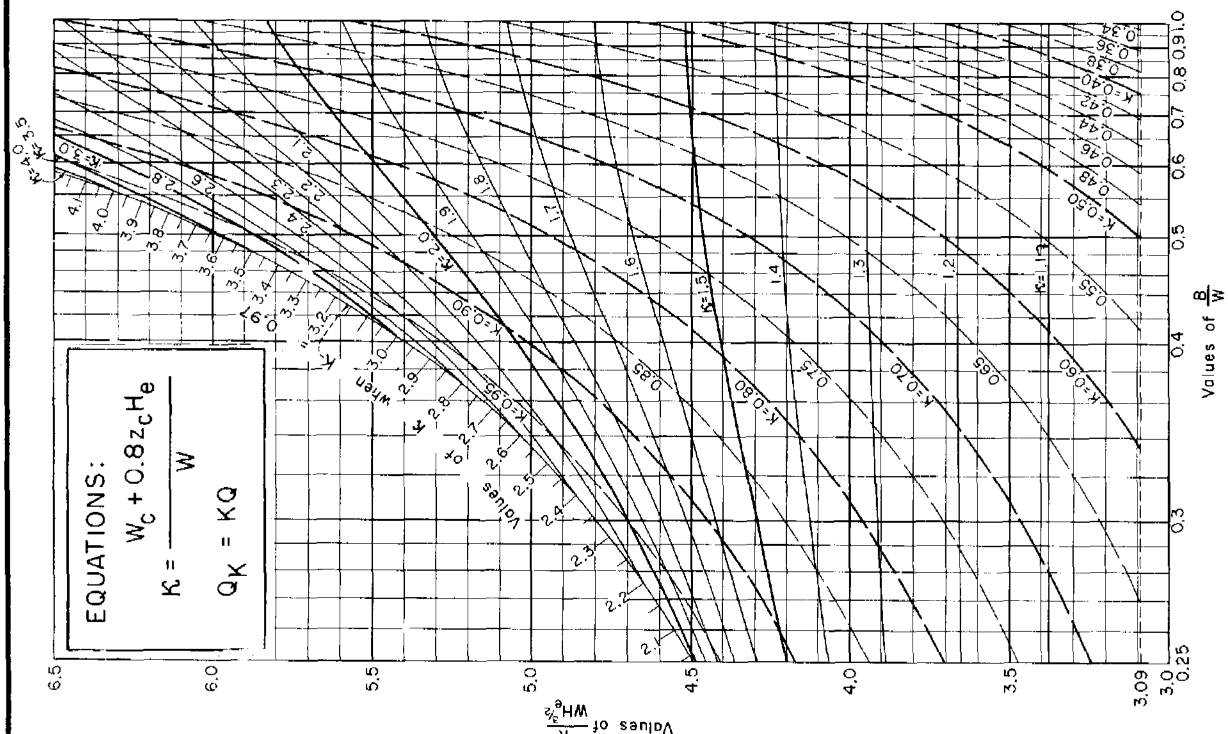


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 8 OF 24 DATE 6-10-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS;

Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.





EQUATIONS:

$$K = \frac{W_c + 0.8 z_c H_e}{W}$$

$$Q_K = KQ$$

REFERENCE

This chart was developed by Paul D. Doubt of the Design Section.

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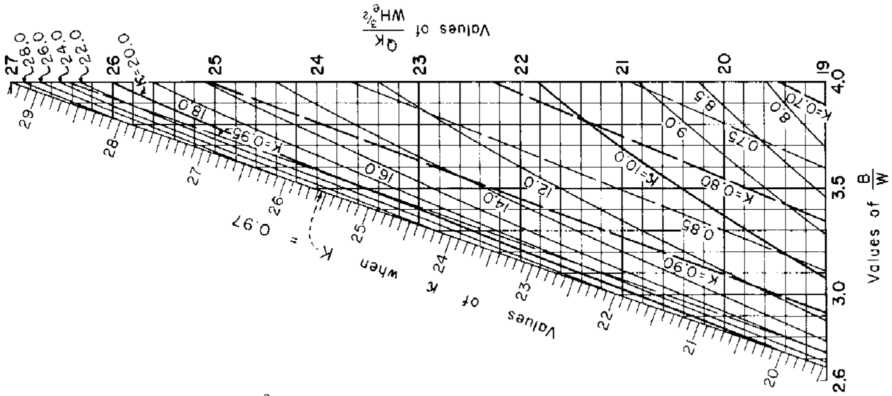
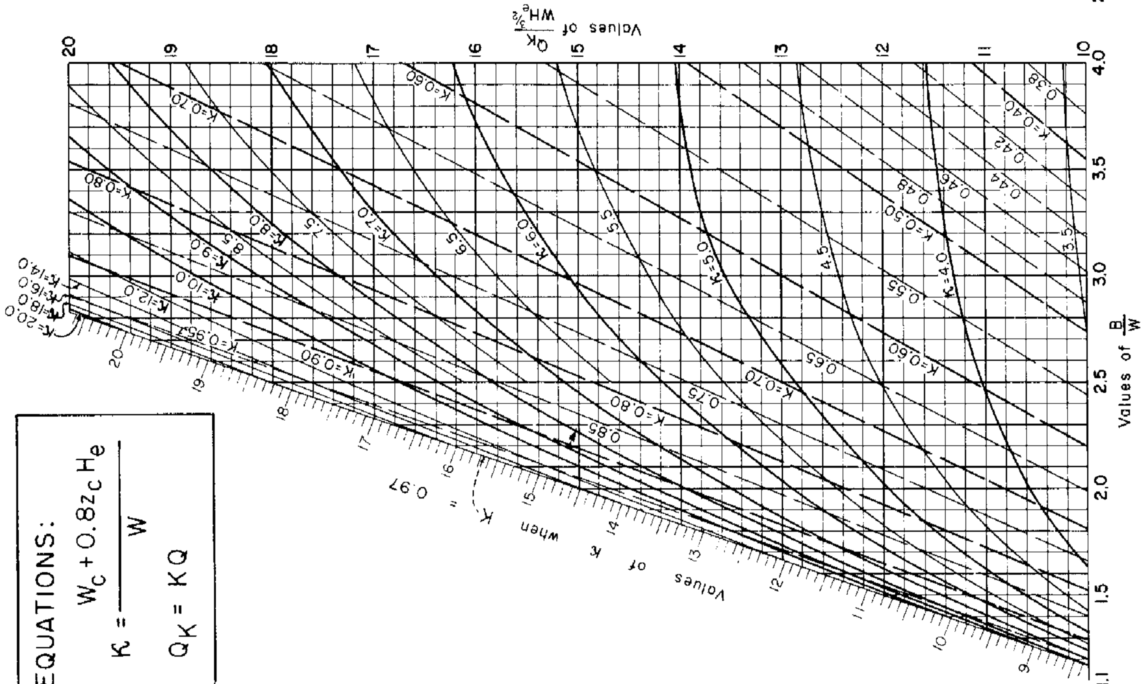
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES- 90
SHEET 9 OF 24
DATE 5-20-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS;
Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.

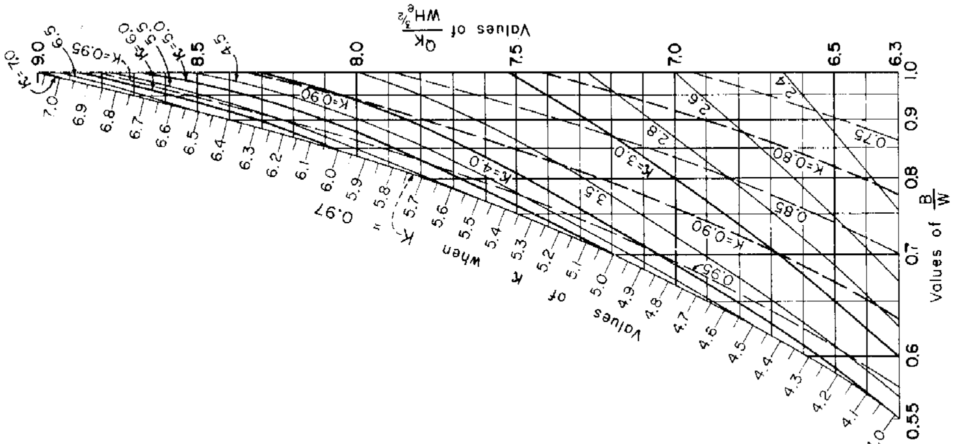




EQUATIONS:

$$K = \frac{W_c + 0.8 z_c H_e}{W}$$

$$Q_K = KQ$$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

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SOIL CONSERVATION SERVICE
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STANDARD DWG. NO.
ES-90
SHEET 10 OF 24
DATE 5-20-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.

Equation for discharge of a box inlet having a dike is $Q_\lambda = \lambda Q$. Effective toe of dike is a distance of $0.4\, z_s H_e$ (or $0.4\, z_u H_e$) from toe of dike. Thus $\eta_o = X + 0.4\, z_s H_e$ and $\bar{\eta}_i = \frac{\eta_{i-1} + \eta_i}{2}$ and $\beta_1 + \beta_2 + \cdots + \beta_i + \cdots + \beta_n = B$ where the subscript n is equal to the integer designating the number of increments considered in the length B. The increments β are numbered by subscripts in an upstream direction. The subscripts of η pertain to end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The subscript of $\bar{\eta}$ equals the subscript of β when $\bar{\eta}$ is associated with the same incremental length β.

$$\tau_1 = \frac{\beta_1}{W}$$

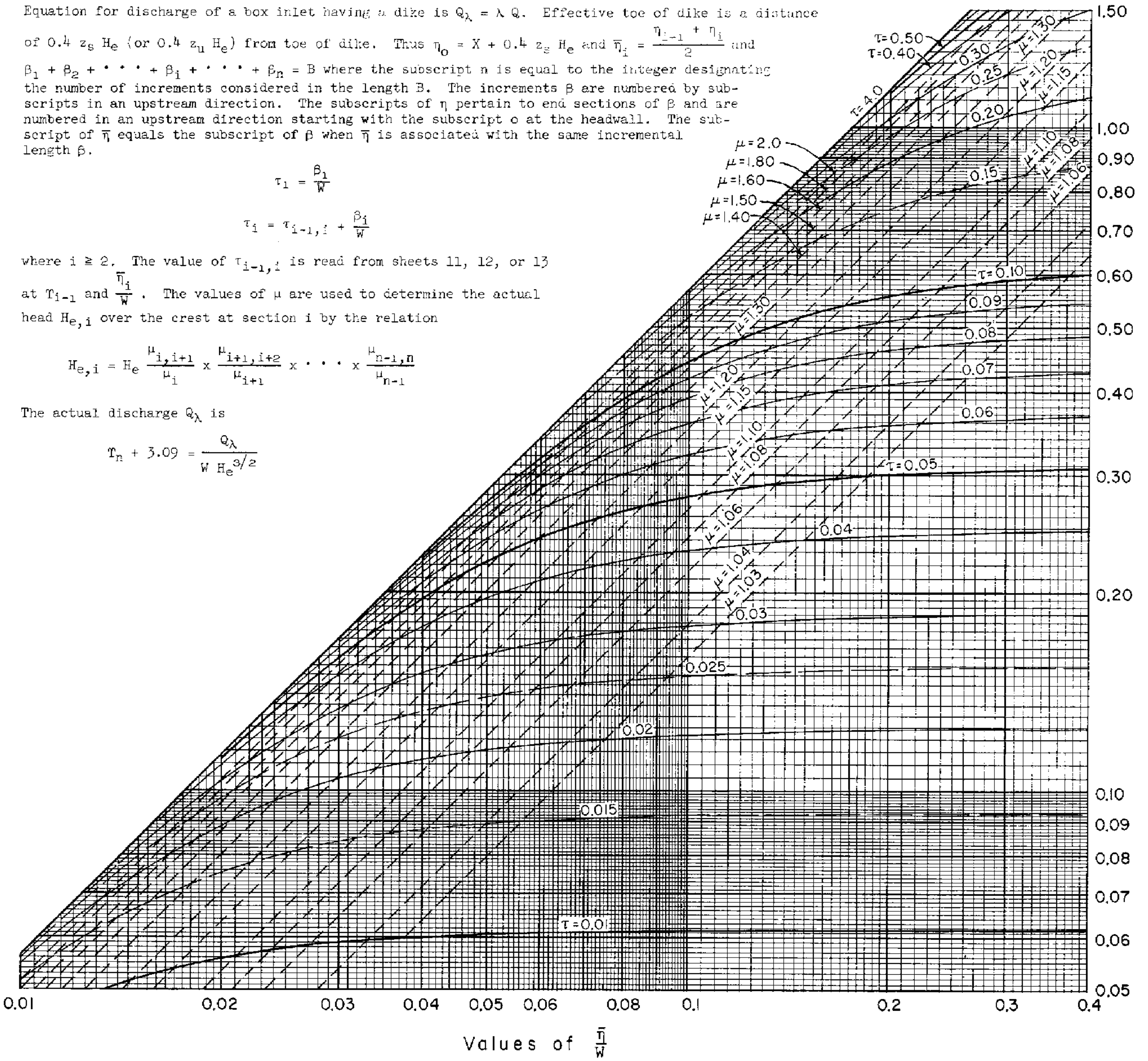
$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W}$$

where $i \geq 2$. The value of $\tau_{i-1,i}$ is read from sheets 11, 12, or 13 at τ_{i-1} and $\frac{\bar{\eta}_i}{W}$. The values of μ are used to determine the actual head $H_{e,i}$ over the crest at section i by the relation

$$H_{e,i} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdots \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

$$\tau_n + 3.09 = \frac{Q_\lambda}{W H_e^{3/2}}$$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

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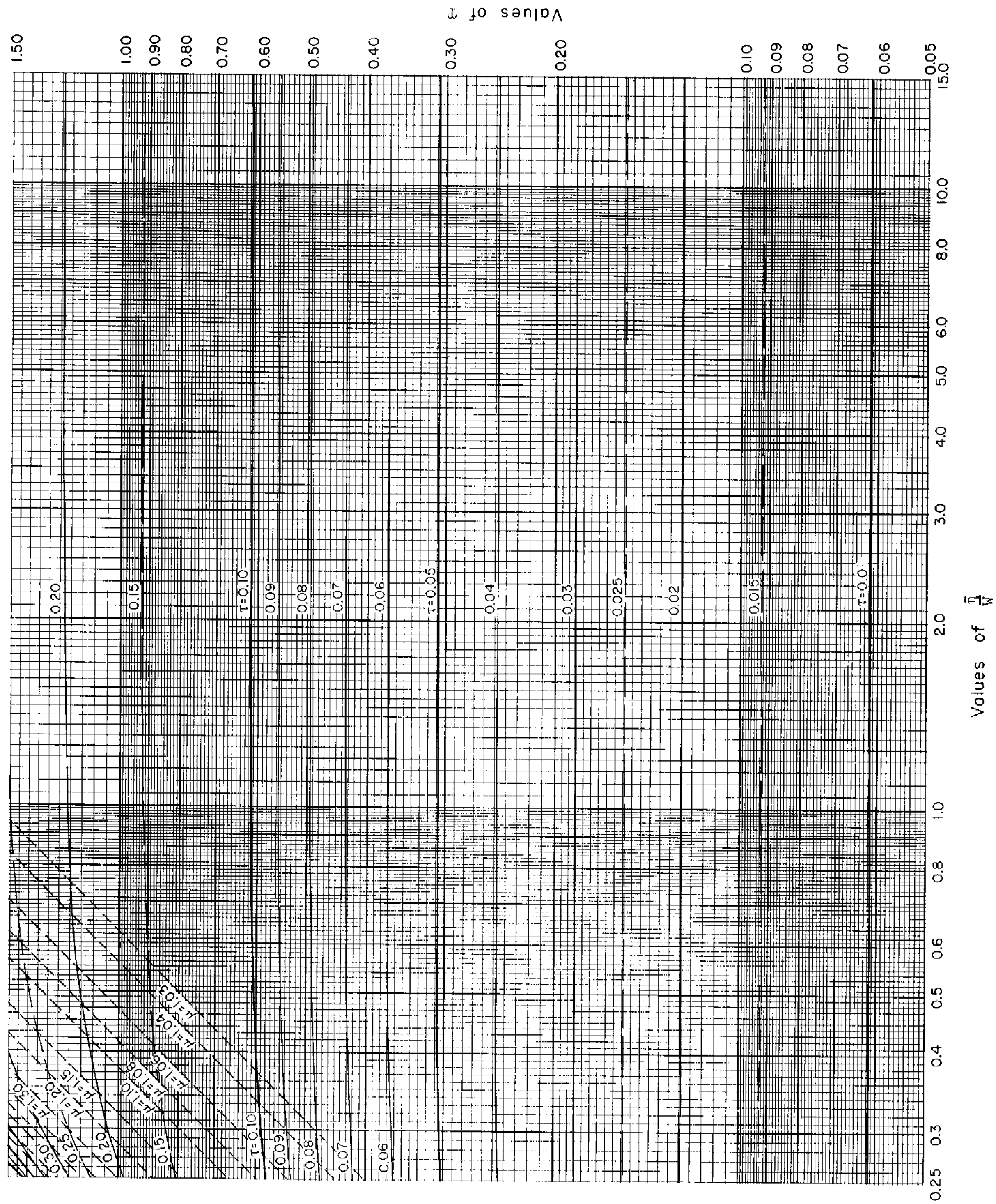
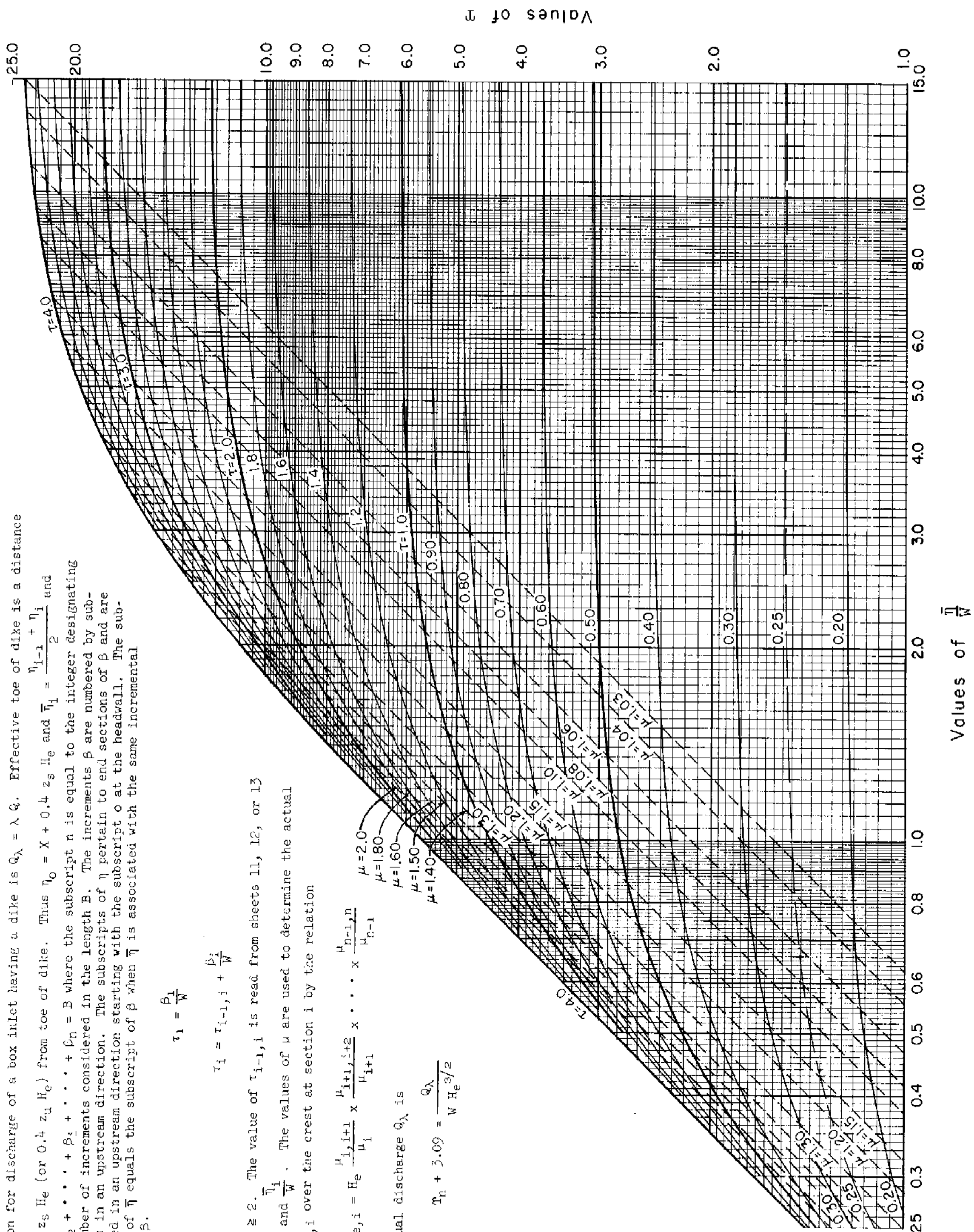
STANDARD DWG. NO.
ES-90
SHEET 11 OF 24
DATE 6-14-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.



CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.



Equation for discharge of a box inlet having a dike is $Q_\lambda = \lambda Q$. Effective toe of dike is a distance of $0.4\, z_s H_e$ (or $0.4\, z_u H_e$) from toe of dike. Thus $\eta_o = X + 0.4\, z_s H_e$ and $\bar{\eta}_i = \frac{\eta_{i-1} + \eta_i}{2}$ and $\beta_1 + \beta_2 + \cdot\cdot\cdot + \beta_i + \cdot\cdot\cdot + \beta_n = B$ where the subscript n is equal to the integer designating the number of increments considered in the length B. The increments β are numbered by subscripts in an upstream direction. The subscripts of η pertain to end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The subscript of $\bar{\eta}$ equals the subscript of β when $\bar{\eta}$ is associated with the same incremental length β.

$$\tau_1 = \frac{\beta_1}{W}$$

$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W}$$

where $i \geq 2$. The value of $\tau_{i-1,i}$ is read from sheets 11, 12, or 13 at τ_{i-1} and $\frac{\bar{\eta}_i}{W}$. The values of μ are used to determine the actual head $H_{e,i}$ over the crest at section i by the relation

$$H_{e,i} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdot\cdot\cdot \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

$$\tau_n + 3.09 = \frac{Q_\lambda}{W H_e^{3/2}}$$

REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
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STANDARD DWG. NO. ES-90
SHEET 13 OF 24
DATE 6-14-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

EXAMPLE 1

Given: A flat-rectangular weir box inlet for a chute spillway. The inside dimensions are W = 10 ft, B = 6 ft, and D = 4 ft. The approach channel and the dike covering the headwall have no effect on the discharge of the inlet.

Determine: 1. The head H_e over the crest at which the discharge Q begins to be affected by the dimension D; that is, the head H_e corresponding to impending submerged flow conditions at the crest.

2. The discharge corresponding to the head H_e determined in (1).

Solution: 1. Solving for the head H_e over the crest at which the discharge is affected by the dimension D. The value of $\frac{B}{W}$ is $\frac{6}{10} = 0.6$. The value of $\delta = \frac{D}{W}$ is $\frac{4}{10} = 0.4$. The point of intersection of the line having the value of $\frac{B}{W} = 0.6$ and the line $\delta = 0.4$, sheet 5, has a value $\gamma = \frac{H_e}{W} = 0.256$ or

$$H_e = 0.256\ (10) = 2.56 \text{ ft}$$

For heads over the crest greater than $H_e = 2.56$ ft, the discharge depends on the value of D = 4 ft as well as B, W, and H_e because submerged flow at the crest occurs.

2. Solving for the discharge corresponding to $H_e = 2.56$ ft. Since D is sufficiently large to insure no submergence of the crest, obtain from sheet 5 at the intersection of $\frac{B}{W} = 0.6$ and $\delta = \frac{D}{W} = 0.4$ the value $\frac{Q}{W^{5/2}} = 0.883$ or

$$Q = 0.883\ (10)^{5/2} = 279 \text{ cfs}$$

If the value of D had been greater than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.56$ ft remains the same; i.e., Q = 279 cfs. If the value of D had been less than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.56$ ft is not determinable from sheet 5 because the crest would be submerged as a result of a shallow box.

EXAMPLE 2

Given: A flat-rectangular weir box inlet. The inside dimensions are W = 5 ft, B = 2 ft, and $H_e = 3.5$ ft. The approach channel and the dike covering the headwall and the crest of the box inlet are sufficiently large to prevent any effect on the discharge of the inlet.

Determine: 1. The actual discharge Q of the box inlet if flow at the crest is not submerged.

2. The depth D_r of the box inlet required to prevent submergence of the crest for this discharge.

3. The theoretical discharge Q_t of the box inlet as determined by the weir formula.

Solution: 1. Solving for the actual discharge of the box inlet. The value of $\frac{B}{W}$ is $\frac{2}{5} = 0.4$ and $\gamma = \frac{H_e}{W}$ is $\frac{3.5}{5} = 0.7$. The point of intersection of the lines having the values of $\frac{B}{W} = 0.4$ and $\gamma = \frac{H_e}{W} = 0.7$ corresponds to a value of $\frac{Q}{W^{5/2}} = 2.92$ and a value of $\delta = \frac{D_r}{W} = 0.866$.

$$Q = 2.92\ W^{5/2} = 2.92\ (5)^{5/2} = 163.2 \text{ cfs}$$

2. Solving for the required depth D_r of the box inlet to prevent submergence

$$D_r = 0.866\ W = 0.866\ (5) = 4.33 \text{ ft}$$

3. Solving for the theoretical discharge of the box inlet as given by the weir formula

$$Q_t = 3.1\ (2\ B + W)\ H_e^{3/2}$$
$$= 3.1 \left[2\ (2) + 5\right] (3.5)^{3/2}$$
$$Q_t = 182.6 \text{ cfs}$$

The stippled region shown on sheet 5 signifies the weir formula is not applicable in predicting the discharge for the points corresponding to the values of B, W, and H_e in this region. Therefore Part 3 is not a valid solution.

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

EXAMPLE 3

Given: A flat-rectangular weir box inlet for a chute spillway. The dimensions of the box inlet are W = 10 ft, B = 6 ft, D = 4 ft, h = 2.50 ft, and M = 3.75 ft. There is no effect on the discharge due to a narrow channel or dike.

Determine: 1. The capacity without freeboard at the crest Q_{mh} in cfs.

2. The capacity without freeboard at the origin of the upper vertical curve Q_{mM} in cfs.

3. The capacity without freeboard of the box inlet Q_{mi} in cfs.

4. The capacity of the inlet Q_{si} if the total drop of the chute is Z = 25 ft.

Solution: No consideration of channel and dike effect will be required.

1. Solving for the capacity without freeboard at the crest Q_{mh}

$$\frac{B}{W} = \frac{6}{10} = 0.6 \qquad \delta = \frac{D}{W} = \frac{4}{10} = 0.4 \qquad \gamma = \frac{h}{W} = \frac{2.5}{10} = 0.25$$

At the intersection of lines (see sheet 5) $\frac{B}{W} = 0.6$ and $\gamma = 0.25$, read $\frac{Q_{mh}}{W^{5/2}} = 0.855$. Observe that the required value of δ is $0.39 < 0.4 = \frac{D}{W}$. If the value of $\delta = \frac{D_r}{W}$ read from the chart had been greater than 0.4, then the value of Q_{mh} is indeterminable from the chart.

$$Q_{mh} = 0.855\, W^{5/2} = 0.855\, (10)^{5/2} = 270 \text{ cfs}$$

2. The capacity without freeboard at the downstream end of the box inlet Q_{mM} may be read from Table 1, sheet 3, ES-88, for M = 3.75 ft and q_{mM} = 26.74 cfs/ft.

$$Q_{mM} = W\, q_{mM} = 10\ (26.74) = 267.4 \text{ cfs}$$

3. The capacity without freeboard of the box inlet Q_{mi} is the lesser of the values Q_{mh} and Q_{mM} or is Q_{mM} = 267.4 cfs.

4. The capacity of the inlet having the recommended freeboard is

$$Q_{si} = \frac{Q_{mi}}{(1.2 + 0.003\ Z)} = \frac{267.4}{1.2 + 0.003\ (25)} = 209.7 \text{ cfs}$$

EXAMPLE 4

Given: A design discharge Q_r = 270 cfs for a chute of width W = 10 ft and a sidewall height over the crest h = 2 ft. The vertical drop of the chute from the crest of the inlet to the floor of the SAF outlet is Z = 30 ft. No wave action is anticipated in the channel upstream from the inlet.

Determine: 1. The required capacity without freeboard Q_{fr}.

2. The required ratio of $\frac{B}{W}$ for a flat-rectangular weir if the approach channel and dike are to have no effect on the discharge equal to the design discharge without freeboard Q_{fr}.

3. The dimensions B, D, and M for the flat-rectangular weir box inlet if the approach channel and dike have no effect on the discharge Q_{fr}.

Solution: 1. Solving for the required capacity without freeboard Q_{fr}

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right] 270$$
$$Q_{fr} = 348.3 \text{ cfs}$$

2. When the discharge of the inlet is Q_{fr}, the value of B is to be determined such that the head over the crest is h = 2.0 ft. The value of $\frac{Q_{fr}}{W^{5/2}} = \frac{348.3}{(10)^{5/2}} = 1.101$ and $\gamma = \frac{h}{W} = \frac{2.0}{10} = 0.20$. From sheet 5, read the value of $\frac{B}{W} = 1.485$ for free-flow conditions.

Concluded on Sheet 16

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 15

3. (a) The required value of B is

$$B = W\left[\frac{B}{W}\right] = 10\ (1.485) = 14.85 \text{ ft}$$

Use B = 15 ft

(b) The required value of D_r to prevent submergence at the crest is obtained by reading the value of δ at the point of intersection of the lines $\gamma = 0.20$ and $\frac{Q_{fr}}{W^{5/2}} = 1.101$ or $\delta = 0.475$. The required value of D_r is

$$D_r = W\ \delta = 10\ (0.475) = 4.75 \text{ ft}$$

Use D = 4.75 ft

(c) The value of M may be read from Table 1, sheet 3, ES-88, when

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{348.3}{10} = 34.83 \text{ cfs/ft}$$

$$M = 4.50 \text{ ft}$$

EXAMPLE 5

Given: A flat-rectangular weir box inlet with the dimensions B = 13.5 ft, W = 9 ft, h = 2.0 ft, and M = 4.00 ft; W_c = 35.2 ft and the headwall is extended across the channel. Thus no effect on the discharge is obtained by a dike. The side slope of the approach channel is 3 to 1; $z_c = 3$.

Determine: 1. The capacity without freeboard at the crest of this inlet Q_{mh} when the effect of the narrow approach channel is not considered, and the value of $\delta = \frac{D}{W}$ is sufficiently large to prevent submergence of the crest.

2. The capacity without freeboard at the origin of the vertical curve Q_{mM}.

3. The value of K.

4. The capacity without freeboard at the crest of this inlet $(Q_K)_{mh}$ when the effect of the narrow approach channel is considered, and the value of $\delta = \frac{D}{W}$ is sufficiently large to prevent submergence of the crest.

5. The required depth of the box inlet D_r to insure free-flow conditions at the crest corresponding to the discharge $(Q_K)_{mh}$

6. The capacity without freeboard of this inlet $(Q_K)_{mi}$ when the effect of the narrow approach channel is considered.

Solution: 1. Solving for the capacity without freeboard at the crest Q_{mh} of the box inlet when the width of the approach channel is sufficiently great to prevent an effect on the capacity of the inlet and the depth D is sufficiently large to prevent submergence of the crest. The capacity Q_{mh} of the box inlet is equal to the discharge of the box inlet with a head h over the crest.

$$\frac{B}{W} = \frac{13.5}{9} = 1.5 \qquad \text{and} \qquad \gamma = \frac{h}{W} = \frac{2}{9} = 0.222$$

At the intersection of $\frac{B}{W} = 1.5$ and $\gamma = 0.222$, sheet 5, read the value $\frac{Q_{mh}}{W^{5/2}} = 1.30$.

$$Q_{mh} = 1.3\ W^{5/2} = 1.3\ (9)^{5/2} = 316 \text{ cfs}$$

This is the capacity without freeboard Q_{mh} at the crest of the box inlet if D and the channel width W_c are both sufficiently great.

2. Solving for the capacity without freeboard Q_{mM} at the origin of the vertical curve section. This is read from Table 1, sheet 3, ES-88. When M = 4.00 ft, then q_{mM} = 29.47 cfs/ft.

$$Q_{mM} = W\ q_{mM} = 9\ (29.47) = 265.2 \text{ cfs}$$

Concluded on Sheet 17

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 16

3. Solving for the ratio

$$\kappa = \frac{W_c + 0.8\ z_c\ h}{W} = \frac{35.2 + 0.8\ (3)(2)}{9} = \frac{40}{9} = 4.444$$

From sheet 9, the corresponding value of K when $\kappa = 4.444$ and $\frac{B}{W} = 1.5$ is K = 0.82.

4. Solving for the capacity without freeboard $(Q_K)_{mh}$ at the crest of the box inlet when the narrow channel effects are considered and free-flow conditions exist at the crest.

$$(Q_K)_{mh} = K\ Q_{mh} = 0.82\ (316) = 259\text{ cfs}$$

This could also be obtained from sheet 9 when $\kappa = 4.444$ and $\frac{B}{W} = 1.5$, read $\frac{(Q_K)_{mh}}{W\ h^{3/2}} = 10.18$ or

$$(Q_K)_{mh} = 10.18\ W\ h^{3/2}$$
$$= 10.18\ (9)(2)^{3/2}$$
$$(Q_K)_{mh} = 259\text{ cfs}$$

5. Solving for the required depth D_r of the box inlet having the five given dimensions is read on sheet 5 at the intersection of the lines $\frac{(Q_K)_{mh}}{W^{5/2}} = \frac{259}{(9)^{5/2}} = 1.066$ and $\frac{B}{W} = 1.5$ or

$$\delta = \frac{D_r}{W} = 0.465 \quad \text{and} \quad D_r = 0.465\ (9) = 4.18\text{ ft}$$

The depth D_r is required to prevent submergence of the crest when $W_c = 35.2$ ft, and the discharge is $(Q_K)_{mh} = 259$ cfs. A value of $D > 4.18$ ft will not increase the capacity without freeboard of this channel and box inlet. The capacity of the channel and box inlet for a $D < 4.18$ ft is not determinable by these charts; such a value will cause submergence at the crest. See Ex. 1. For construction purposes D will generally be chosen to be the next size larger than D_r when D is a multiple of 3 inches, or D = 4.25 ft.

6. The smaller of the two values $(Q_K)_{mh} = 259$ cfs or $Q_{mM} = 265.2$ cfs is the capacity without freeboard $(Q_K)_{mi}$ of the box inlet when the narrow approach channel effect is considered.

$$(Q_K)_{mi} = (Q_K)_{mh} = 259\text{ cfs}$$

EXAMPLE 6

Given: The problem of designing a flat-rectangular weir box inlet for the design discharge $Q_r = 200$ cfs. The approach channel to the inlet has a width of $W_c = 24.6$ ft. The vertical drop from the crest of the inlet to the floor of the outlet is Z = 30 ft. The width W of the chute is 8 ft and the dimension h is 2.25 ft. The headwall is to extend across this channel and thus no consideration of dike effect is required. The side slopes of the approach channel are 3 to 1; $z_c = 3$.

Determine: 1. The required capacity without freeboard Q_{fr} and q_{fr}.

2. The value of B when the effect on the discharge of the narrow approach channel is neglected.

3. The value of K.

4. The value of B when the effect of the narrow channel on the discharge is considered.

5. The value of D_r required to prevent submerged flow conditions at the crest when the effect of the narrow channel is considered.

6. The capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the capacity of the approach channel and the dimension of B obtained in (4).

7. The dimension M of the box inlet.

8. The capacity of the box inlet without freeboard $(Q_K)_{mi}$ when considering the effect of the narrow approach channel.

Concluded on Sheet 18

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 17

Solution: 1. Solving for the required capacity without freeboard

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right] 200$$
$$Q_{fr} = 258 \text{ cfs}$$
$$q_{fr} = \frac{Q_{fr}}{W} = \frac{258}{8} = 32.25 \text{ cfs/ft}$$

2. The value of B when the effect on the discharge of the narrow approach channel is neglected may be obtained from sheet 5. At the intersection of lines $\frac{Q_{fr}}{W^{5/2}} = \frac{258}{8^{5/2}} = 1.425$ and $\gamma = \frac{h}{W} = \frac{2.25}{8} = 0.281$, read $\frac{B}{W} = 1.04$.

$$B = 1.04\ W = 1.04\ (8) = 8.32 \text{ ft}$$

3. The value of K may be read from sheet 9 at the intersection of the lines $\frac{Q_{fr}}{W\ h^{3/2}} = \frac{258}{8\ (2.25)^{3/2}} = 9.56$ and $\kappa = \frac{W_c + 0.8\ z_c\ h}{W} = \frac{24.6 + 0.8\ (3)(2.25)}{8} = 3.75$. Read K = 0.745.

4. The value of B when the effect of the narrow channel on the discharge is considered is again obtained at the intersection of lines $\kappa = 3.75$ and $\frac{Q_{fr}}{W\ h^{3/2}} = 9.56$, read $\frac{B}{W} = 1.575$ or

$$B = 1.575\ (8) = 12.6 \text{ ft}; \quad \text{Use } B = 12.75 \text{ ft}$$

5. The value of D_r may be obtained on sheet 5 at the intersection of the lines $\frac{Q_{fr}}{W^{5/2}} = \frac{258}{8^{5/2}} = 1.425$ and $\frac{B}{W} = 1.575$. This reads

$$\delta = \frac{D_r}{W} = 0.5625 \quad \text{or} \quad D_r = 0.5625\ W = 0.5625\ (8) = 4.50 \text{ ft}$$

Use D = 4.50 ft

6. Solving for the capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the narrow approach channel. From sheet 5 when $\frac{B}{W} = \frac{12.75}{8} = 1.59$ and $\gamma = \frac{h}{W} = \frac{2.25}{8} = 0.281$, read

$$\frac{Q_{mh}}{W^{5/2}} = 1.95$$
$$Q_{mh} = 1.95\ W^{5/2} = 1.95\ (8)^{5/2} = 353 \text{ cfs}$$
$$(Q_K)_{mh} = K\ (Q_{mh}) = 0.745\ (353) = 263 \text{ cfs}$$

7. Solving for the dimension M at the origin of the vertical curve section. Given $q_{fr} = 32.25$, see step 1. Read from Table 1, sheet 3, ES-88, the value M = 4.25 when $q_{mM} = 32.27$ and $Q_{mM} = W\ q_{mM} = (8)\ 32.27 = 258.16$ cfs.

8. Solving for the capacity without freeboard of the box inlet $(Q_K)_{mi}$ considering the effect of the narrow channel and free-flow conditions. The value of $(Q_K)_{mi}$ is equal to the smaller of the values $(Q_K)_{mh}$ and Q_{mM}.

$$(Q_K)_{mi} = Q_{mM} = 258.16 \text{ cfs}$$

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

EXAMPLE 7

This example pertains to the determination of the discharge (actually a capacity) for certain inlet, dike, and approach channel dimensions when the head over the crest is given. The example requires that the effective toe of the dike be determined. This determination is a converging approximation procedure. The first approximation is made by assuming the head over the crest as a constant value (H_e = 3 ft) along the length B and the effective toe of the dike is determined corresponding to this head. This is shown by sheet 20. The second and final approximation is made from results obtained in the first approximation. These results are shown on sheet 24.

Example 7 of ES-91 illustrates the determination of the dimension B for a given discharge, the head over the crest, and other inlet, dike, and approach channel dimensions.

Given: A flat-rectangular weir box inlet with the dimensions B = 24 ft, W = 12 ft, h = 3 ft, and M = 6.75 ft; W_c = 100 ft, X = 5 ft, t_1 = 4 ft, h_t = 1.0 ft, $z_u = z_s = z_c = 3$.

Determine: 1. The capacity without freeboard at the crest of this inlet Q_{mh} when the narrow approach channel and dike effect on discharge is not considered, and the value of D is assumed to be sufficiently large for free-flow conditions at the crest.

2. The capacity without freeboard at the section coincident with the origin of the upper vertical curve.

3. The values of η_i, $\overline{\eta}_i$, λ_i, and τ_i for β_1 = 4 ft, β_2 = 5.94 ft, β_3 = 2.46 ft, β_4 = 11.6 ft.

4. The capacity without freeboard at the crest of this inlet $(Q_\lambda)_{mh}$ when the effect on the discharge due to the narrow approach channel and the dike is considered and free-flow conditions exist at the crest.

5. The required depth of the box inlet D_r to insure free-flow conditions at the crest corresponding to the discharge $(Q_\lambda)_{mh}$

6. The capacity without freeboard of this box inlet $(Q_\lambda)_{mi}$ when the effect on the discharge due to the narrow approach channel and the dike is considered.

7. The value of λ for this box inlet and dike arrangement.

Solution: 1. Solving for the capacity without freeboard at the crest Q_{mh} of this box inlet when the dike effect is not considered.

$$\frac{B}{W} = \frac{24}{12} = 2.0 \; ; \qquad \gamma = \frac{h}{W} = \frac{3}{12} = 0.25$$

At the intersection of $\frac{B}{W} = 2.0$ and $\gamma = 0.25$, sheet 5, read the value $\frac{Q_{mh}}{W^{5/2}} = 1.94$

$$Q_{mh} = 1.94\, W^{5/2} = 1.94\,(12)^{5/2} = 968 \text{ cfs}$$

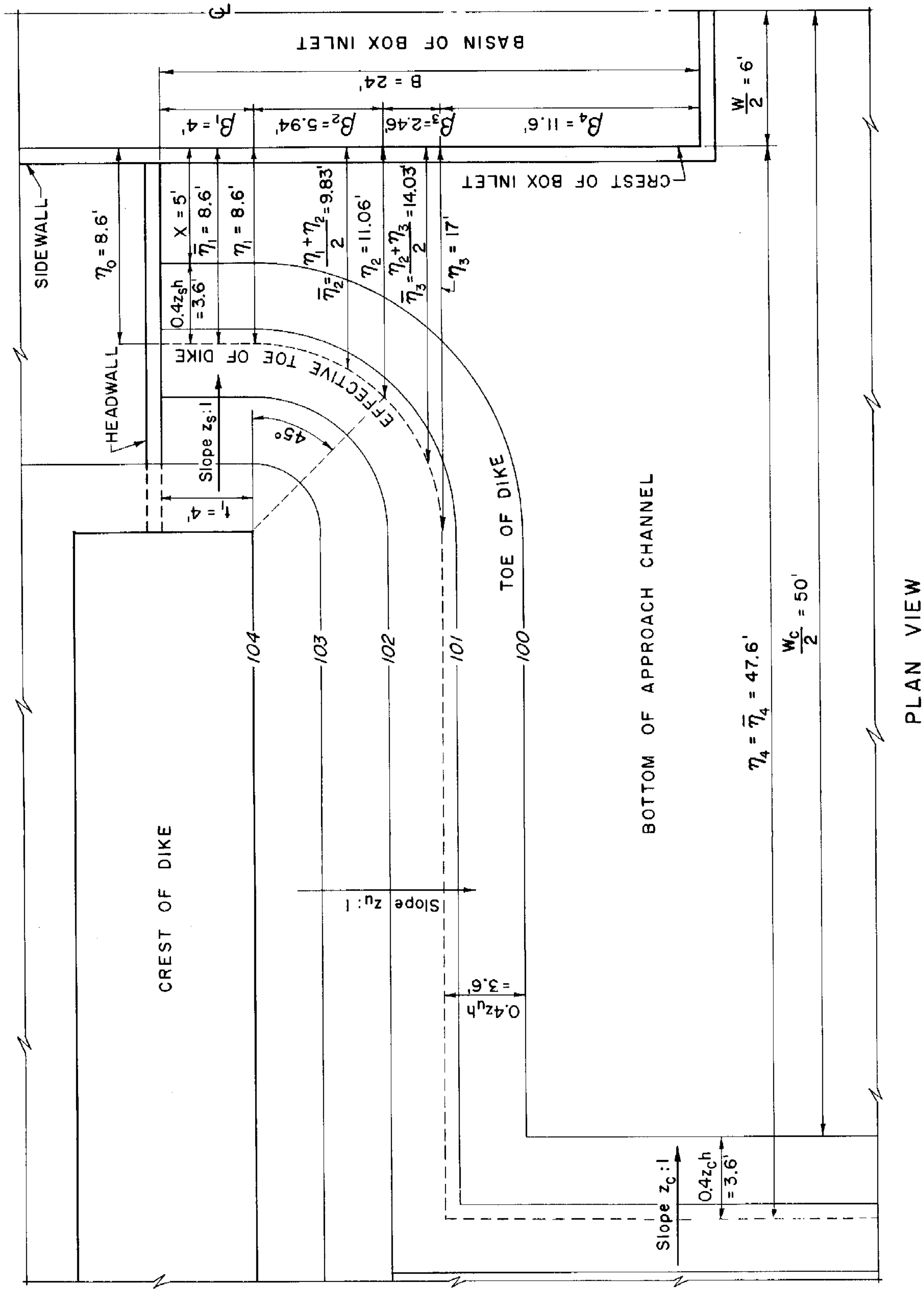
This is the capacity without freeboard Q_{mh} at the crest of the box inlet if D, W_c, and X are all sufficiently large.

2. Solving for the capacity without freeboard Q_{mM} at the origin of the upper vertical curve. This is read from Table 1, sheet 3, ES-88. When M = 6.75 ft, then q_{mM} = 64.59 cfs/ft.

$$Q_{mM} = W\, q_{mM} = 12\,(64.59) = 775.1 \text{ cfs}$$

Continued on Sheet 21

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples



REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 20 OF 24 DATE 5-26-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 19

3. The dimensions η_o, η_1, η_2, η_3, η_4 and $\bar{\eta}_1$, $\bar{\eta}_2$, $\bar{\eta}_3$, $\bar{\eta}_4$ corresponding to β_1 = 4 ft, β_2 = 5.94 ft, β_3 = 2.46 ft, and β_4 = 11.6 ft (when the head h = H_e = 3 ft) are given in the figure on sheet 20. These values along with values of $\frac{\beta_i}{W}$ and $\frac{\bar{\eta}_i}{W}$ are tabulated

i	β_i	$\bar{\eta}_i$	$\frac{\beta_i}{W}$	$\frac{\bar{\eta}_i}{W}$
1	4.0	8.6	0.333	0.717
2	5.94	9.83	0.495	0.819
3	2.46	14.03	0.205	1.169
4	11.6	47.6	0.967	3.967
Σ	24.00		2.000	

The subscript i is an index. For example, in the tabulation, when i = 3, $\beta_i = \beta_3$ = 2.46 and $\bar{\eta}_3$ = 14.03. The various values of β_i were arbitrarily selected. The upstream section of β_2 was selected to be coincident with the point of intersection of the effective toe line of the dike and a 45° plane from the corner of the dike. See sheet 20. Other end sections of β were selected according to location of changes in the values of η.

The values of β_i and $\bar{\eta}_i$ are calculated using H_e = 3 ft. The head over the crest does not remain 3 ft for each β and an adjustment for the variation in head will be made after using H_e = 3 ft.

4. From the tabulation in step 3 and sheet 13, determine T_4 in the following manner.

ia. Read the intersection of $\frac{\beta_1}{W} = \tau_1 = 0.333$ and $\frac{\bar{\eta}_1}{W} = 0.717$ and obtain $T_1 = 1.86$ and $\mu_1 = 1.095$.

b. Read the intersection of $T_1 = 1.86$ and $\frac{\bar{\eta}_2}{W} = 0.819$ and obtain $\tau_{1,2} = 0.326$ and $\mu_{1,2} = 1.07$.

iia. The value of $\tau_2 = \tau_{1,2} + \frac{\beta_2}{W} = 0.326 + 0.495 = 0.821$. Read the intersection of $\tau_2 = 0.821$ and $\frac{\bar{\eta}_2}{W} = 0.819$ and obtain $T_2 = 3.64$ and $\mu_2 = 1.45$.

b. Read the intersection of $T_2 = 3.64$ and $\frac{\bar{\eta}_3}{W} = 1.169$ and obtain $\tau_{2,3} = 0.678$ and $\mu_{2,3} = 1.14$.

iiia. The value of $\tau_3 = \tau_{2,3} + \frac{\beta_3}{W} = 0.678 + 0.205 = 0.883$. Read the intersection of $\tau_3 = 0.883$ and $\frac{\bar{\eta}_3}{W} = 1.169$ and obtain $T_3 = 4.40$ and $\mu_3 = 1.25$

b. Read the intersection of $T_3 = 4.40$ and $\frac{\bar{\eta}_4}{W} = 3.967$ and obtain $\tau_{3,4} = 0.727$ and $\mu_{3,4} = 1.03$.

iva. The value of $\tau_4 = \tau_{3,4} + \frac{\beta_4}{W} = 0.727 + 0.967 = 1.694$. Read the intersection of $\tau_4 = 1.694$ and $\frac{\bar{\eta}_4}{W} = 3.967$ and obtain $T_4 = 9.7$.

Continued on Sheet 22

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 21

The head over the crest H_e is taken to be equal to the value of h because the maximum discharge which this inlet is capable of handling through the weir section is being determined. This maximum discharge $(Q_\lambda)_{mh}$ corresponds to a head over the crest of $H_e = h = 3$ ft. As water approaches the headwall, the depth of flow decreases and thus the head over the crest also decreases in the direction towards the headwall. The head over the crest at sections 1, 2, and 3 are to be evaluated. The head H_e used in preparing the graph of sheets 11, 12, and 13 is that head over the crest at the upstream section of the particular incremental length β under consideration. Calculating the head over the crest at sections 3, 2, and 1, obtain

$$H_{e_4} = h = 3 \text{ ft (Given)}$$

$$H_{e_3} = h \frac{\mu_{3,4}}{\mu_3} = 3 \frac{1.03}{1.25} = 2.47 \text{ ft}$$

$$H_{e_2} = h \frac{\mu_{2,3}}{\mu_2} \times \frac{\mu_{3,4}}{\mu_3} = 3 \frac{1.14}{1.45} \times \frac{1.03}{1.25} = 1.94 \text{ ft}$$

$$H_{e_1} = h \frac{\mu_{1,2}}{\mu_1} \times \frac{\mu_{2,3}}{\mu_2} \times \frac{\mu_{3,4}}{\mu_3} = 3 \frac{1.07}{1.095} \times \frac{1.14}{1.45} \times \frac{1.03}{1.25} = 1.90 \text{ ft}$$

The distance between the effective toe line and the crest of the inlet is recomputed at sections 1, 2, 3, and 4. The upstream section of the incremental length β_3 is relocated since the head over the crest at this section has been reduced from 3 ft to 2.47 ft and thus the effective toe of the dike has shifted in an upstream direction a distance of 0.4 (3)(3.00 − 2.47) = 0.64 ft. This causes β_3 to change from a value of 2.46 ft to 3.1 ft and β_4 to change from 11.6 ft to 10.96 ft. The lower heads over the crest at sections 1 and 2 cause the effective toe of the dike to shift in a direction toward the crest. The location of the upstream section of the incremental lengths β_1 and β_2 remain unchanged.

Recomputing the effective toe line and values of $\overline{\eta}_i$ and $\frac{\overline{\eta}_i}{W}$. The result of the computations are illustrated on sheet 24 and shown in the following tabulation.

i	$H_{e,i}$	β_i	$\overline{\eta}_i$	$\frac{\beta_i}{W}$	$\frac{\overline{\eta}_i}{W}$
1	1.90	4.00	7.28	0.333	0.606
2	1.94	5.94	8.34	0.495	0.695
3	2.47	3.10	13.2	0.258	1.100
4	3.00	10.96	47.6	0.914	3.967
Σ		24.00		2.000	

ia. Read the intersection of $\frac{\beta_1}{W} = \tau_1 = 0.333$ and $\frac{\overline{\eta}_1}{W} = 0.606$ and obtain $T_1 = 1.80$.

b. Read the intersection of $T_1 = 1.80$ and $\frac{\overline{\eta}_2}{W} = 0.695$ and obtain $\tau_{1,2} = 0.320$.

iia. The value of $\tau_2 = \tau_{1,2} + \frac{\beta_2}{W} = 0.320 + 0.495 = 0.815$. Read the intersection of $\tau_2 = 0.815$ and $\frac{\overline{\eta}_2}{W} = 0.695$ and obtain $T_2 = 3.32$.

b. Read the intersection of $T_2 = 3.32$ and $\frac{\overline{\eta}_3}{W} = 1.1$ and obtain $\tau_{2,3} = 0.614$.

Concluded on Sheet 23

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 22

iiia. The value of $\tau_3 = \tau_{2,3} + \frac{\beta_3}{W} = 0.614 + 0.258 = 0.872$. Read the intersection of $\tau_3 = 0.872$ and $\frac{\bar{\eta}_3}{W} = 1.1$ and obtain $\Upsilon_3 = 4.25$.

b. Read the intersection of $\Upsilon_3 = 4.25$ and $\frac{\bar{\eta}_4}{W} = 3.967$ and obtain $\tau_{3,4} = 0.70$.

iva. The value of $\tau_4 = \tau_{3,4} + \frac{\beta_4}{W} = 0.70 + 0.914 = 1.614$. Read the intersection of $\tau_4 = 1.614$ and $\frac{\bar{\eta}_4}{W} = 3.967$ and obtain $\Upsilon_4 = 9.3$.

The capacity without freeboard at the crest $(Q_\lambda)_{mh}$ when free-flow conditions exist at the crest and the effect of the narrow approach channel and dike on the capacity becomes

$$\frac{(Q_\lambda)_{mh}}{W\ h^{3/2}} = 3.09 + \Upsilon_4$$

or

$$(Q_\lambda)_{mh} = (3.09 + 9.3)(12)(3)^{3/2} = 773 \text{ cfs}$$

A closer evaluation would be obtained by subdividing the intervals β_2 and β_3.

5. The depth D_r required to insure free-flow conditions at the crest of the inlet can be obtained by reading the intersection of lines $\frac{(Q_\lambda)_{mh}}{W^{5/2}} = \frac{773}{12^{5/2}} = 1.55$ and $\frac{B}{W} = 2.0$. From sheet 5 obtain $\delta = \frac{D_r}{W} = 0.605$ or

$$D_r = 0.605\ W = 0.605\ (12) = 7.26 \text{ ft}$$

$$\text{Use } D = 7.50 \text{ ft}$$

The depth D_r is required to prevent submergence of the crest of the inlet for the given narrow channel and dike when the discharge is $(Q_\lambda)_{mh} = 773$ cfs. A value of $D > 7.26$ ft will not increase the capacity without freeboard for this narrow channel, dike, and box inlet. The capacity of the channel, dike, and box inlet for a $D < 7.26$ ft is not determinable by these charts; such a value will cause submergence at the crest. See Ex. 1. For construction purposes D will generally be chosen to be the next size larger than D_r when D is a multiple of 3 inches or D = 7.50 ft.

6. The smaller of the two values $(Q_\lambda)_{mh} = 773$ cfs or $Q_{mM} = 775.1$ cfs is the capacity without freeboard $(Q_\lambda)_{mi}$ of the box inlet when the effect of the narrow approach channel and dike on the capacity is considered.

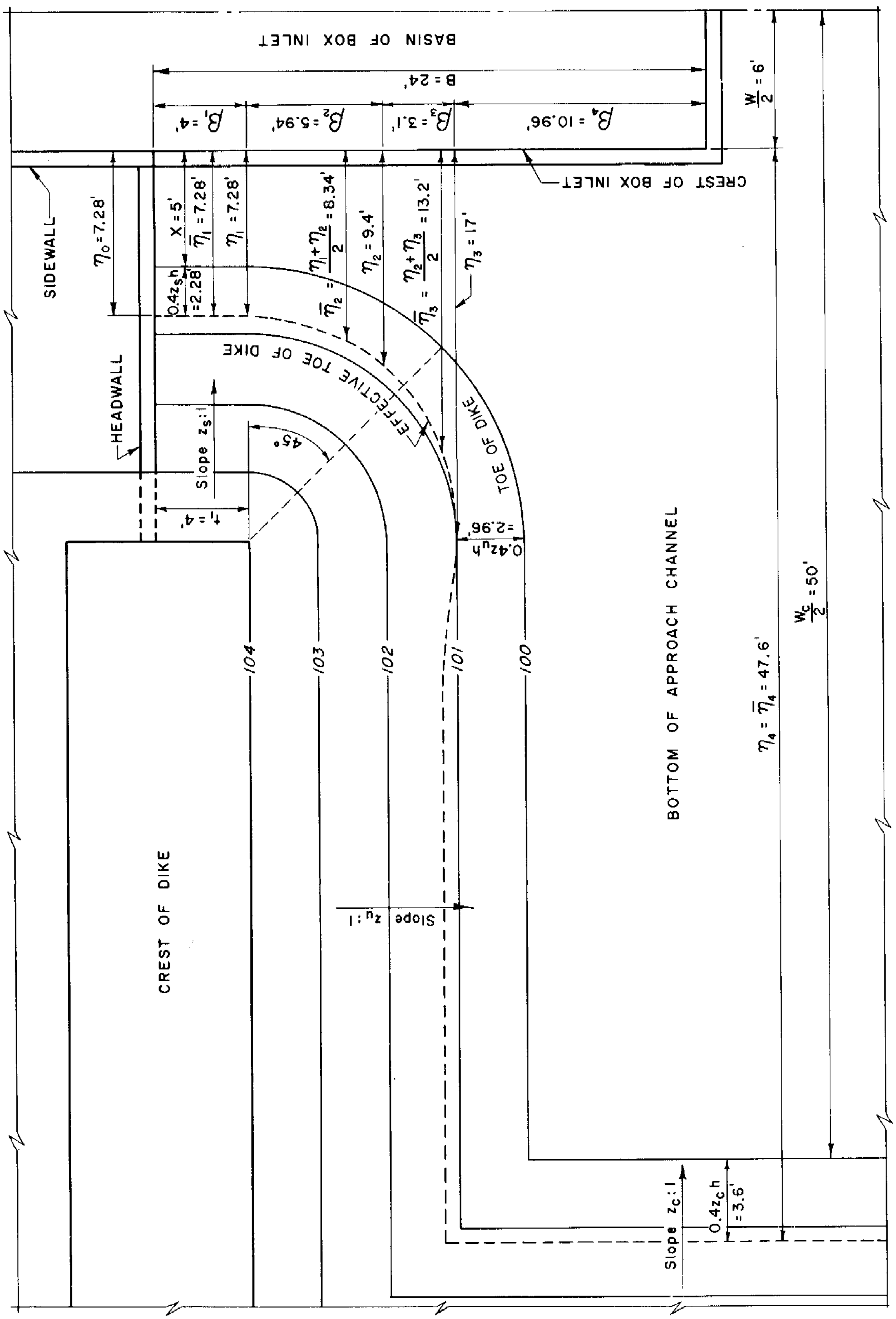
$$(Q_\lambda)_{mi} = (Q_\lambda)_{mh} = 773 \text{ cfs}$$

7. The value of λ is determined by the relation

$$(Q_\lambda)_{mh} = \lambda\ Q_{mh}$$

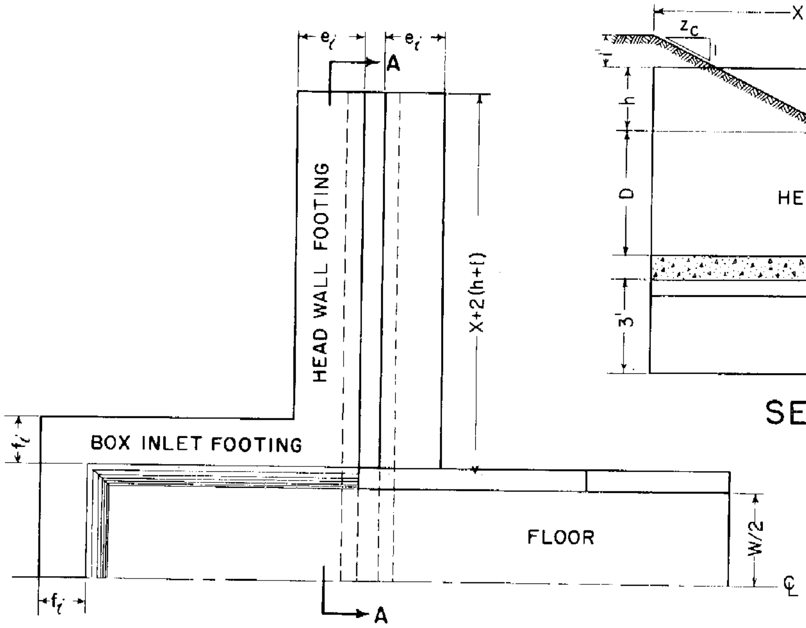
$$\lambda = \frac{(Q_\lambda)_{mh}}{Q_{mh}} = \frac{773}{968} = 0.799$$

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

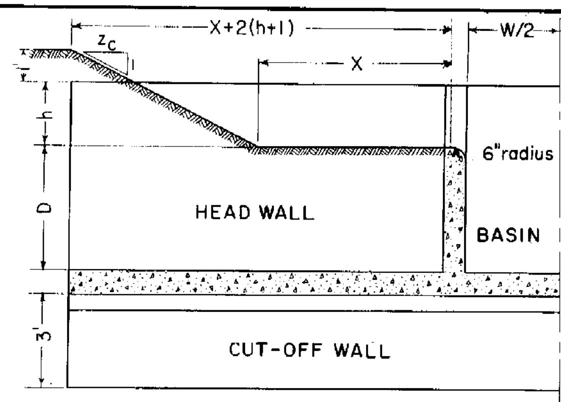


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 24 OF 24 DATE 6-14-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLET; General layout



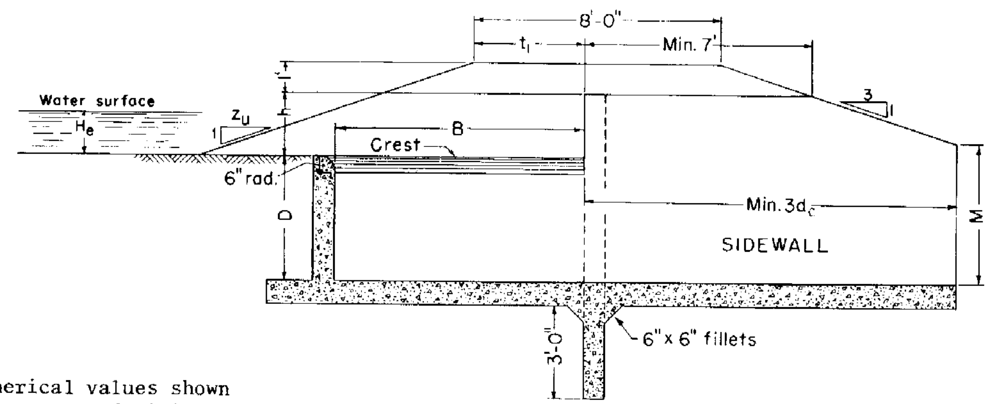
HALF-PLAN



SECTION A-A

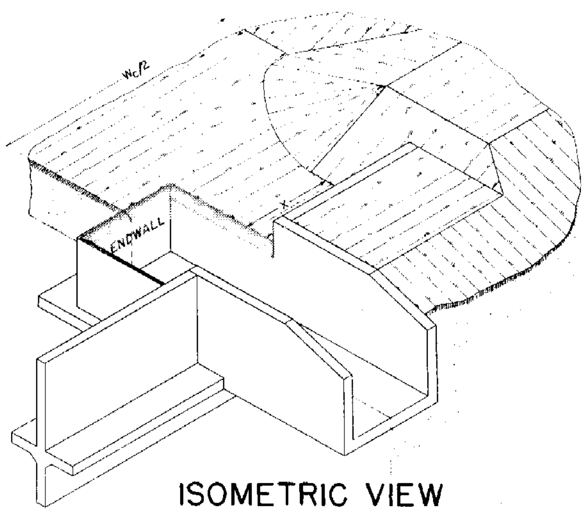
Note-
Hydraulic formulas are given on sheet 4.

Capacities for this structure with a wide approach channel and no dike effect, are given on sheets 5,6,and 7.



Numerical values shown are suggested minimums.

SECTION ALONG CENTER LINE

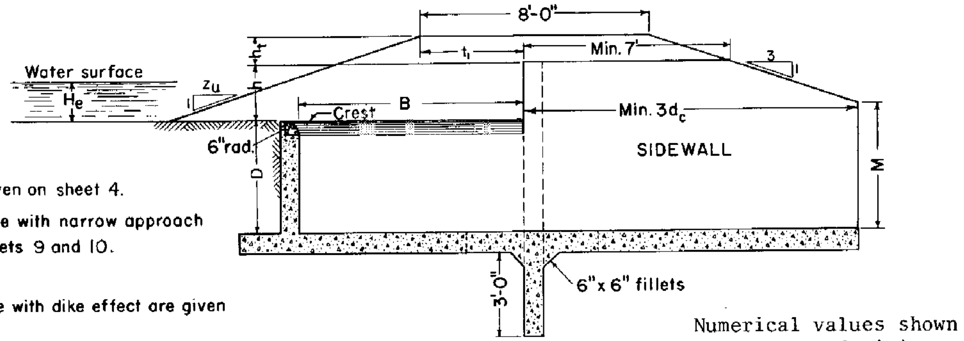


ISOMETRIC VIEW

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 91 SHEET 1 OF 24 DATE 3-1-55

Revised 10/77

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLET; Effect of narrow channel and dike on discharge



Note –

Hydraulic formulas are given on sheet 4.

Capacities for this structure with narrow approach channel are given by sheets 9 and 10.

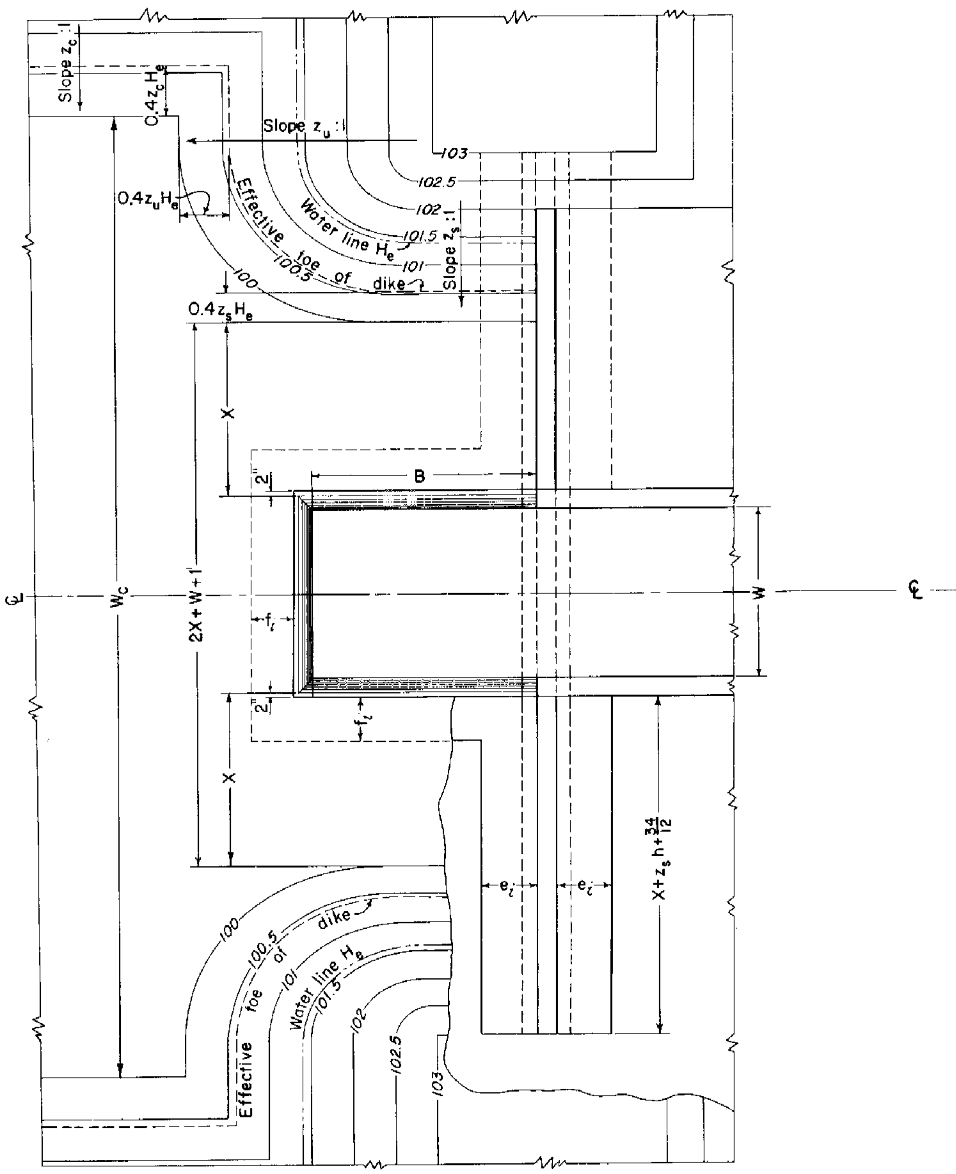
Capacities of this structure with dike effect are given by sheets 11, 12, and 13.

Required depths of box inlets are given by sheets 5, 6 and 7.

(See sheet 1 for isometric view)

Numerical values shown are suggested minimums.

SECTION ALONG CENTER LINE



PLAN

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 91 SHEET 2 OF 24 DATE 3-1-55

Revised 10/77

DEFINITION OF SYMBOLS

B = Inside length of the box inlet measured from the downstream face of the endwall to the upstream face of the headwall in ft
D = Depth (i.e., distance from the crest to the floor) of the box inlet in ft
D_r = Required depth of box inlet to prevent submergence at the crest when the discharge is Q in ft
h = Height of sidewalls above the crest of the box inlet in ft
h_t = Height of embankment above the top of sidewalls in ft
H_e = Specific energy head above the crest of the inlet corresponding to any discharge Q the inlet is capable of conveying in ft
i = Indices used for β, η, $\bar{\eta}$, τ, and T
K = $\frac{Q_K}{Q}$
L = Length of developed crest = 2 B + W + 2
M = Height of sidewall above the floor of the box inlet at the junction with the vertical curve section in ft
q = Discharge per unit width W or $q = \frac{Q}{W}$ in cfs/ft
Q = Discharge corresponding to the head H_e of a box inlet having no narrow approach channel or dike effect in cfs
Q_r = Design discharge in cfs
Q_{fr} = Required capacity without freeboard in cfs
Q_{si} = Capacity of inlet in cfs
Q_{mi} = Capacity of inlet without freeboard in cfs
Q_{mh} = Capacity of inlet without freeboard at the crest in cfs; the discharge $Q = Q_{mh}$ when $H_e = h$
Q_{mM} = Capacity of inlet without freeboard at the origin of the upper vertical curve in cfs
$(Q_K)_{mh}$ = Capacity without freeboard of a box inlet at the crest when a narrow approach channel is considered in cfs; the discharge $Q = (Q_K)_{mh}$ when $H_e = h$
Q_K = Discharge corresponding to the head H_e of a box inlet having a narrow approach channel in cfs
Q_λ = Discharge corresponding to the head of H_e of a box inlet having dike effect in cfs
$(Q_K)_{mi}$ = Capacity without freeboard of a box inlet and narrow approach channel of width W_c and downstream end section having a sidewall height M in cfs
$(Q_\lambda)_{mh}$ = Capacity without freeboard of a box inlet at the crest when a narrow channel and dike are considered in cfs; the discharge $Q_\lambda = (Q_\lambda)_{mh}$ when $H_e = h$
$(Q_\lambda)_{mi}$ = Capacity without freeboard of a box inlet when a narrow channel and dike effects are both considered as well as the downstream section having a sidewall height M in cfs
t_1 = That portion of the top width of the embankment covering the headwall upstream from the upstream face of the headwall in ft
W = Width of inlet in ft
W_c = Bottom width of the approach channel for the box inlet in ft
z_c = Side slope (horizontal distance per vertical foot) of approach channel
z_s = Side slope (horizontal distance per vertical foot) of dike covering the headwall in the direction towards the crest of the box inlet (see sheet 2)
z_u = Side slope (horizontal distance per vertical foot) of dike covering the headwall in an upstream direction. (S (see sheet 2)
X = Distance of the toe of the dike covering the headwall from the crest of the box inlet in ft
Z = Vertical drop from the crest of the inlet to the floor of the SAF outlet in ft
β = An incremental length of distance B + 0.5 in ft (see figure, sheet 20)
κ = Ratio $\frac{W_c + 0.8\, z_c H_e}{W + 1}$
λ = $\frac{Q_\lambda}{Q}$
τ = See formula sheet 4 or sheets 11 and 13
T = Values read on chart, sheets 11, 12, and 13
η = Distance between effective toe of dike covering the headwall and the crest of the inlet in ft
$\bar{\eta}$ = Average distance of effective toe of dike covering the headwall from the crest of the box inlet in the incremental length β in ft
ψ = $\frac{1.2\, g^{1/3}\, W^{2/3}}{Q^{2/3}} D_r$ where $\psi > 1$ (see equations, sheet 4)
γ = Ratio $\frac{H_e}{W + 1}$
δ = Ratio $\frac{W^{2/3}}{(W + 1)^{5/3}} D_r$
μ = Values read from graph, sheets 11, 12, and 13

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-91 SHEET 3 OF 24 DATE 6-4-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Formulas

FORMULAS

The relationship of the discharge-head over the crest for a rounded-rectangular weir box inlet having a wide approach channel and no dike effect is

$$Q = 3.1\ (2\ B + W + 2)\ H_e^{3/2} \qquad \text{when}$$

$$0 < H_e \leq 0.49\ W + 0.04\ B + 0.51; \quad (W \geq 4\ \text{ft}) \qquad \text{and}$$

$$0 < Q \leq 5.5\ (W + 1)^{5/2} \qquad \text{and}$$

$$\psi^3 - 3\ \psi + 2\left[\frac{W + 1}{2\ B + W + 2}\right]^2 = 0 \qquad \text{where}$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi > 1$$

These relations are expressed in graphical form by sheets 5, 6, and 7 where

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}}\ D_r \qquad \text{and} \qquad \gamma = \frac{H_e}{W + 1}$$

values of $H_e^{3/2}$, $(W + 1)^{5/2}$, and $\frac{W^{2/3}}{(W + 1)^{5/3}}$ are given on sheet 8. When $H_e > 0.49\ W + 0.04\ B + 0.51$, no algebraic relationship is given. The last two relations are a requirement of the value of D to prevent submergence of the crest. The relationship of the discharge-head over the crest of a rounded-rectangular weir box inlet having a narrow channel effect but no dike effect is

$$Q_K = K\ Q$$

where the value of K is obtained from sheets 9 and 10. The value of Q_K may be obtained from sheets 9 and 10 without determining the value of K. The value of κ is

$$\kappa = \frac{W_c + 0.8\ z_c\ H_e}{W + 1}$$

The discharge-head relationship of a rounded-rectangular weir box inlet having a narrow channel and dike effect is given in graphical form by sheets 11, 12, and 13.

$$Q_\lambda = \lambda\ Q$$

The effective toe of the dike is a distance of $0.4\ z_s\ H_e$ (or $0.4\ z_u\ H_e$) from the toe of the dike. At the headwall the effective toe of the dike is a distance η_o from the crest of the spillway or

$$\eta_o = X + 0.4\ z_s\ H_e \qquad \text{and} \qquad \overline{\eta}_i = \frac{\eta_{i+1} + \eta_i}{2}$$

and

$$\beta_1 + \beta_2 + \cdots + \beta_i + \cdots + \beta_n = B + 0.5$$

where the subscript n is equal to the integer designating the number of increments considered in the length B + 0.5. The increments β are numbered by subscripts in an upstream direction. The subscripts of η pertain to the end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The subscript of $\overline{\eta}$ equals the subscript of β when $\overline{\eta}$ is associated with the same incremental length β.

$$\tau_1 = \frac{\beta_1}{W + 1} \qquad \text{and} \qquad \tau_i = \tau_{i-1,i} + \frac{\beta_i}{W + 1} \qquad \text{where} \qquad i \geq 2$$

The value of $\tau_{i-1,i}$ is read from sheets 11, 12, and 13 at τ_{i-1} and $\frac{\overline{\eta}_i}{W + 1}$. The values of μ are used to determine the head over the crest at the various sections along the length B + 0.5 and to determine the location of the effective toe of the dike. The head over the crest at section i is

$$H_{e,i} = H_e\ \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdots \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

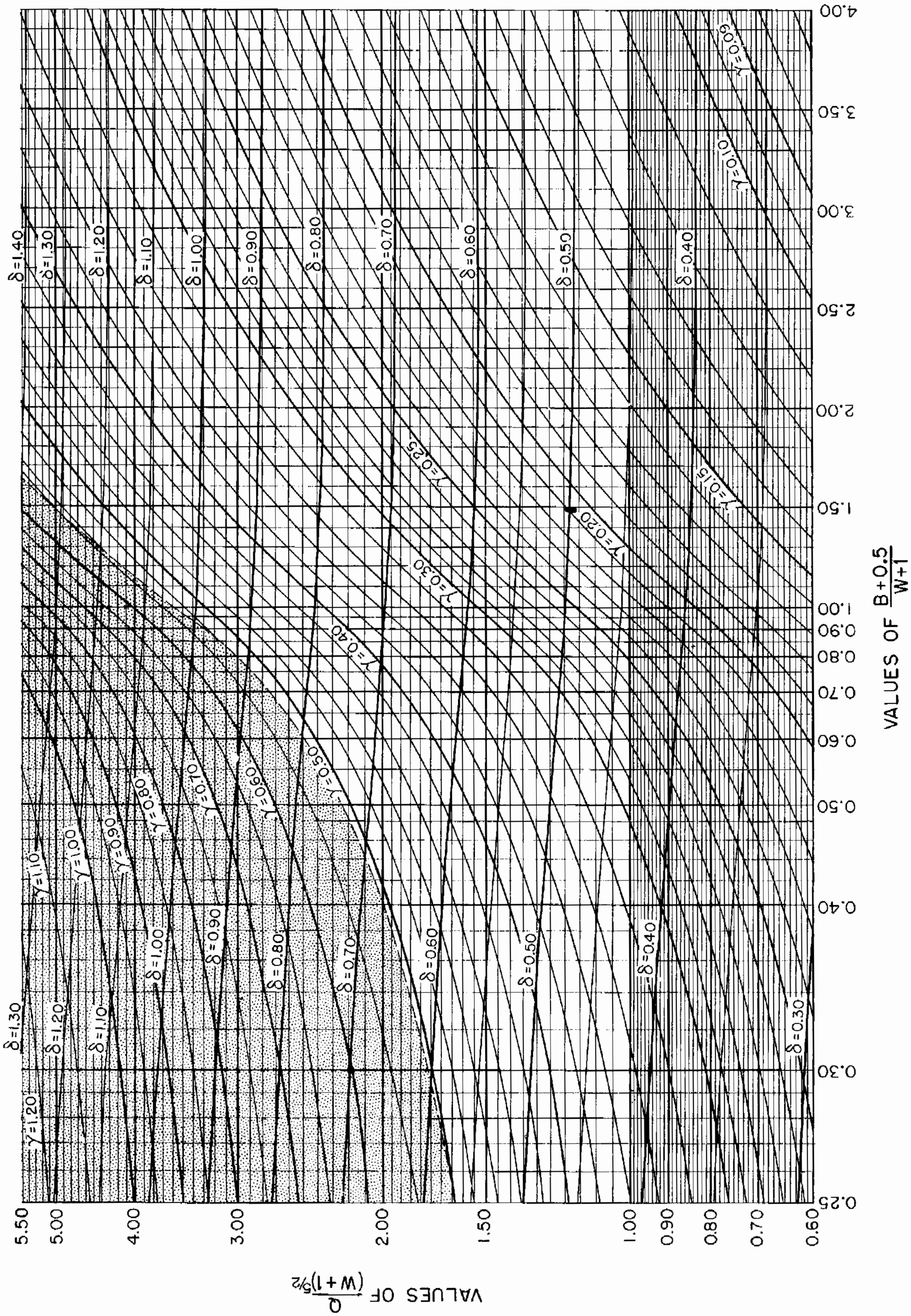
$$\tau_n + 3.09 = \frac{Q_\lambda}{(W + 1)\ H_e^{3/2}}$$

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 91 SHEET 4 OF 24 DATE 6-4-55

CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or narrow channel effects.

$\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D_r$

$\gamma = \frac{H_e}{W+1}$



Stippled area gives those values of B, W, and He for flow which the weir formula is not applicable.

REFERENCE
This chart was developed by Paul. D. Doubt of the Design Section.

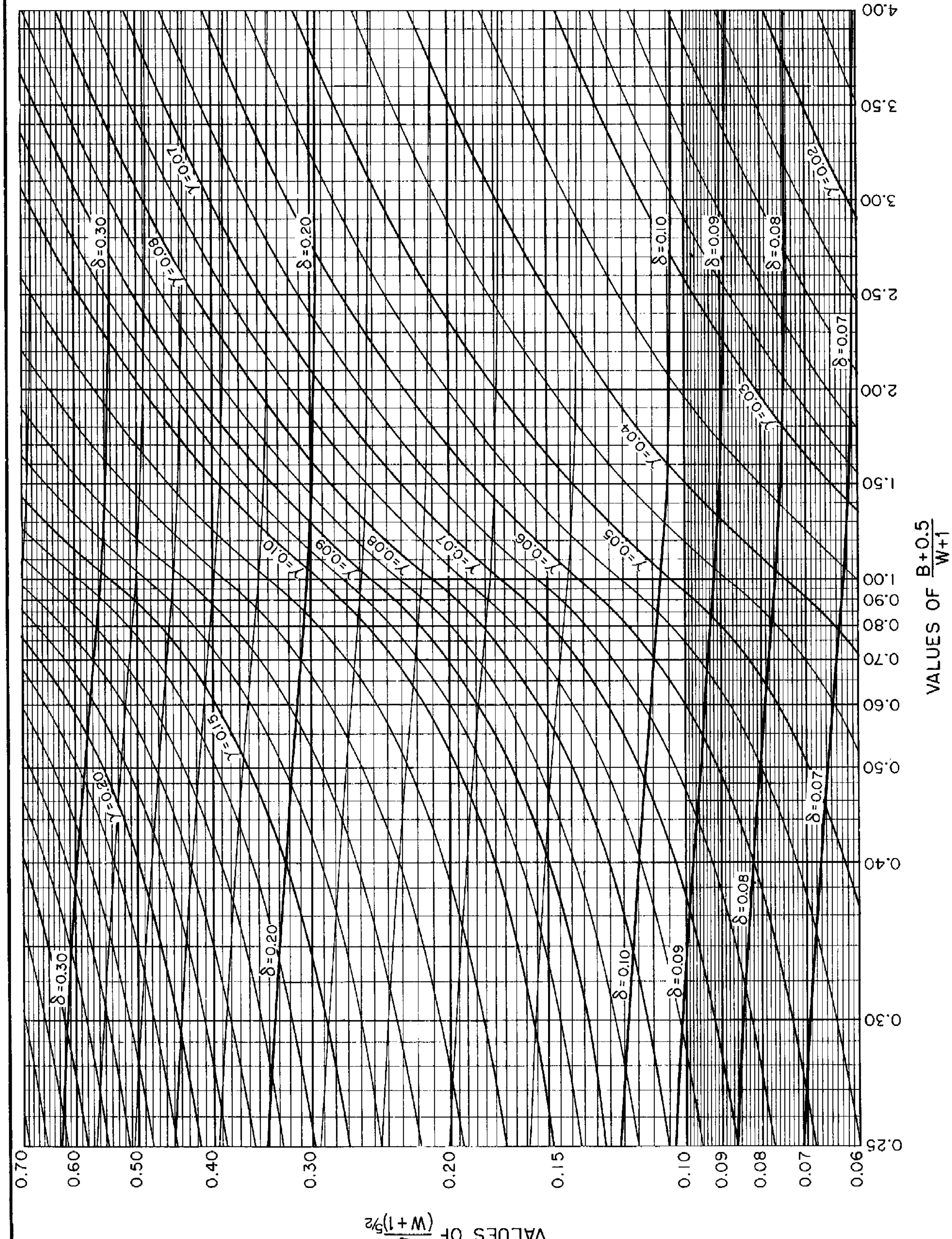
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-91
SHEET 5 OF 24
DATE 4-5-55

CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or narrow channel effects.

$\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D_r$

$\gamma = \frac{H_e}{W+1}$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

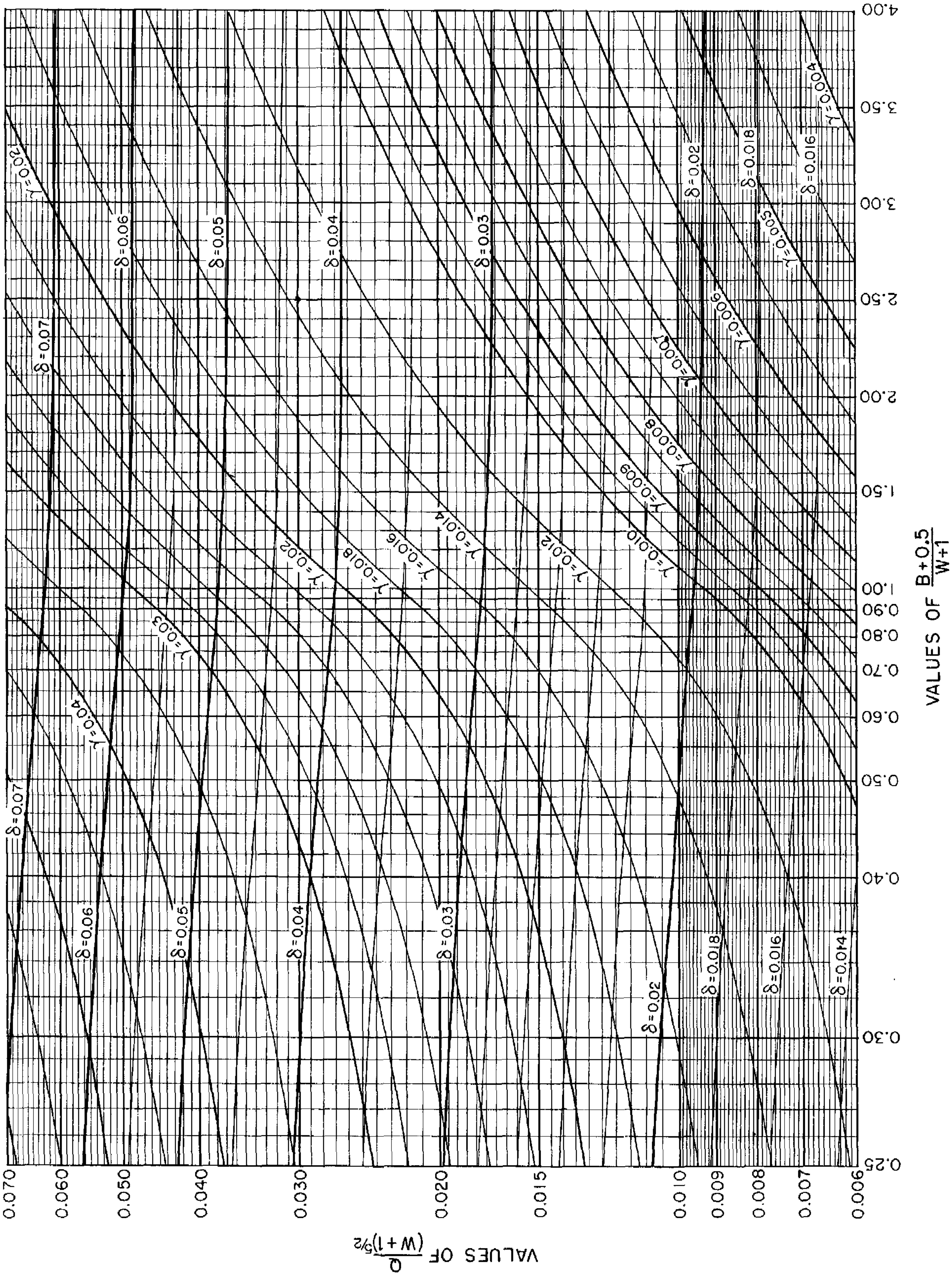
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-91
SHEET 6 OF 24
DATE 4-5-55

CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or narrow channel effects.

$\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D_r$

$\gamma = \frac{H_e}{W+1}$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

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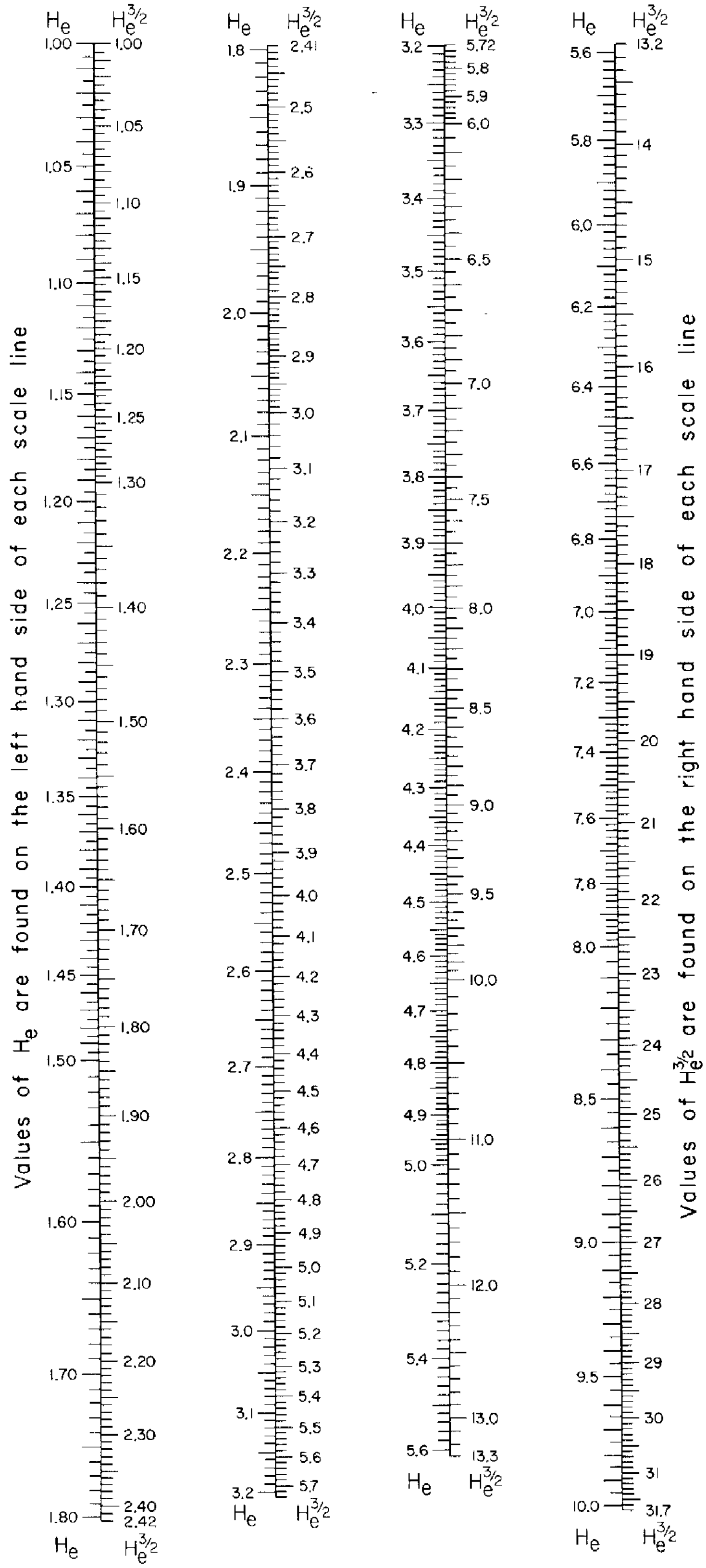
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-91
SHEET 7 OF 24
DATE 4-5-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS.

W-ft	$(W+1)^{5/2}$	$\frac{W^{2/3}}{(W+1)^{5/3}}$
3.0	32.000	0.2064
3.5	42.957	0.1918
4.0	55.902	0.1724
4.5	70.943	0.1591
5.0	88.182	0.1476
5.5	107.72	0.1376
6.0	129.64	0.1289
6.5	154.05	0.1212
7.0	181.02	0.1144
7.5	210.64	0.1082
8.0	243.00	0.1027
8.5	278.17	0.09774
9.0	316.23	0.09321
9.5	357.25	0.08909
10.0	401.31	0.08532
10.5	448.48	0.08184
11.0	498.83	0.07864
11.5	552.43	0.07568
12.0	609.34	0.07293
12.5	669.63	0.07037
13.0	733.36	0.06799
13.5	800.61	0.06576
14.0	871.42	0.06367
14.5	945.87	0.06171
15.0	1024.0	0.05987
15.5	1105.9	0.05813
16.0	1191.6	0.05649
16.5	1281.1	0.05494
17.0	1374.6	0.05348
17.5	1472.1	0.05209
18.0	1573.6	0.05077
18.5	1679.1	0.04951
19.0	1788.9	0.04832
19.5	1902.8	0.04718
20.0	2020.9	0.04609
20.5	2143.4	0.04506
21.0	2270.2	0.04407
21.5	2401.4	0.04312
22.0	2537.0	0.04221
22.5	2677.1	0.04134
23.0	2821.8	0.04050
23.5	2971.1	0.03970
24.0	3125.0	0.03893
24.5	3283.6	0.03818
25.0	3446.9	0.03747
25.5	3615.1	0.03678
26.0	3788.0	0.03612
26.5	3965.8	0.03548
27.0	4148.5	0.03486
27.5	4336.2	0.03426
28.0	4528.9	0.03369
28.5	4726.7	0.03313
29.0	4929.5	0.03259
29.5	5137.5	0.03208
30.0	5350.6	0.03156
30.5	5569.0	0.03106
31.0	5792.6	0.03060
31.5	6021.6	0.03014
32.0	6255.8	0.02969
32.5	6497.2	0.02925
33.0	6740.6	0.02883
33.5	6991.1	0.02842
34.0	7247.2	0.02802
34.5	7508.8	0.02764
35.0	7776.0	0.02726
35.5	8048.8	0.02690
36.0	8327.3	0.02654
36.5	8611.5	0.02619
37.0	8901.4	0.02585
37.5	9197.1	0.02552
38.0	9498.6	0.02520
38.5	9806.0	0.02488
39.0	10,119	0.02458
39.5	10,439	0.02428
40.0	10,764	0.02399



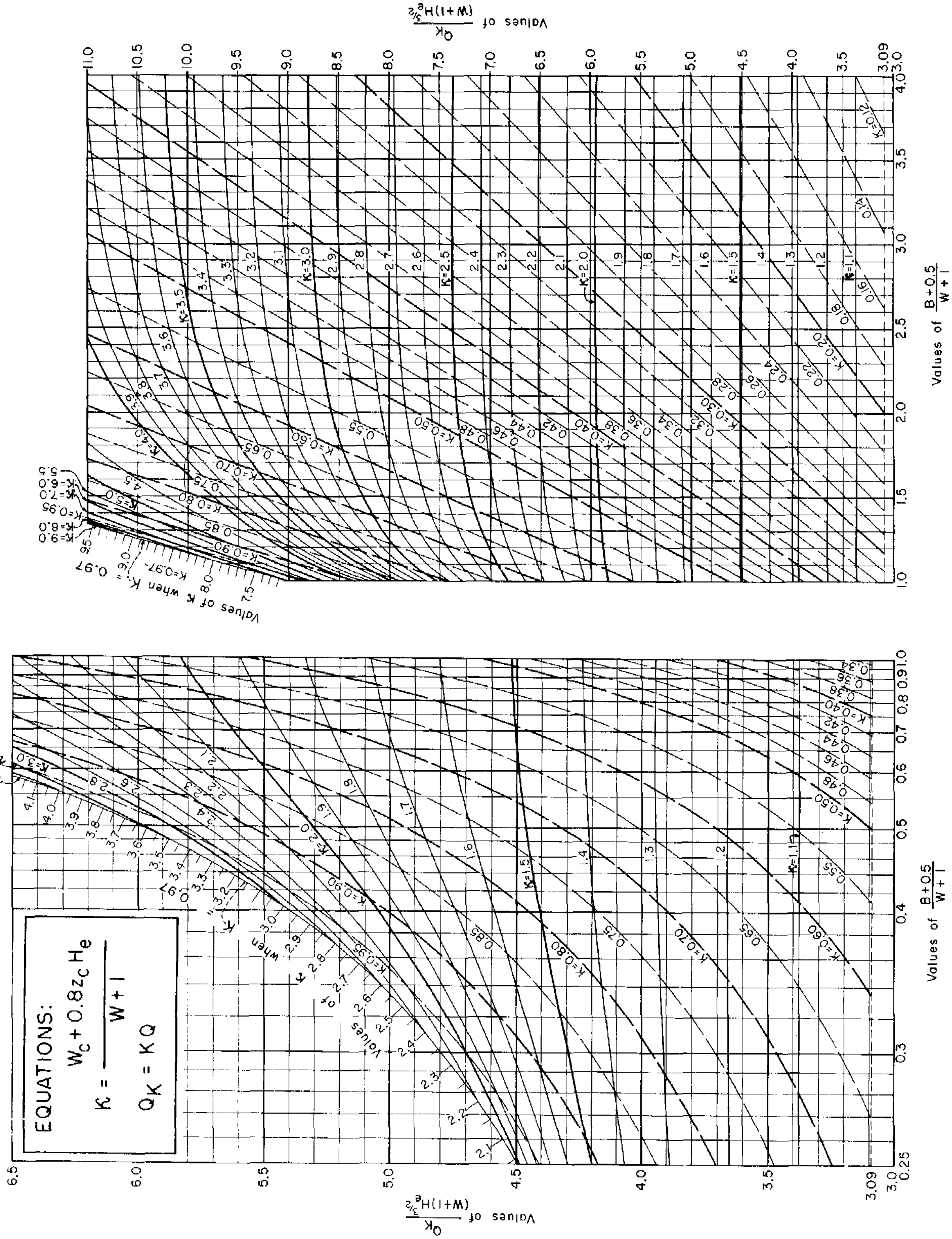
REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-91
SHEET 8 OF 24
DATE 6-10-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS;

Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.



EQUATIONS:

$$K = \frac{W_c + 0.8 z_c H_e}{W+1}$$

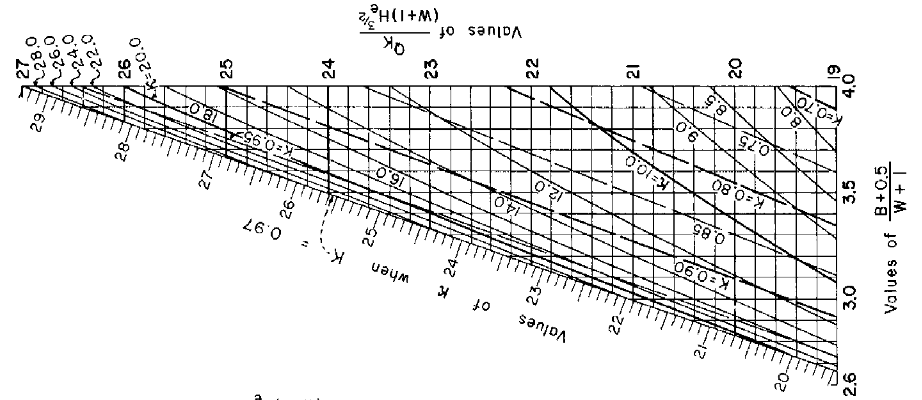
$$Q_K = KQ$$

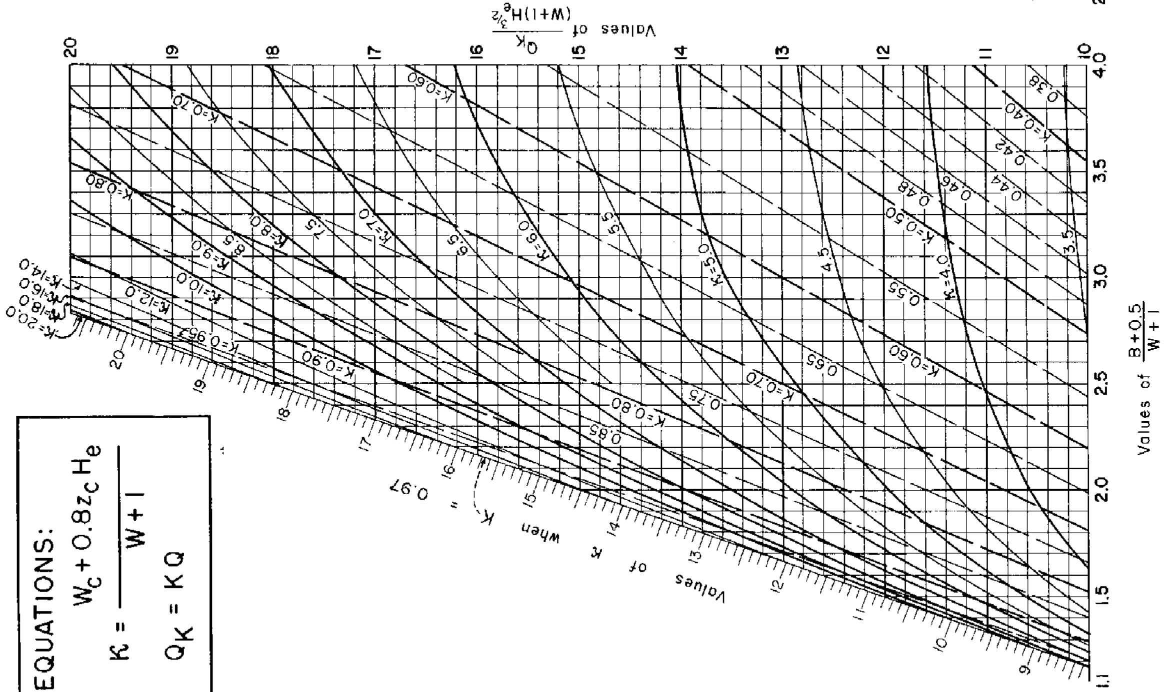
REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION · DESIGN SECTION

STANDARD DWG. NO.
ES- 91
SHEET 9 OF 24
DATE 5-20-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.

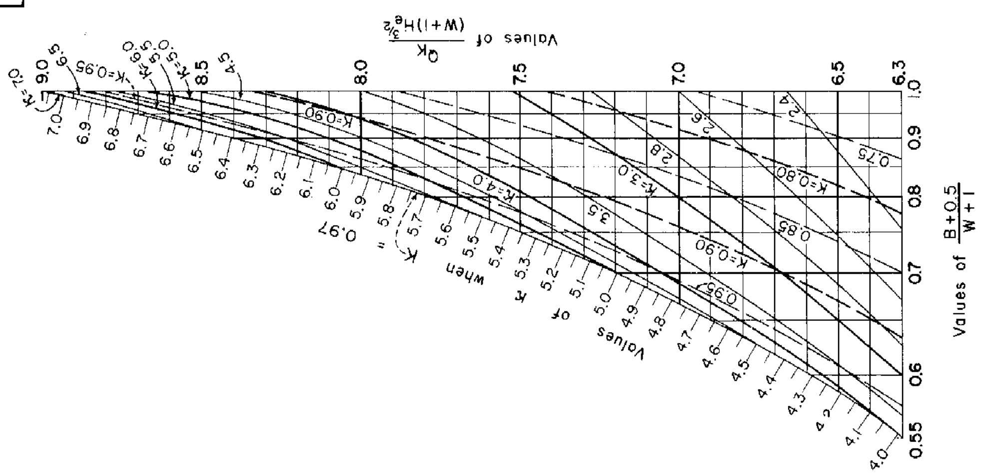




EQUATIONS:

$$K = \frac{W_c + 0.8 z_c H_e}{W+1}$$

$$Q_K = KQ$$



REFERENCE

This chart was developed by Paul D. Doubt of the Design Section.

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SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES-91

SHEET 10 OF 24

DATE 5-20-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.

Equation for discharge of a box inlet having a dike is $Q_\lambda = \lambda Q$. Effective toe of dike is a distance of $0.4\ z_s\ H_e$ (or $0.4\ z_u\ H_e$) from toe of dike. Thus $\eta_o = X + 0.4\ z_s\ H_e$ and $\bar{\eta}_i = \frac{\eta_{i-1} + \eta_i}{2}$ and $\beta_1 + \beta_2 + \cdot\cdot\cdot + \beta_i + \cdot\cdot\cdot + \beta_n = B + 0.5$ where the subscript n is equal to the integer designating the number of increments considered in the length B + 0.5. The increments β are numbered by subscripts in an upstream direction. The subscripts of η pertain to end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The subscript of $\bar{\eta}$ equals the subscript of β when $\bar{\eta}$ is associated with the same incremental length β.

$$\tau_1 = \frac{\beta_1}{W + 1}$$

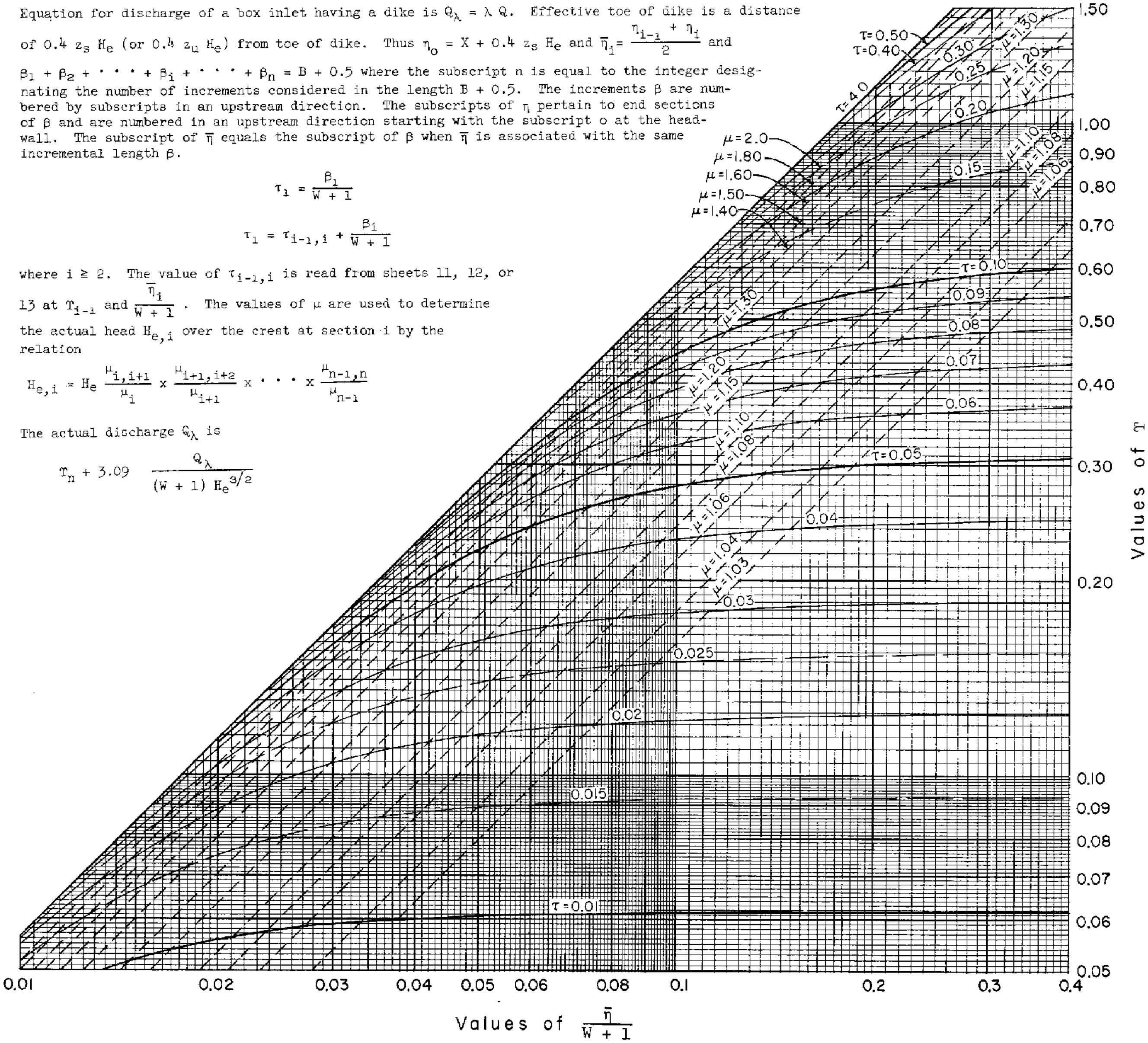
$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W + 1}$$

where i ≥ 2. The value of $\tau_{i-1,i}$ is read from sheets 11, 12, or 13 at T_{i-1} and $\frac{\bar{\eta}_i}{W + 1}$. The values of μ are used to determine the actual head $H_{e,i}$ over the crest at section i by the relation

$$H_{e,i} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdot\cdot\cdot \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

$$T_n + 3.09 \quad \frac{Q_\lambda}{(W + 1)\ H_e^{3/2}}$$

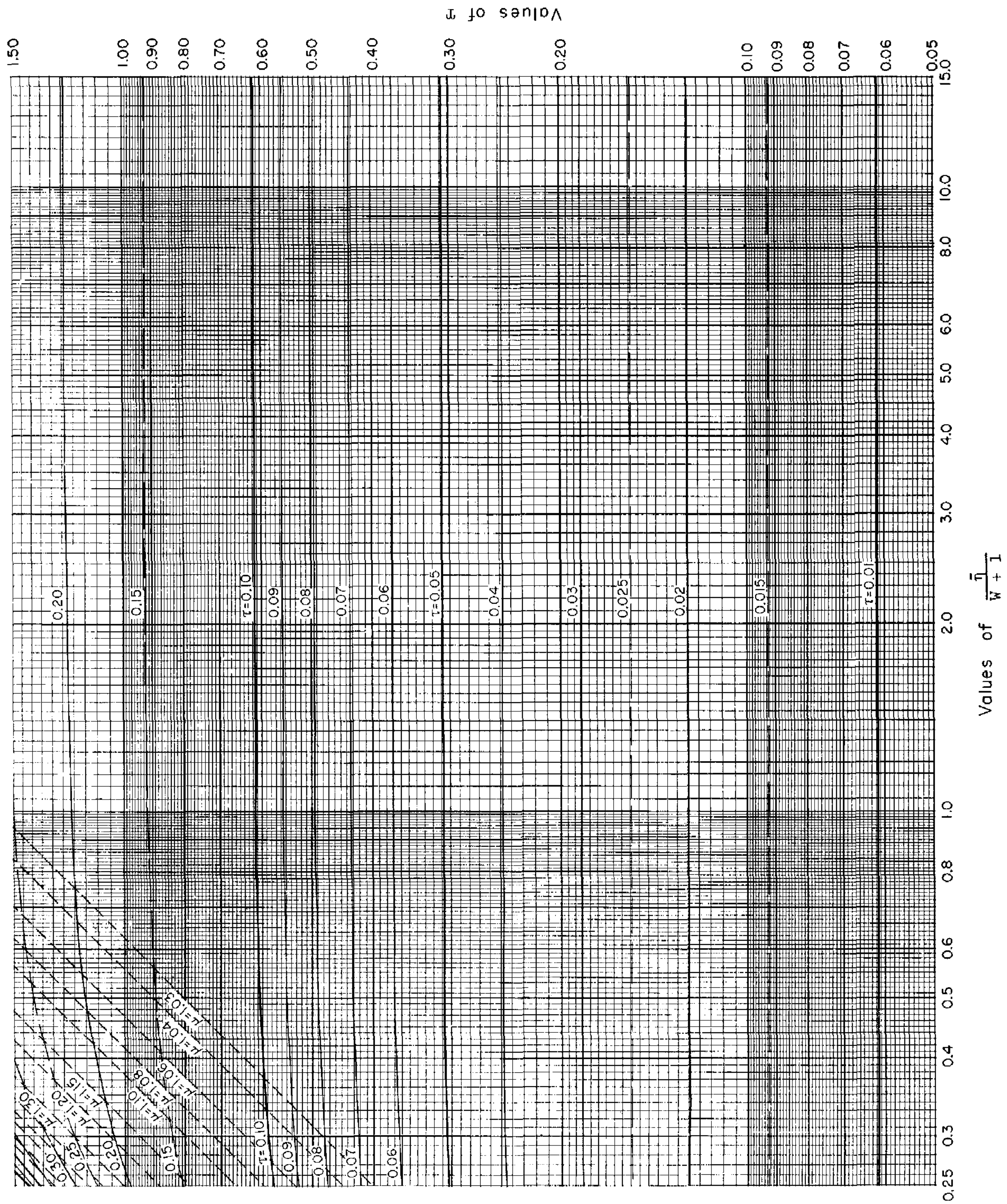


REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

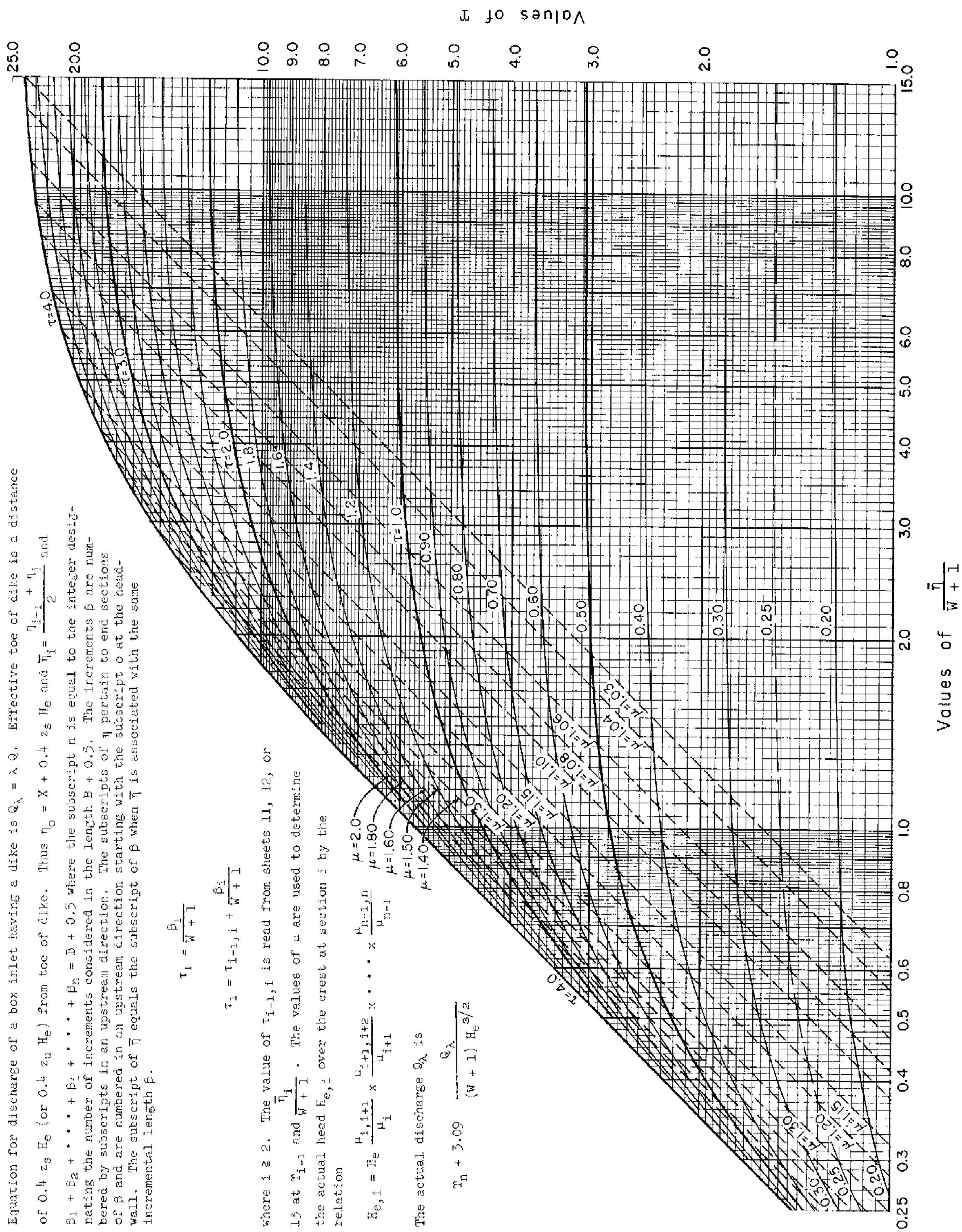
STANDARD DWG. NO. ES-91
SHEET 11 OF 24
DATE 6-14-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.



REFERENCE		STANDARD DWG. NO.
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	ES- 91 SHEET 12 OF 24 DATE 6-14-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.



Equation for discharge of a box inlet having a dike is $Q_\lambda = \lambda\, Q$. Effective toe of dike is a distance of $0.4\, z_s H_e$ (or $0.4\, z_u H_e$) from toe of dike. Thus $\eta_o = X + 0.4\, z_s H_e$ and $\bar{\eta}_i = \frac{\eta_{i-1} + \eta_i}{2}$ and

$\beta_1 + \beta_2 + \cdots + \beta_i + \cdots + \beta_n = B + 0.5$ where the subscript n is equal to the integer designating the number of increments considered in the length B + 0.5. The increments β are numbered by subscripts in an upstream direction. The subscripts of η pertain to end sections of β and are numbered in an upstream direction starting with the subscript o at the headwall. The subscript of $\bar{\eta}$ equals the subscript of β when $\bar{\eta}$ is associated with the same incremental length β.

$$\tau_1 = \frac{\beta_1}{W + 1}$$

$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W + 1}$$

where i ≥ 2. The value of $\tau_{i-1,i}$ is read from sheets 11, 12, or 13 at τ_{i-1} and $\frac{\bar{\eta}_i}{W + 1}$. The values of μ are used to determine the actual head $H_{e,i}$ over the crest at section i by the relation

$$H_{e,i} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdots \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

$$\tau_n + 3.09 \quad \frac{Q_\lambda}{(W + 1)\, H_e^{3/2}}$$

REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO. ES- 91
SHEET 13 OF 24
DATE 6-14-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

EXAMPLE 1

Given: A rounded-rectangular weir box inlet for a chute spillway. The inside dimensions are W = 10 ft, B = 6 ft, and D = 4 ft. The approach channel and the dike covering the headwall have no effect on the discharge of the inlet.

Determine: 1. The head H_e over the crest at which the discharge Q begins to be affected by the dimension D; that is, the head H_e corresponding to impending submerged flow conditions at the crest.

2. The discharge corresponding to the head H_e determined in (1).

Solution: 1. Solving for the head H_e over the crest at which the discharge is affected by the dimension D. The value of $\frac{B + 0.5}{W + 1}$ is $\frac{6.5}{11} = 0.591$. The value of $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D$ is $\frac{(10)^{2/3}}{(10 + 1)^{5/3}} 4 = 0.341$. The point of intersection of the line having the value of $\frac{B + 0.5}{W + 1} = 0.591$ and the line $\delta = 0.341$, sheet 5, has a value $\gamma = \frac{H_e}{W + 1} = 0.218$ or

$$H_e = 0.218\ (10 + 1) = 2.40 \text{ ft}$$

For heads over the crest greater than $H_e = 2.40$ ft, the discharge depends on the value of D = 4 ft as well as B, W, and H_e because submerged flow at the crest occurs.

2. Solving for the discharge corresponding to $H_e = 2.40$ ft. Since D is sufficiently large to insure no submergence of the crest, obtain from the chart at the intersection of $\frac{B + 0.5}{W + 1} = 0.591$ and $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D = 0.341$ the value $\frac{Q}{(W + 1)^{5/2}} = 0.693$ or

$$Q = 0.693\ (10 + 1)^{5/2} = 278 \text{ cfs}$$

If the value of D had been greater than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.40$ ft remains the same; i.e., Q = 278 cfs. If the value of D had been less than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.40$ ft is not determinable from the chart because the crest would be submerged as a result of a shallow box.

EXAMPLE 2

Given: A rounded-rectangular weir box inlet. The inside dimensions are W = 5 ft, B = 2 ft, and $H_e = 3.5$ ft. The approach channel and the dike covering the headwall and the crest of the box inlet are sufficiently large to prevent any effect on the discharge of the inlet.

Determine: 1. The actual discharge Q of the box inlet if flow at the crest is not submerged.

2. The depth D_r of the box inlet required to prevent submergence of the crest for this discharge.

3. The theoretical discharge Q_t of the box inlet as determined by the weir formula.

Solution: 1. Solving for the actual discharge of the box inlet. The value of $\frac{B + 0.5}{W + 1}$ is $\frac{2.5}{6} = 0.417$ and $\gamma = \frac{H_e}{W + 1}$ is $\frac{3.5}{6} = 0.583$. The point of intersection of the lines having the values of $\frac{B + 0.5}{W + 1} = 0.417$ and $\gamma = \frac{H_e}{W + 1} = 0.583$ corresponds to a value of $\frac{Q}{(W + 1)^{5/2}} = 2.43$ and a value of $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 0.765$.

$$Q = 2.43\ (W + 1)^{5/2} = 2.43\ (5 + 1)^{5/2} = 214.3 \text{ cfs}$$

2. Solving for the required depth D_r of the box inlet to prevent submergence

$$D_r = 0.765 \frac{(W + 1)^{5/3}}{W^{2/3}} = 0.765 \frac{(5 + 1)^{5/3}}{5^{2/3}} = 5.18 \text{ ft}$$

3. Solving for the theoretical discharge of the box inlet as given by the weir formula

$$Q_t = 3.1 \left[2\ (B + 0.5) + (W + 1)\right] H_e^{3/2}$$
$$= 3.1 \left[2\ (2 + 0.5) + (5 + 1)\right] 3.5^{3/2}$$
$$Q_t = 223.3 \text{ cfs}$$

The stippled region shown on sheet 5 signifies the weir formula is not applicable in predicting the discharge for the points corresponding to the values of B, W, and H_e in this region. Therefore Part 3 is not a valid solution.

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EXAMPLE 3

Given: A rounded-rectangular weir box inlet for a chute spillway. The dimensions of the box inlet are W = 10 ft, B = 6 ft, D = 4.25 ft, h = 2.5 ft, and M = 4.0 ft. There is no effect on the discharge due to a narrow channel or dike.

Determine: 1. The capacity without freeboard at the crest Q_{mh} in cfs.

2. The capacity without freeboard at the origin of the upper vertical curve Q_{mM} in cfs.

3. The capacity without freeboard of the box inlet Q_{mi} in cfs.

4. The capacity of the inlet Q_{si} if the total drop of the chute is Z = 25 ft.

Solution: No consideration of channel and dike effect will be required.

1. Solving for the capacity without freeboard at the crest Q_{mh}

$$\frac{B + 0.5}{W + 1} = \frac{6.5}{11} = 0.591 \; ; \quad \delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D = \frac{10^{2/3}}{(10 + 1)^{5/3}} 4.25 = 0.363 \; ; \quad \gamma = \frac{h}{W + 1} = \frac{2.5}{11} = 0.227$$

At the intersection of lines (see sheet 5) $\frac{B + 0.5}{W + 1} = 0.591$ and $\gamma = 0.227$, read $\frac{Q_{mh}}{(W + 1)^{5/2}} = 0.730$.

Observe that the required value of δ is $0.350 < 0.363 = \frac{W^{2/3}}{(W + 1)^{5/3}} D$. If the value of $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r$ read from the chart had been greater than 0.363, then the value of Q_{mh} is indeterminable from the chart.

$$Q_{mh} = 0.730 \; (W + 1)^{5/2} = 0.730 \; (10 + 1)^{5/2} = 293 \text{ cfs}$$

2. The capacity without freeboard at the downstream end of the box inlet Q_{mM} may be read from Table 1, sheet 3, ES-88, for M = 4.0 ft and q_{mM} = 29.47 cfs/ft.

$$Q_{mM} = W \; q_{mM} = 10 \; (29.47) = 294.7 \text{ cfs}$$

3. The capacity without freeboard of the box inlet Q_{mi} is the lesser of the values Q_{mh} and Q_{mM} or is Q_{mh} = 293 cfs.

4. The capacity of the inlet having the recommended freeboard is

$$Q_{si} = \frac{Q_{mi}}{(1.2 + 0.003 \; Z)} = \frac{293}{1.2 + 0.003 \; (25)} = 230 \text{ cfs}$$

EXAMPLE 4

Given: A design discharge Q_r = 270 cfs for a chute of width W = 10 ft and a sidewall height over the crest h = 2 ft. The vertical drop of the chute from the crest of the inlet to the floor of the SAF outlet is Z = 30 ft. No wave action is anticipated in the channel upstream from the inlet.

Determine: 1. The required capacity without freeboard Q_{fr}.

2. The required ratio of $\frac{B + 0.5}{W + 1}$ for a rounded-rectangular weir if the approach channel and dike are to have no effect on the discharge equal to the design discharge without freeboard Q_{fr}.

3. The dimensions B, D, and M for the rounded-rectangular weir box inlet if the approach channel and dike have no effect on the discharge Q_{fr}.

Solution: 1. Solving for the required capacity without freeboard Q_{fr}

$$Q_{fr} = (1.2 + 0.003 \; Z) \; Q_r$$
$$= \left[1.2 + 0.003 \; (30)\right] 270$$
$$Q_{fr} = 348.3 \text{ cfs}$$

2. When the discharge of the inlet is Q_{fr}, the value of B is to be determined such that the head over the crest is h = 2.0 ft. The value of $\frac{Q_{fr}}{(W + 1)^{5/2}} = \frac{348.3}{(10 + 1)^{5/2}} = 0.868$ and $\gamma = \frac{h}{W + 1} = \frac{2.0}{11} = 0.182$. From sheet 5, read the value of $\frac{B + 0.5}{W + 1} = 1.29$ for free-flow conditions.

Concluded on Sheet 16

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 15

3. (a) The required value of B is

$$B = (W+1)\left[\frac{B+0.5}{W+1}\right] - 0.5 = (10+1)(1.29) - 0.5 = 13.69 \text{ ft}$$

Take B = 13.75 ft

(b) The required value of D_r to prevent submergence at the crest is obtained by reading the value of δ at the point of intersection of the lines $\gamma = 0.182$ and $\frac{Q_{fr}}{(W+1)^{5/2}} = 0.868$ or $\delta = 0.405$. The required value of D_r is

$$D_r = \frac{\delta\ (W+1)^{5/3}}{W^{2/3}} = \frac{0.405\ (10+1)^{5/3}}{(10)^{2/3}} = 4.747 \text{ ft}$$

Take D = 4.75 ft

(c) The value of M may be read from Table 1, sheet 3, ES-88, when

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{348.3}{10} = 34.83 \text{ cfs/ft}$$

$$M = 4.50 \text{ ft}$$

EXAMPLE 5

Given: A rounded-rectangular weir box inlet with the dimensions B = 13.5 ft, W = 9 ft, h = 2.0 ft, and M = 4.00 ft; W_c = 35.2 ft and the headwall is extended across the channel. Thus no effect on the discharge is obtained by a dike. The side slope of the approach channel is 3 to 1; $z_c = 3$.

Determine: 1. The capacity without freeboard at the crest of this inlet Q_{mh} when the effect of the narrow approach channel is not considered, and the value of $\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D$ is sufficiently large to prevent submergence of the crest.

2. The capacity without freeboard at the origin of the vertical curve Q_{mM}.

3. The value of K.

4. The capacity without freeboard at the crest of this inlet $(Q_K)_{mh}$ when the effect of the narrow approach channel is considered, and the value of $\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D$ is sufficiently large to prevent submergence of the crest.

5. The required depth of the box inlet D_r to insure free-flow conditions at the crest corresponding to the discharge $(Q_K)_{mh}$.

6. The capacity without freeboard of this inlet $(Q_K)_{mi}$ when the effect of the narrow approach channel is considered.

Solution: 1. Solving for the capacity without freeboard at the crest Q_{mh} of the box inlet when the width of the approach channel is sufficiently great to prevent an effect on the capacity of the inlet and the depth D is sufficiently large to prevent submergence of the crest. The capacity Q_{mh} of the box inlet is equal to the discharge of the box inlet with a head h over the crest.

$$\frac{B+0.5}{W+1} = \frac{14}{10} = 1.4 \quad \text{and} \quad \gamma = \frac{h}{W+1} = \frac{2}{10} = 0.20$$

At the intersection of $\frac{B+0.5}{W+1} = 1.4$ and $\gamma = 0.20$, sheet 5, read the value $\frac{Q_{mh}}{(W+1)^{5/2}} = 1.055$

$$Q_{mh} = 1.055\ (W+1)^{5/2} = 1.055\ (9+1)^{5/2} = 334 \text{ cfs}$$

This is the capacity without freeboard Q_{mh} at the crest of the box inlet if D and the channel width W_c are both sufficiently great.

2. Solving for the capacity without freeboard Q_{mM} at the origin of the vertical curve section. This is read from Table 1, sheet 3, ES-88. When M = 4.00 ft, then q_{mM} = 29.47 cfs/ft.

$$Q_{mM} = W\ q_{mM} = 9\ (29.47) = 265.2 \text{ cfs}$$

Concluded on Sheet 17

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 16

3. Solving for the ratio

$$\kappa = \frac{W_c + 0.8\ z_c\ h}{(W + 1)} = \frac{35.2 + 0.8\ (3)(2)}{10} = \frac{40}{10} = 4.0$$

From sheet 9, the corresponding value of K when $\kappa = 4.0$ and $\frac{B + 0.5}{W + 1} = 1.4$ is $K = 0.813$.

4. Solving for the capacity without freeboard $(Q_K)_{mh}$ at the crest of the box inlet when the narrow channel effects are considered and free-flow conditions exist at the crest.

$$(Q_K)_{mh} = K\ Q_{mh} = 0.813\ (334) = 271 \text{ cfs}$$

This could also be obtained from sheet 9 when $\kappa = 4.0$ and $\frac{B + 0.5}{W + 1} = 1.4$, read $\frac{(Q_K)_{mh}}{(W + 1)\ h^{3/2}} = 9.55$ or

$$(Q_K)_{mh} = 9.55\ (W + 1)\ h^{3/2}$$
$$= 9.55\ (10)(2)^{3/2}$$
$$(Q_K)_{mh} = 270 \text{ cfs}$$

5. Solving for the required depth D_r of the box inlet having the five given dimensions is read on sheet 5 at the intersection of the lines $\frac{(Q_K)_{mh}}{(W + 1)^{5/2}} = \frac{271}{(10)^{5/2}} = 0.857$ and $\frac{B + 0.5}{W + 1} = 1.4$ or

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}}\ D_r = 0.402 \qquad \text{and} \qquad D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.402\ (9 + 1)^{5/3}}{9^{2/3}} = 4.31 \text{ ft}$$

The depth D_r is required to prevent submergence of the crest when $W_c = 35.2$ ft, and the discharge is $(Q_K)_{mh} = 271$ cfs. A value of $D > 4.31$ ft will not increase the capacity without freeboard of this channel and box inlet. The capacity of the channel and box inlet for a $D < 4.31$ ft is not determinable by these charts; such a value will cause submergence at the crest. See Ex. 1. For construction purposes D will generally be chosen to be the next size larger than D_r when D is a multiple of 3 inches, or $D = 4.50$ ft.

6. The smaller of the two values $(Q_K)_{mh} = 271$ cfs or $Q_{mM} = 265.2$ cfs is the capacity without freeboard $(Q_K)_{mi}$ of the box inlet when the narrow approach channel effect is considered.

$$(Q_K)_{mi} = (Q_K)_{mM} = 265.2 \text{ cfs}$$

EXAMPLE 6

Given: The problem of designing a rounded-rectangular weir box inlet for the design discharge $Q_r = 200$ cfs. The approach channel to the inlet has a width of $W_c = 24.6$ ft. The vertical drop from the crest of the inlet to the floor of the outlet is $Z = 30$ ft. The width W of the chute is 8 ft and the dimension h is 2.25 ft. The headwall is to extend across this channel and thus no consideration of dike effect is required. The side slopes of the approach channel are 3 to 1; $z_c = 3$.

Determine: 1. The required capacity without freeboard Q_{fr} and q_{fr}.

2. The value of B when the effect on the discharge of the narrow approach channel is neglected.

3. The value of K.

4. The value of B when the effect of the narrow channel on the discharge is considered.

5. The value of D_r required to prevent submerged flow conditions at the crest when the effect of the narrow channel is considered.

6. The capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the capacity of the approach channel and the dimension of B obtained in (4).

7. The dimension M of the box inlet.

8. The capacity of the box inlet without freeboard $(Q_K)_{mi}$ when considering the effect of the narrow approach channel.

Concluded on Sheet 18

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 17

Solution: 1. Solving for the required capacity without freeboard

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right] 200$$
$$Q_{fr} = 258 \text{ cfs}$$
$$q_{fr} = \frac{Q_{fr}}{W} = \frac{258}{8} = 32.25 \text{ cfs/ft}$$

2. The value of B when the effect on the discharge of the narrow approach channel is neglected may be obtained from sheet 5. At the intersection of lines $\frac{Q_{fr}}{(W + 1)^{5/2}} = \frac{258}{(8 + 1)^{5/2}}$ $= 1.062$ and $\gamma = \frac{h}{W + 1} = \frac{2.25}{(8 + 1)} = 0.250$, read $\frac{B + 0.5}{W + 1} = 0.875$.

$$B = 0.875\ (W + 1) - 0.5 = 0.875\ (8 + 1) - 0.5 = 7.38 \text{ ft}$$

3. The value of K may be read from sheet 9 at the intersection of the lines $\frac{Q_{fr}}{(W + 1)\ h^{3/2}} = \frac{258}{(8 + 1)(2.25)^{3/2}} = 8.49$ and $\kappa = \frac{W_c + 0.8\ z_c\ h}{W + 1} = \frac{24.6 + 0.8\ (3)(2.25)}{8 + 1} = 3.33$.
Read K = 0.774.

4. The value of B when the effect of the narrow channel on the discharge is considered is again obtained at the intersection of lines $\kappa = 3.33$ and $\frac{Q_{fr}}{(W + 1)\ h^{3/2}} = 8.49$, read $\frac{B + 0.5}{W + 1} = 1.275$ or

$$B = 1.275\ (W + 1) - 0.5 = 1.275\ (8 + 1) - 0.5 = 10.975 \text{ ft}$$

Use B = 11 ft

5. The value of D_r may be obtained on sheet 5 at the intersection of the lines $\frac{Q_{fr}}{(W + 1)^{5/2}} = \frac{258}{(8 + 1)^{5/2}} = 1.062$ and $\frac{B + 0.5}{W + 1} = 1.275$. This reads

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 0.465 \quad \text{or} \quad D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.465\ (8 + 1)^{5/3}}{(8)^{2/3}} = 4.53 \text{ ft}$$

Use D = 4.75 ft

6. Solving for the capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the narrow approach channel. From sheet 5 when $\frac{B + 0.5}{W + 1} = \frac{11 + 0.5}{8 + 1}$ $= 1.28$ and $\gamma = \frac{h}{W + 1} = \frac{2.25}{8 + 1} = 0.250$, read

$$\frac{Q_{mh}}{(W + 1)^{5/2}} = 1.38$$
$$Q_{mh} = 1.38\ (W + 1)^{5/2} = 1.38\ (8 + 1)^{5/2} = 335 \text{ cfs}$$
$$(Q_K)_{mh} = K\ (Q_{mh}) = 0.774\ (335) = 259 \text{ cfs}$$

7. Solving for the dimension M at the origin of the vertical curve section. Given $q_{fr} = 32.25$, see step 1. Read from Table 1, sheet 3, ES-88, the value M = 4.25 when $q_{mM} = 32.27$ and $Q_{mM} = W\ q_{mM} = (8)\ 32.27 = 258.16$ cfs.

8. Solving for the capacity without freeboard of the box inlet $(Q_K)_{mi}$ considering the effect of the narrow channel and free-flow conditions. The value of $(Q_K)_{mi}$ is equal to the smaller of the values $(Q_K)_{mh}$ and Q_{mM}.

$$(Q_K)_{mi} = Q_{mM} = 258.16 \text{ cfs}$$

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EXAMPLE 7

This example pertains to the determination of the dimension B required to convey a given discharge (Q_{fr}) when the head over the crest, dike, and approach channel dimensions are given. The example requires that the effective toe of the dike be determined. This determination is a converging approximation procedure. The first approximation is made by assuming the head over the crest as a constant value (H_e = 3 ft) along the length B and the location of the effective toe of the dike is determined corresponding to this head. This is shown by sheet 20. The second and final approximation is made from results obtained in the first approximation. These results are shown on sheet 24.

Example 7 of ES-90 illustrates the determination of a discharge (actually a capacity) for certain inlet, dike, and approach channel dimensions when the head over the crest is given.

Given: The problem of designing a rounded-rectangular weir box inlet for a design discharge Q_r = 500 cfs. The box inlet is for a chute having a width of W = 10 ft and the approach channel is W_c = 61 ft. The height of the sidewalls over the crest is h = 3.0 ft and the toe of the dike covering the headwall is 8 ft from the crest. The side slopes of the channel and dike are to be 3 to 1 or $z_c = z_u = z_s = 3$. The total drop Z from the crest of the inlet to t the floor of the outlet is 40 ft. The value of t_1 is 4 ft and h_t is 1 ft.

Determine: 1. The design discharge without freeboard Q_{fr}.

2. The dimension B of the box inlet required to convey a discharge of Q_{fr} if the approach channel and dike have no influence on the discharge and free-flow conditions occur at the crest.

3. The dimension B of the box inlet required to convey a discharge of Q_{fr} when the effect of the narrow approach channel and dike is considered and free-flow conditions occur at the crest.

4. The dimension M at the outlet of the box inlet.

5. The value λ.

6. The dimension D_r required to prevent submergence at the crest.

Solution: 1. The design discharge without freeboard is

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (40)\right] 500$$
$$Q_{fr} = 660 \text{ cfs}$$

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{660}{10} = 66 \text{ cfs/ft}$$

2. The dimension B of the box inlet required to convey a discharge of Q_{fr} = 660 cfs with free-flow conditions at the crest if the effect of the narrow approach channel and dike is neglected can be determined from sheet 5. The point of intersection of the lines

$$\frac{Q_{fr}}{(W+1)^{5/2}} = \frac{660}{(10+1)^{5/2}} = 1.642 \quad \text{and} \quad \gamma = \frac{h}{W+1} = \frac{3}{10+1} = 0.273 \quad \text{is at} \quad \frac{B+0.5}{W+1} = 1.35 \quad \text{or}$$

$$B + 0.5 = 1.35\ (W + 1)$$
$$B = 14.35 \text{ ft}$$

3. The dimension B of the box inlet required to convey a discharge of Q_{fr} = 660 cfs with free-flow conditions at the crest and the given approach conditions is determined in the following manner. The value of B is greater than 14.35 ft for these conditions.

The dimensions η_0, η_1, η_2, η_3, η_4, and $\bar{\eta}_1$, $\bar{\eta}_2$, $\bar{\eta}_3$, $\bar{\eta}_4$ corresponding to β_1 = 4 ft, β_2 = 5.94 ft, β_3 = 2.46 ft, and β_4 = ? (when the head h = H_e = 3 ft) are given in the figure on sheet 20. These values along with the values of $\frac{\beta_i}{W+1}$ and $\frac{\bar{\eta}_i}{W+1}$ are tabulated.

Continued on Sheet 21

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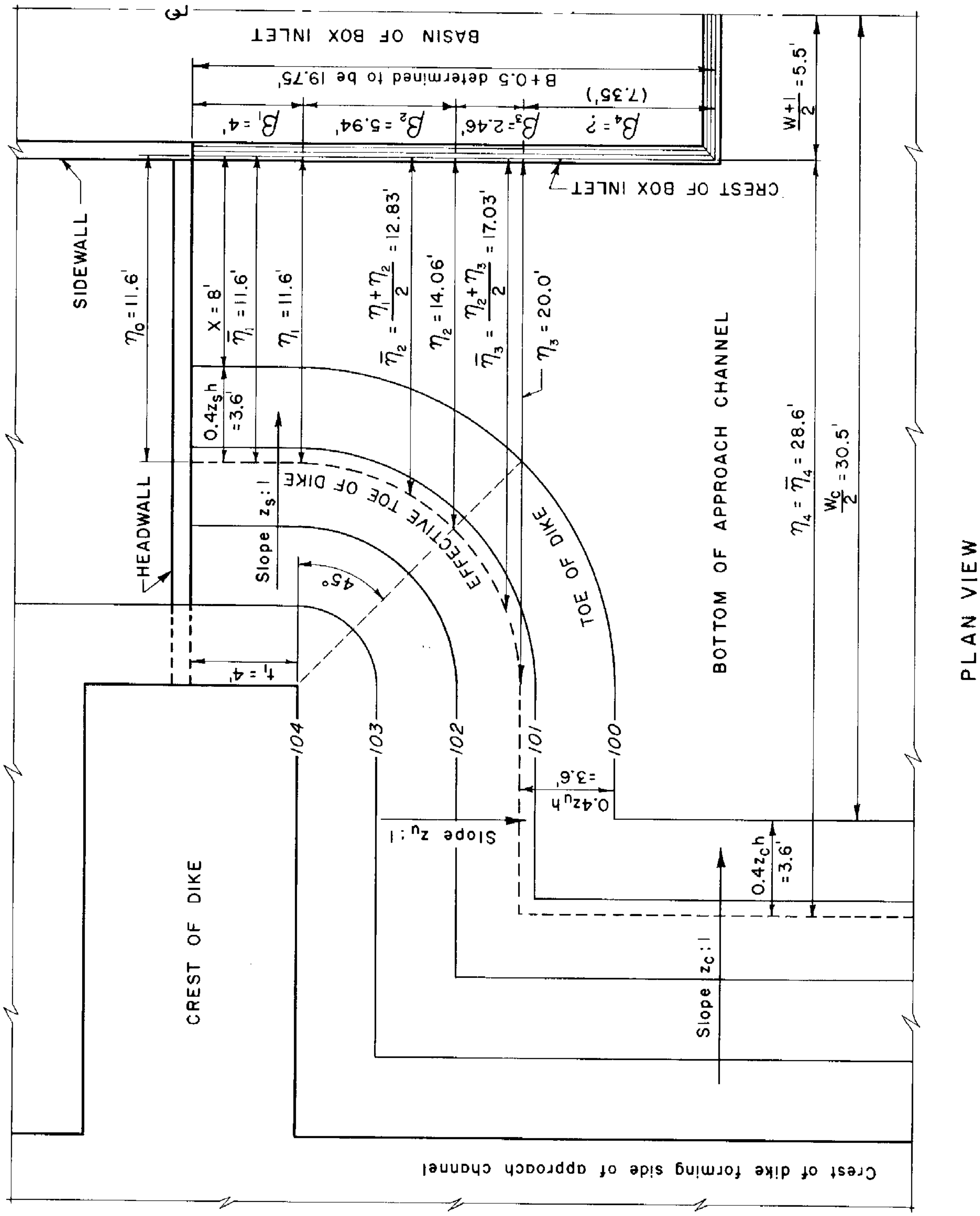

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-91 SHEET 20 OF 24 DATE 6-14-55

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Continuation from Sheet 19

i	β_i	$\overline{\eta}_i$	$\frac{\beta_i}{W+1}$	$\frac{\overline{\eta}_i}{W+1}$
1	4.00	11.6	0.364	1.052
2	5.94	12.83	0.540	1.168
3	2.46	17.03	0.224	1.55
4	?	28.6	?	2.60

The subscript i is an index. For example, in the tabulation, when i = 3, $\beta_i = \beta_3 = 2.46$ and $\overline{\eta}_3 = 17.03$. The various values of β_i were arbitrarily selected. The upstream section of β_2 was selected to be coincident with the point of intersection of the effective toe line of the dike and a 45^o plane from the corner of the dike. See sheet 20. Other end sections of β were selected according to location of changes in the values of η.

The values of β_i and $\overline{\eta}_i$ are calculated using $H_e = 3$ ft. The head over the crest does not remain 3 ft for each β and an adjustment for the variation in head will be made after using $H_e = 3$ ft. The value of β_4 is to be determined.

i. Calculate the value of

$$T_n = \frac{Q_{fr}}{(W+1)\,H_e^{3/2}} - 3.09 = \frac{660}{(10+1)(3)^{3/2}} - 3.09 = 11.52 - 3.09$$

$$T_n = 8.43$$

iia. Find the value of T_1 and μ_1 corresponding to $\frac{\overline{\eta}_1}{W+1} = 1.052$ and $\tau_1 = \frac{\beta_1}{W+1} = 0.364$. From sheet 13, read $T_1 = 2.11$ and $\mu_1 = 1.053$.

$$T_n > T_1$$

b. Read the intersection of $T_1 = 2.11$ and $\frac{\overline{\eta}_2}{W+1} = 1.168$ and obtain $\tau_{1,2} = 0.361$ and $\mu_{1,2} = 1.042$.

iiia. The value of $\tau_2 = \tau_{1,2} + \frac{\beta_2}{W+1} = 0.361 + 0.540 = 0.901$. Read the intersection of $\tau_2 = 0.901$ and $\frac{\overline{\eta}_2}{W+1} = 1.168$ and obtain $T_2 = 4.47$ and $\mu_2 = 1.27$.

$$T_n > T_2$$

b. Read the intersection of $T_2 = 4.47$ and $\frac{\overline{\eta}_3}{W+1} = 1.55$ and obtain $\tau_{2,3} = 0.811$ and $\mu_{2,3} = 1.124$.

iva. The value of $\tau_3 = \tau_{2,3} + \frac{\beta_3}{W+1} = 0.811 + 0.224 = 1.035$. Read the intersection of $\tau_3 = 1.035$ and $\frac{\overline{\eta}_3}{W+1} = 1.55$ and obtain $T_3 = 5.37$ and $\mu_3 = 1.19$.

$$T_n > T_3$$

b. Read the intersection of $T_3 = 5.37$ and $\frac{\overline{\eta}_4}{W+1} = 2.60$ and obtain $\tau_{3,4} = 0.917$ and $\mu_{3,4} = 1.055$.

va. Find the value of τ_n corresponding to $\frac{\overline{\eta}_4}{W+1} = 2.60$ and $T_n = 8.43$ and obtain from sheet 13.

$$\tau_n = 1.584 \qquad \text{where} \qquad \tau_n = \tau_{3,4} + \frac{\beta_4}{W+1}$$

$$\frac{\beta_4}{W+1} = 1.584 - 0.917 = 0.667$$

Continued on Sheet 22

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 21

$$\beta_4 = 0.667\ (10 + 1) = 7.337 \text{ ft}$$

$$B + 0.5 = \beta_1 + \beta_2 + \beta_3 + \beta_4$$

$$B + 0.5 = 4.0 + 5.94 + 2.46 + 7.337 = 19.737 \text{ ft}$$

$$B = 19.237 \text{ ft}$$

The head over the crest H_e is taken to be equal to the value of h because the dimension of B is being determined which will convey the maximum discharge Q_{fr} through this inlet. The maximum discharge Q_{fr} corresponds to a head over the crest of $H_e = h = 3$ ft. As water approaches the headwall, the depth of flow decreases and the head over the crest also decreases. The heads over the crest at sections 1, 2, and 3 decrease in the direction of the headwall and are to be evaluated. The head H_e used in preparing the graph of sheets 11, 12, and 13 is that head over the crest at the upstream section of the particular incremental length β under consideration. Calculating the head over the crest at sections 3, 2, and 1, obtain

$$H_{e_4} = h = 3 \text{ ft} \quad \text{(Given)}$$

$$H_{e_3} = h \frac{\mu_{3,4}}{\mu_3} = 3 \frac{1.055}{1.19} = 2.66 \text{ ft}$$

$$H_{e_2} = h \frac{\mu_{2,3}}{\mu_2} \times \frac{\mu_{3,4}}{\mu_3} = 3 \frac{1.124}{1.27} \times \frac{1.055}{1.19} = 2.354 \text{ ft}$$

$$H_{e_1} = h \frac{\mu_{1,2}}{\mu_1} \times \frac{\mu_{2,3}}{\mu_2} \times \frac{\mu_{3,4}}{\mu_3} = 3 \frac{1.042}{1.053} \times \frac{1.124}{1.27} \times \frac{1.055}{1.19} = 2.33 \text{ ft}$$

The distance between the effective toe of the dike and the crest of the inlet is recomputed at sections 1, 2, and 3. The upstream section of the incremental length β_3 is relocated since the head over the crest at this section has been reduced from 3 ft to 2.66 ft. The effective toe of the dike has shifted in an upstream direction a distance of 0.4 (3)(3.00 − 2.66) = 0.41 ft. This causes β_3 to change from a value of 2.46 ft to 2.87 ft and β_4 will be re-evaluated. The lower heads over the crest of sections 1 and 2 cause the effective toe of the dike to shift in a direction towards the crest. The location of the upstream section of the incremental lengths β_1 and β_2 remain unchanged.

Recomputing the effective toe line and values of $\bar{\eta}_i$ and $\frac{\bar{\eta}_i}{W+1}$. The result of the computations are illustrated on sheet 24 and shown in the following tabulation.

i	$H_{e,i}$	β_i	$\bar{\eta}_i$	$\frac{\beta_i}{W+1}$	$\frac{\bar{\eta}_i}{W+1}$
1	2.33	4.00	10.8	0.364	0.982
2	2.35	5.94	11.90	0.540	1.082
3	2.66	2.87	16.50	0.261	1.50
4	3.00	?	28.6	?	2.60

ia. Read the intersection of $\frac{\beta_1}{W+1} = \tau_1 = 0.364$ and $\frac{\bar{\eta}_1}{W+1} = 0.982$ and obtain $T_1 = 2.10$.

$$T_n > T_1$$

b. Read the intersection of $T_1 = 2.10$ and $\frac{\bar{\eta}_2}{W+1} = 1.082$ and obtain $\tau_{1,2} = 0.360$.

iia. The value of $\tau_2 = \tau_{1,2} + \frac{\beta_2}{W+1} = 0.360 + 0.540 = 0.900$. Read the intersection of of $\tau_2 = 0.900$ and $\frac{\bar{\eta}_2}{W+1} = 1.082$ and obtain $T_2 = 4.33$.

$$T_n > T_2$$

Concluded on Sheet 23

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

Continuation from Sheet 22

b. Read the intersection of $T_2 = 4.33$ and $\frac{\bar{\eta}_3}{W + 1} = 1.50$ and obtain $\tau_{2,3} = 0.790$.

iiia. The value of $\tau_3 = \tau_{2,3} + \frac{\beta_3}{W + 1} = 0.790 + 0.261 = 1.051$. Read the intersection of $\tau_3 = 1.051$ and $\frac{\bar{\eta}_3}{W + 1} = 1.50$ and obtain $T_3 = 5.37$.

$$T_n > T_3$$

b. Read the intersection of $T_3 = 5.37$ and $\frac{\bar{\eta}_4}{W + 1} = 2.60$ and obtain $\tau_{3,4} = 0.920$.

iva. Find the value of τ_n corresponding to $\frac{\bar{\eta}_4}{W + 1} = 2.60$ and $T_n = 8.43$ and obtain from sheet 13

$$\tau_n = 1.585 \qquad \text{where} \qquad \tau_n = \tau_{3,4} + \frac{\beta_4}{W + 1}$$

$$\frac{\beta_4}{W + 1} = \tau_n - \tau_{3,4} = 1.585 - 0.92 = 0.665$$

$$\beta_4 = 0.665\ (10 + 1) = 7.315 \text{ ft}$$

$$B + 0.5 = \beta_1 + \beta_2 + \beta_3 + \beta_4$$

$$B + 0.5 = 4.0 + 5.94 + 2.87 + 7.315 = 20.125 \text{ ft}$$

$$B = 19.625 \text{ ft}$$

$$\text{Use} \quad B = 19.75 \text{ ft}$$

4. The value of M may be read from Table 1, sheet 3, ES-88, and knowing $q_{fr} = 66$ cfs/ft, read M = 7 ft and $q_{mM} = 68.22$ cfs/ft.

5. A box inlet with free-flow conditions at the crest and dimensions B = 19.75 ft, W = 10 ft, h = 3 ft, will have a capacity at the crest as given by sheet 5. At the intersection of lines $\frac{B + 0.5}{W + 1} = \frac{20.25}{11} = 1.84$ and $\gamma = \frac{h}{W + 1} = \frac{3}{11} = 0.273$, read

$$\frac{Q_{mh}}{(W + 1)^{5/2}} = 2.09 \quad \text{or} \quad Q_{mh} = 2.09\ (10 + 1)^{5/2} = 839 \text{ cfs}$$

The value of λ is

$$\lambda = \frac{(Q_\lambda)_{mh}}{Q_{mh}} = \frac{660}{839} = 0.787$$

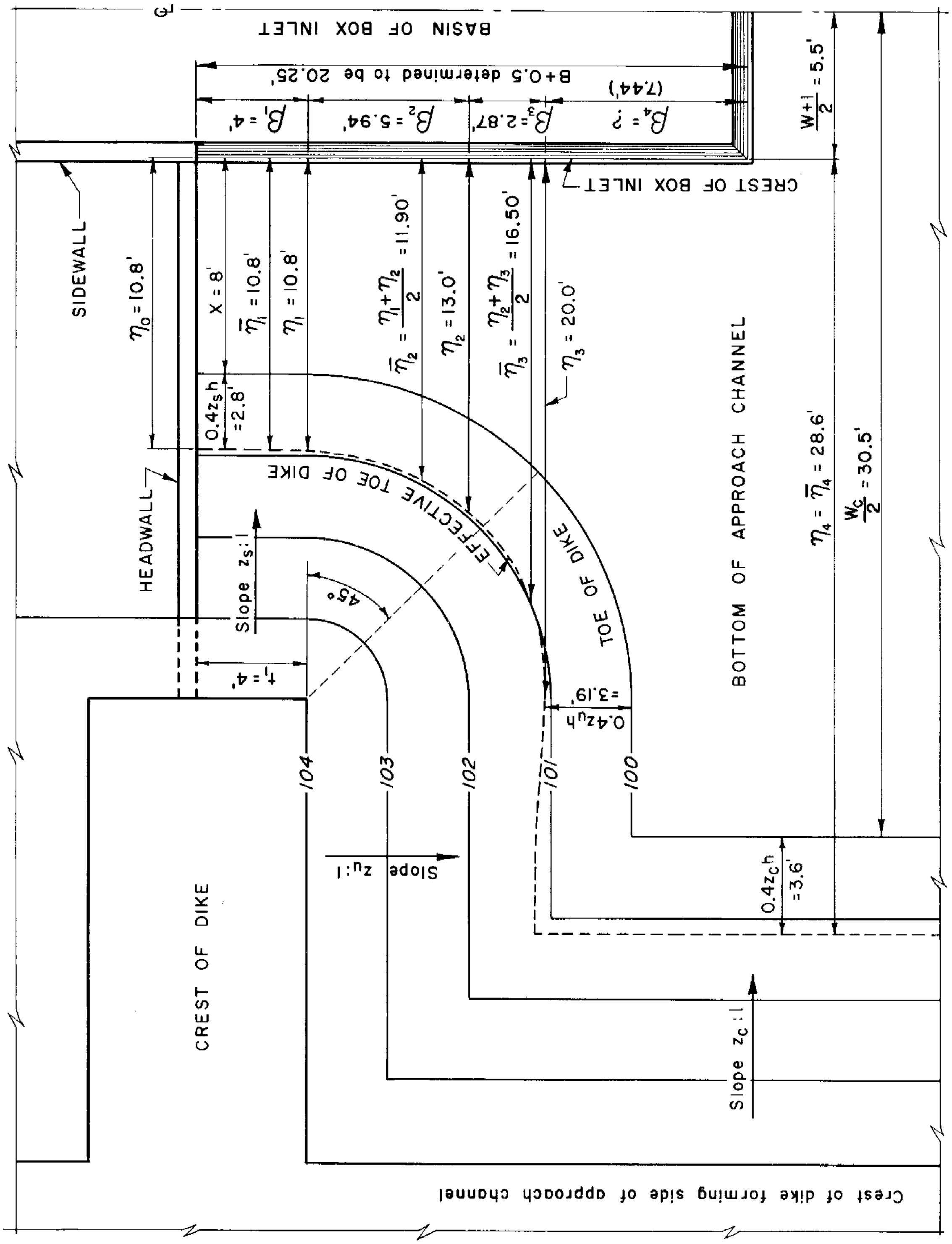
6. The required depth of box inlet D_r to prevent submergence of the crest may be determined at the point of intersection of lines $\frac{(Q_\lambda)_{mh}}{(W + 1)^{5/2}} = \frac{660}{(10 + 1)^{5/2}} = 1.645$ and $\frac{B + 0.5}{W + 1} = \frac{20.25}{11} = 1.84$. From sheet 5, read

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 0.627 \qquad \text{or}$$

$$D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.627\ (10 + 1)^{5/3}}{10^{2/3}} = 7.35$$

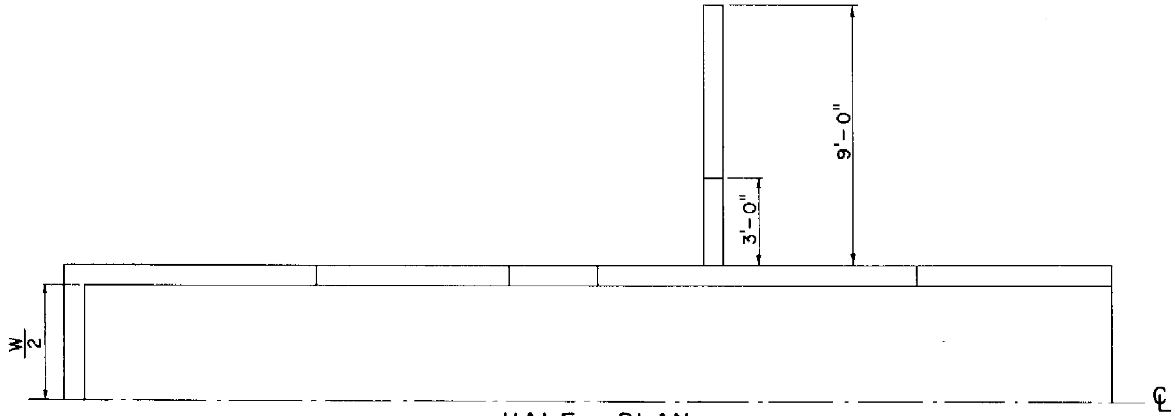
$$\text{Use} \quad D = 7.5 \text{ ft}$$

CHUTE SPILLWAYS : ROUNDED-RECTANGULAR WEIR BOX INLETS ; Examples

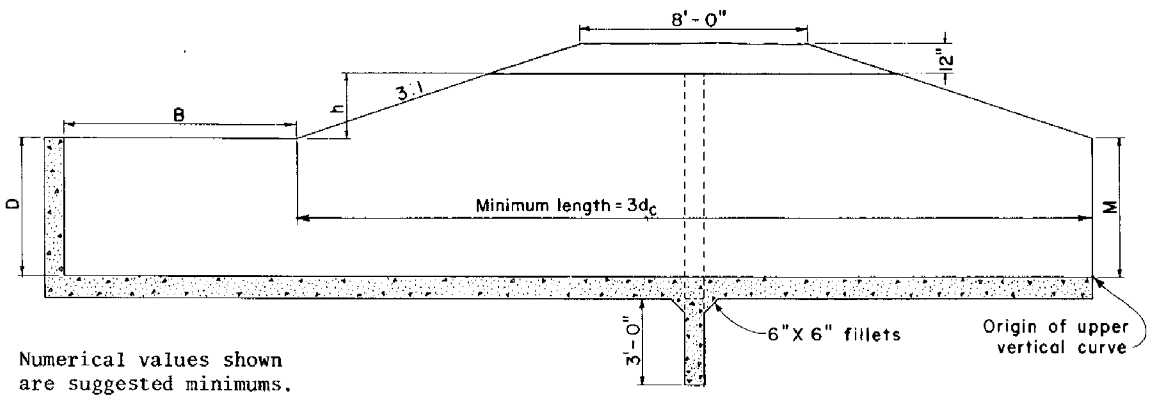


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-91 SHEET 24 OF 24 DATE 6-14-55

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLET; General layout.



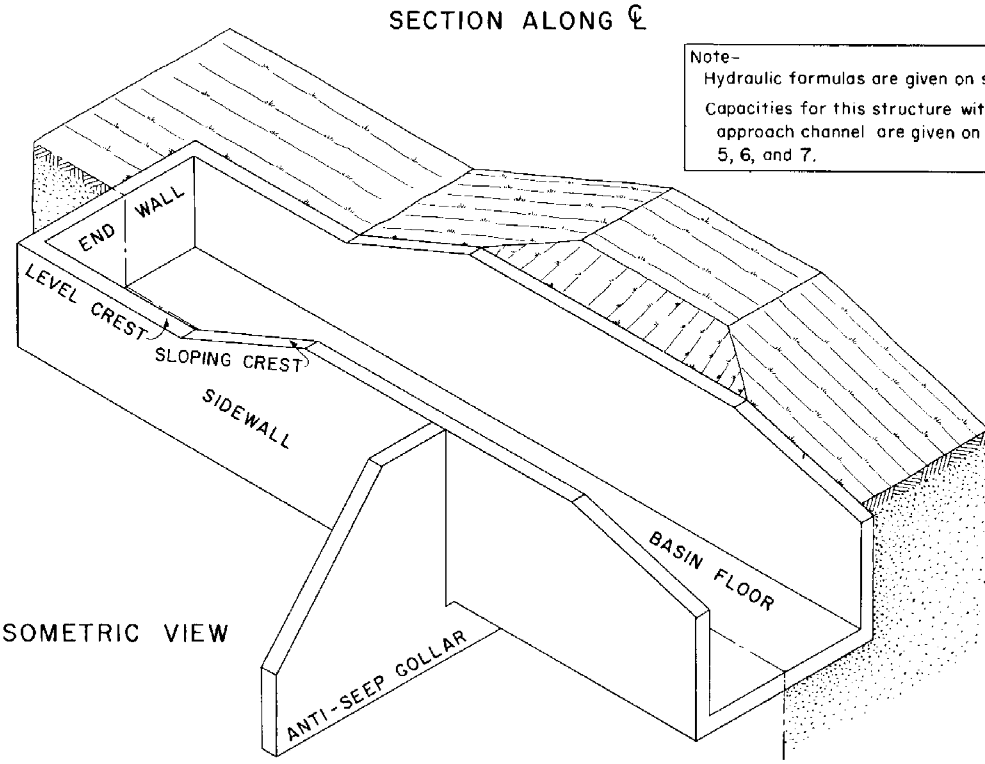
HALF – PLAN



Numerical values shown are suggested minimums.

SECTION ALONG ℄

Note–
Hydraulic formulas are given on sheet 4.
Capacities for this structure with a wide approach channel are given on sheets 5, 6, and 7.

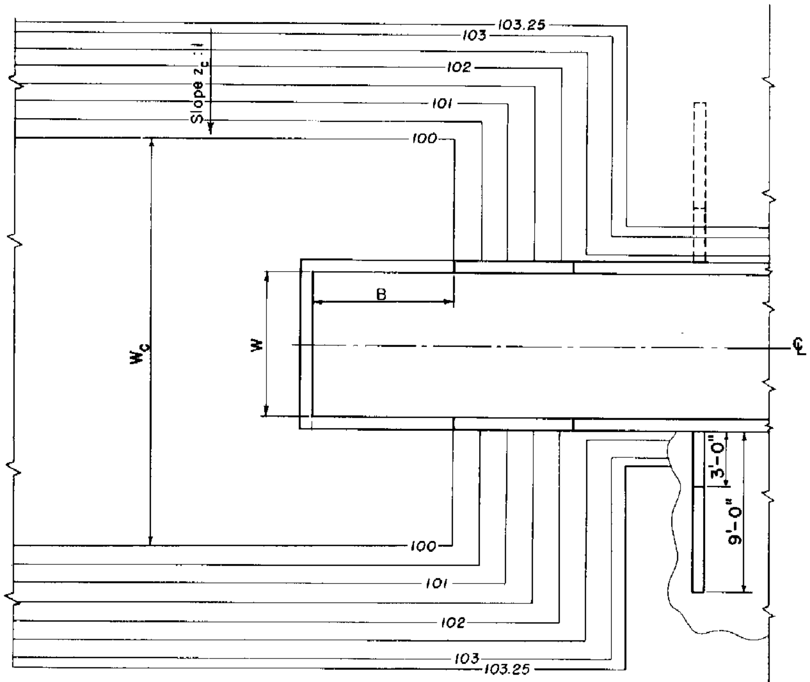


ISOMETRIC VIEW

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 92 SHEET 1 OF 16 DATE 2-16-55

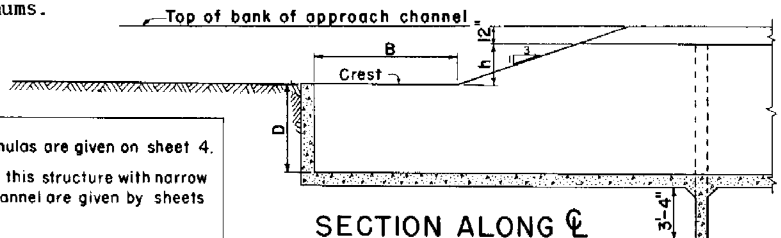
Revised 10/77

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLET; Effect of narrow channels on discharge.



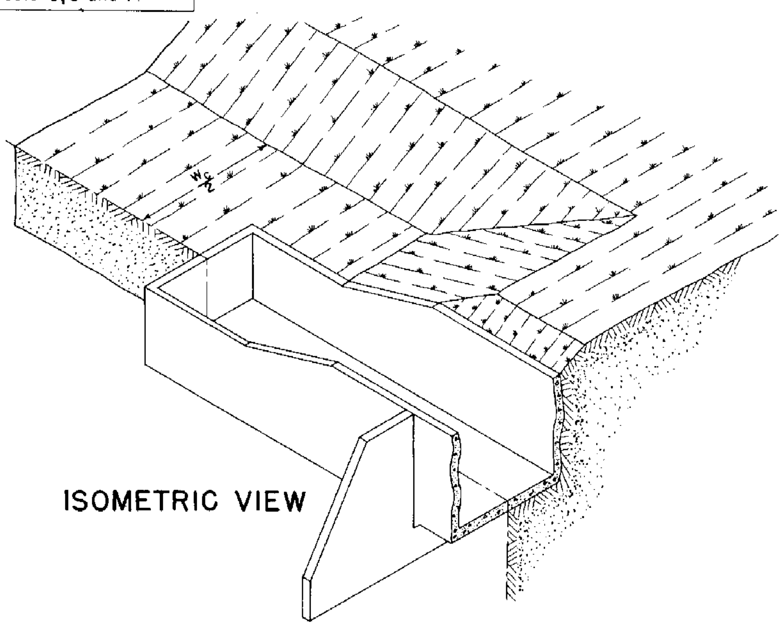
PLAN

Numerical values shown
are suggested minimums.



SECTION ALONG ℄

Note –
Hydraulic formulas are given on sheet 4.
Capacities for this structure with narrow approach channel are given by sheets 9 and 10.
Required values of depths of box inlet are given by sheets 5, 6 and 7.



ISOMETRIC VIEW

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 92 SHEET 2 OF 16 DATE 2-17-55

Revised 10/77

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Definition of symbols

DEFINITION OF SYMBOLS

B = Inside length of the box inlet measured from the downstream face of the endwall to the upstream face of the headwall in ft

D = Depth (i.e., distance from the crest to the floor) of the box inlet in ft

D_r = Required depth of box inlet to prevent submergence at the crest when the discharge is Q in ft

h = Height of sidewalls above the crest of the box inlet in ft

H_e = Specific energy head above the crest of the inlet corresponding to any discharge Q the inlet is capable of conveying in ft

K = $\frac{Q_K}{Q}$

L = Length of developed crest = $2\,B + W + 0.4\,z_o\,H_e$

M = Height of sidewall above the floor of the box inlet at the junction with the vertical curve section in ft

q = Discharge per unit width W or $q = \frac{Q}{W}$ in cfs/ft

Q = Discharge corresponding to the head H_e of a box inlet having no narrow approach channel or dike effect in cfs

Q_r = Design discharge in cfs

Q_{fr} = Required capacity without freeboard in cfs

Q_{si} = Capacity of inlet in cfs

Q_{mi} = Capacity of inlet without freeboard in cfs

Q_{mh} = Capacity of inlet without freeboard at the crest; discharge $Q = Q_{mh}$ when $H_e = h$

Q_{mM} = Capacity of inlet without freeboard at the origin of the upper vertical curve in cfs

$(Q_K)_{mh}$ = Capacity without freeboard of a box inlet at the crest when a narrow approach channel is considered in cfs; the discharge $Q = (Q_K)_{mh}$ when $H_e = h$

Q_K = Discharge corresponding to the head H_e of a box inlet having a narrow approach channel in cfs

$(Q_K)_{mi}$ = Capacity without freeboard of a box inlet and narrow approach channel of width W_c and downstream end section having a sidewall height M in cfs

W = Width of inlet in ft

W_c = Bottom width of the approach channel for the box inlet in ft

z_c = Side slope (horizontal distance per vertical foot) of approach channel

z_o = Side slope (horizontal distance per vertical foot) of spillway crest

Z = Vertical drop from the crest of the inlet to the floor of the SAF outlet in ft

κ = Ratio $\frac{W_c + 0.8\,z_c\,H_e}{W}$

ψ = $\frac{1.2\,g^{1/3}\,W^{2/3}}{Q^{2/3}}\,D_r$ where $\psi > 1$ (see equations, sheet 4)

γ = Ratio $\frac{H_e}{W}$

δ = Ratio $\frac{D_r}{W}$

CHUTE SPILLWAYS : FLAT-TRAPEZOIDAL WEIR BOX INLETS ; Formulas

FORMULAS

The relationship of the discharge-head over the crest for a flat-trapezoidal weir box inlet having a wide approach channel and no dike effect is

$$Q = 3.1\ (2\ B + W + 0.8\ z_o\ H_e)\ H_e^{3/2} \qquad \text{when}$$

$$0 < H_e \leq \frac{0.49\ W}{1 - 0.016\ z_o} + \frac{0.04\ B}{1 - 0.016\ z_o} \qquad \text{and}$$

$$0 < Q \leq 5.5\ W^{5/2} \qquad \text{and}$$

$$\psi^3 - 3\ \psi + 2 \left[\frac{W}{2\ B + W + 0.8\ z_o\ H_e} \right]^2 = 0 \qquad \text{where}$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi > 1$$

These relations are expressed in graphical form by sheets 5, 6, and 7 where $z_o = 3$ and

$$\delta = \frac{D_r}{W} \qquad \text{and} \qquad \gamma = \frac{H_e}{W}$$

values of $H_e^{3/2}$ and $W^{5/2}$ are given on sheet 8. When $H_e > 0.51\ W + 0.04\ B$, no algebraic relationship is given. The last two relations are a requirement of the value of D to prevent submergence of the crest. The relationship of the discharge-head over the crest for a flat-trapezoidal weir box inlet having a narrow channel effect but no dike effect is

$$Q_K = K\ Q$$

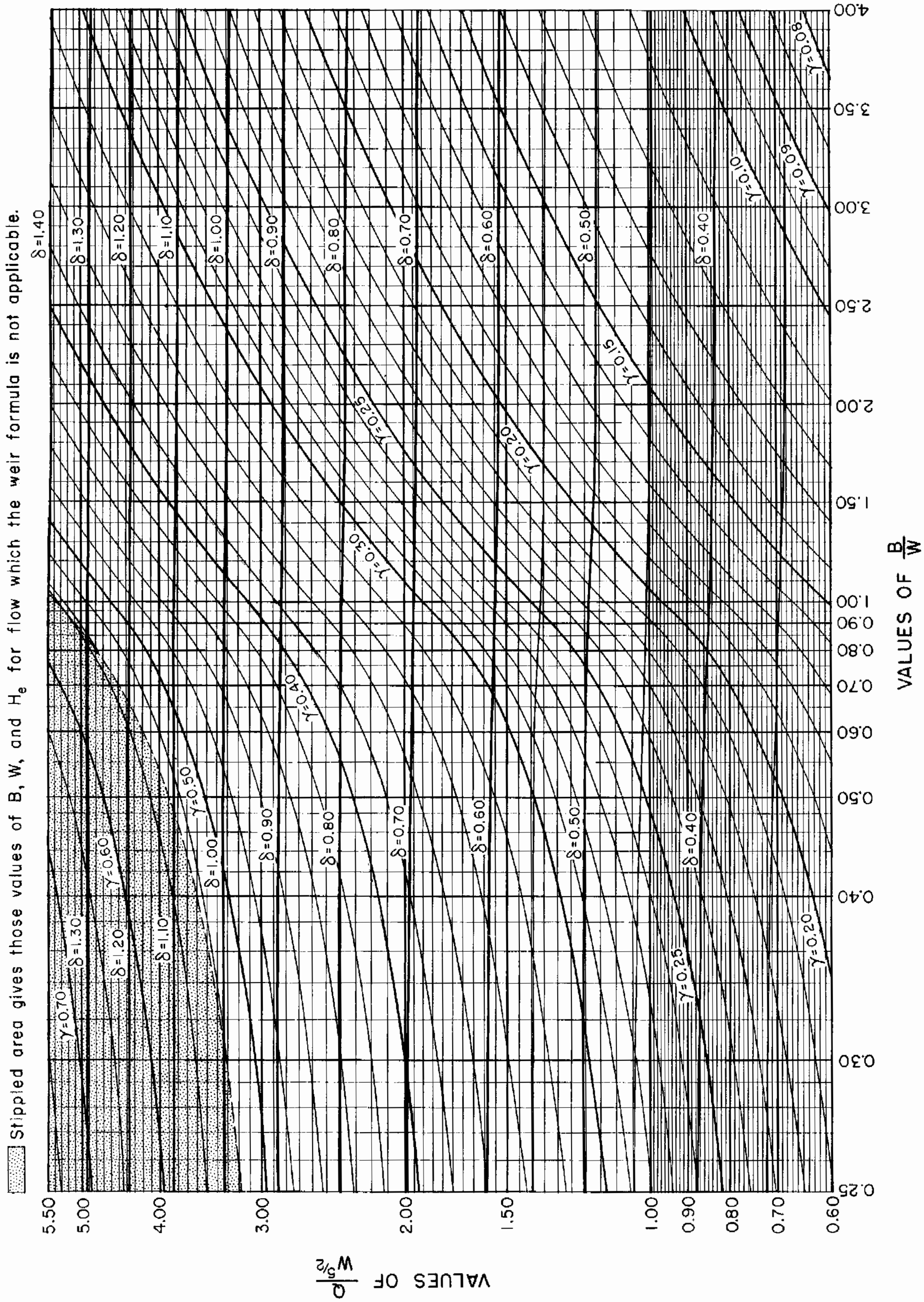
where the value of K is obtained from sheets 9 and 10. The value of Q_K may be obtained from sheets 9 and 10 without determining the value of K. The value of κ is

$$\kappa = \frac{W_c + 0.8\ z_c\ H_e}{W}$$

CHUTE SPILLWAYS: The discharge-head relationship for a FLAT-TRAPEZOIDAL weir box inlet with free-flow conditions at the crest and no narrow channel effects, $z_o = 3:1$

$\delta = \frac{D_r}{W}$

$\gamma = \frac{H_e}{W}$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

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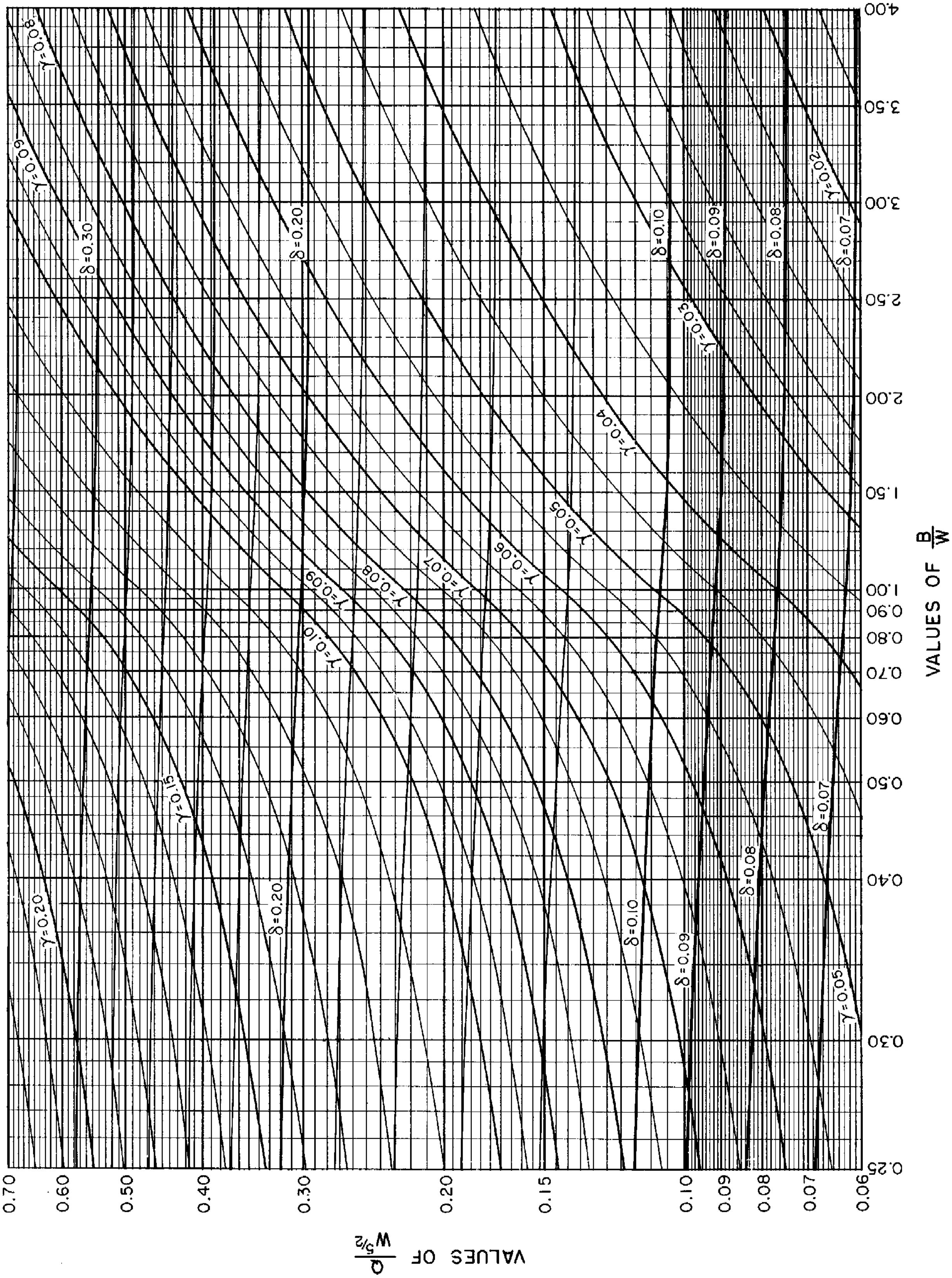
CHUTE SPILLWAYS: The discharge-head relationship for a FLAT-TRAPEZOIDAL weir box inlet with free-flow conditions at the crest and no narrow channel effects, $z_o = 3:1$

$\delta = \frac{D_r}{W}$

$\gamma = \frac{H_e}{W}$



REFERENCE
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SHEET 6 OF 16
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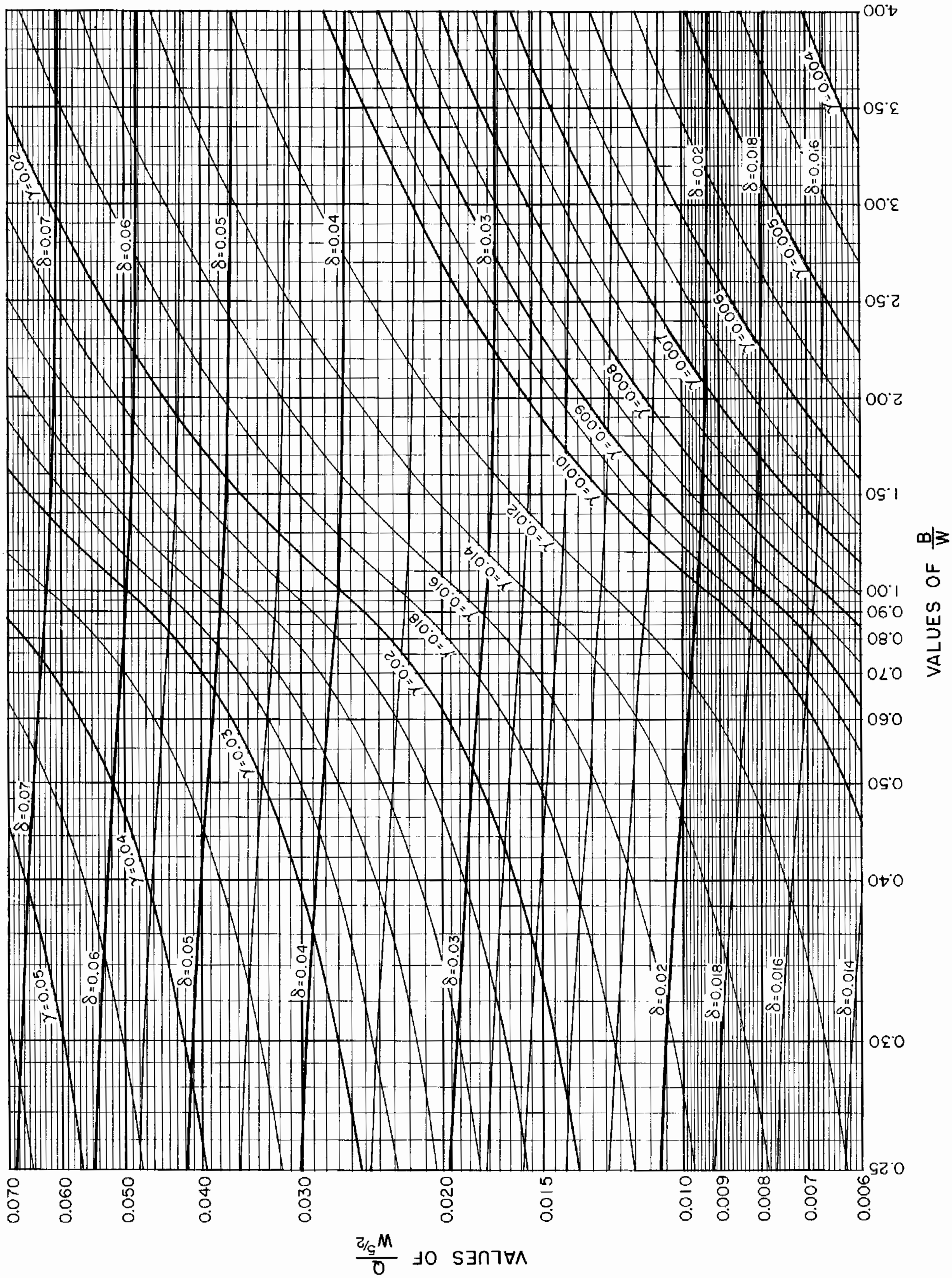
CHUTE SPILLWAYS: The discharge-head relationship for a FLAT-TRAPEZOIDAL weir box inlet with free-flow conditions at the crest and no narrow channel effects, $z_o = 3:1$

$\delta = \frac{D_r}{W}$

$\gamma = \frac{H_e}{W}$



REFERENCE
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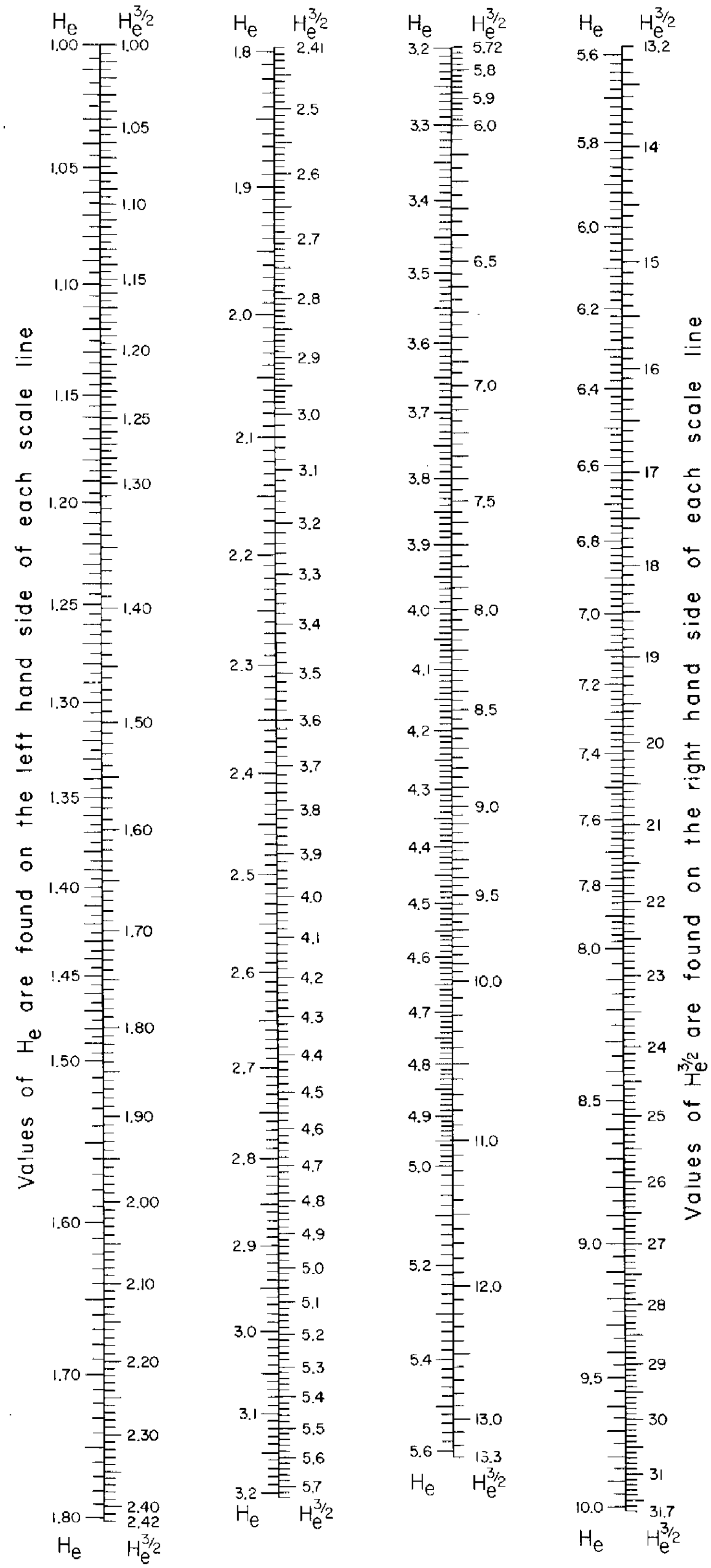
CHUTE SPILLWAYS : FLAT-TRAPEZOIDAL WEIR BOX INLETS.

W-ft	$W^{5/2}$
3.0	15.588
3.5	22.918
4.0	32.000
4.5	42.957
5.0	55.902
5.5	70.943
6.0	88.182
6.5	107.72
7.0	129.64
7.5	154.05
8.0	181.02
8.5	210.64
9.0	243.00
9.5	278.17
10.0	316.23
10.5	357.25
11.0	401.31
11.5	448.48
12.0	498.83
12.5	552.43
13.0	609.34
13.5	669.63
14.0	733.36
14.5	800.61
15.0	871.42
15.5	945.87
16.0	1024.0
16.5	1105.9
17.0	1191.6
17.5	1281.1
18.0	1374.6
18.5	1472.1
19.0	1573.6
19.5	1679.1
20.0	1788.9
20.5	1902.8
21.0	2020.9
21.5	2143.4
22.0	2270.2
22.5	2401.4
23.0	2537.0
23.5	2677.1
24.0	2821.8
24.5	2971.1
25.0	3125.0
25.5	3283.6
26.0	3446.9
26.5	3615.1
27.0	3788.0
27.5	3965.8
28.0	4148.5
28.5	4336.2
29.0	4528.9
29.5	4726.7
30.0	4929.5
30.5	5137.5
31.0	5350.6
31.5	5569.0
32.0	5792.6
32.5	6021.6
33.0	6255.8
33.5	6497.2
34.0	6740.6
34.5	6991.1
35.0	7247.2
35.5	7508.8
36.0	7776.0
36.5	8048.8
37.0	8327.3
37.5	8611.5
38.0	8901.4
38.5	9197.1
39.0	9498.6
39.5	9806.0
40.0	10,119



REFERENCE

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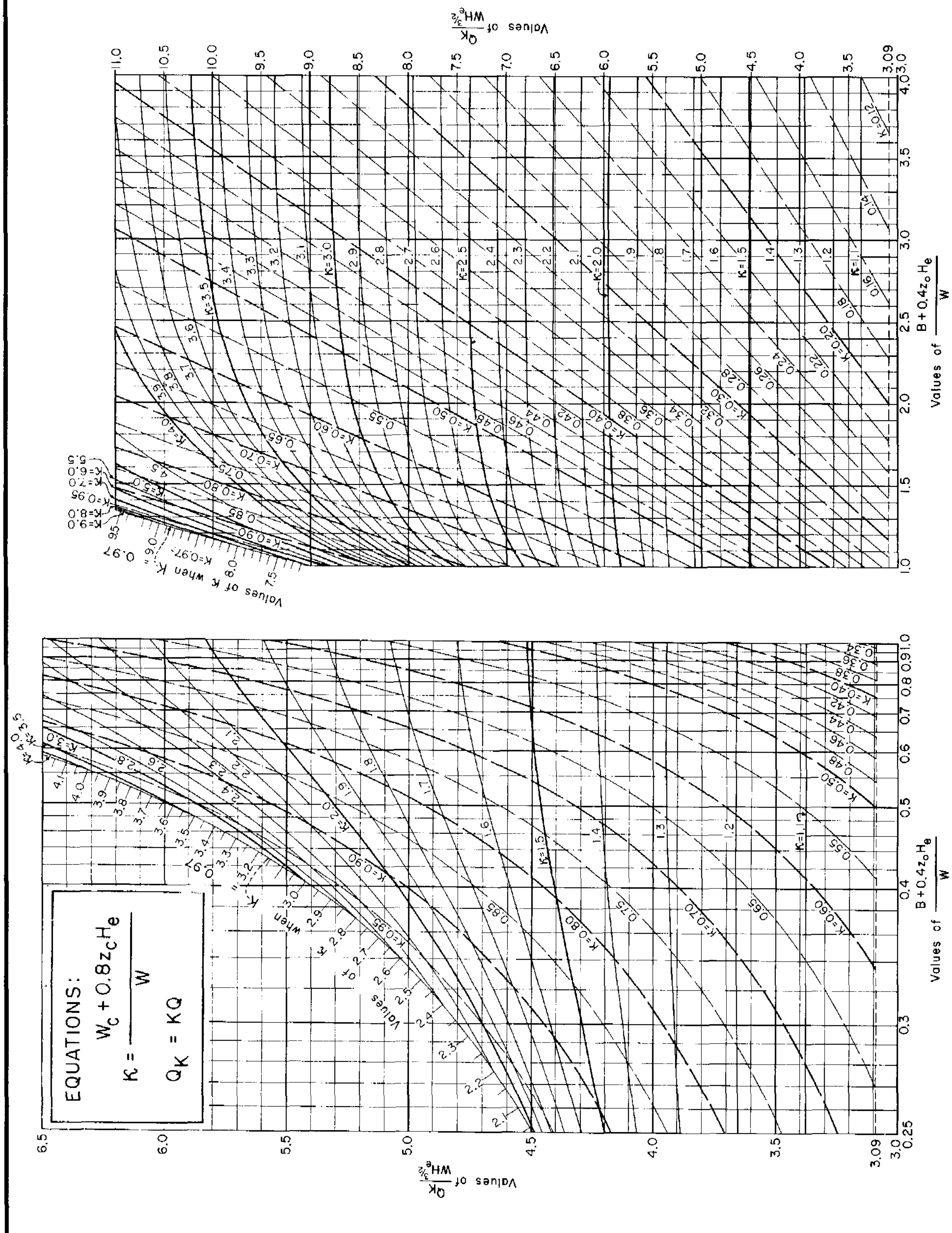
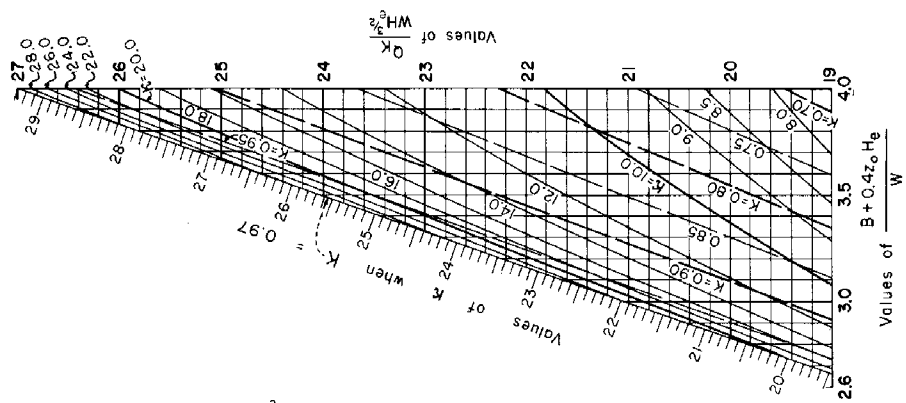
CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS;

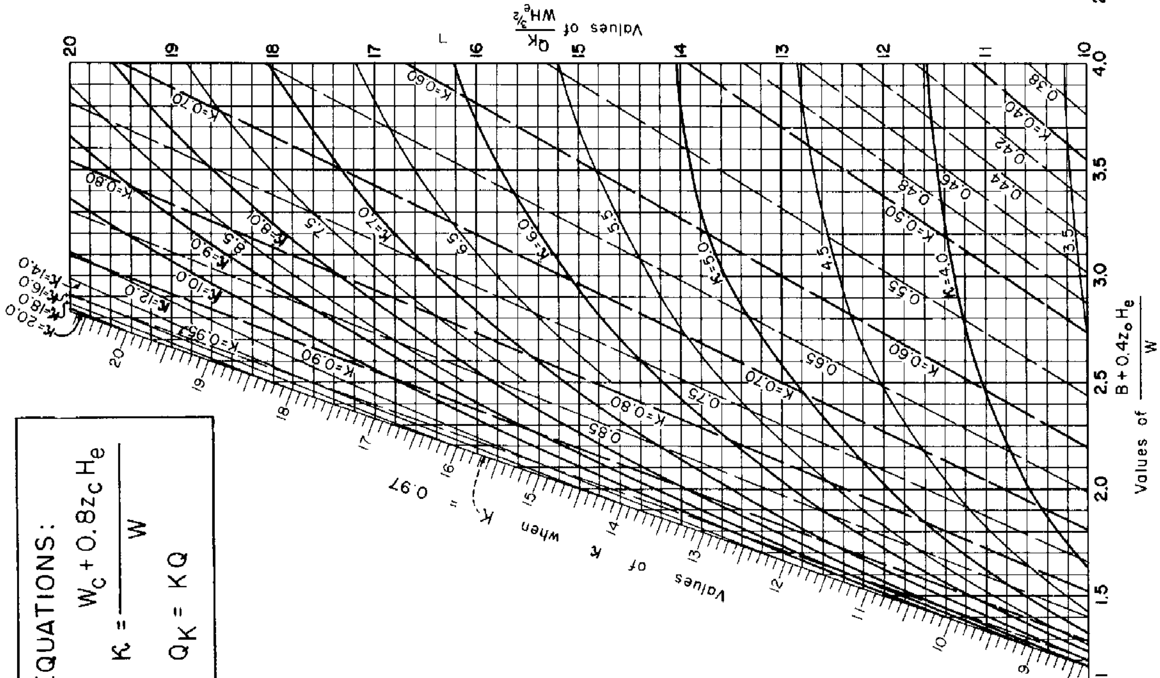
Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.



REFERENCE		
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 92 SHEET 9 OF 16 DATE 5-20-55

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS;
Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.

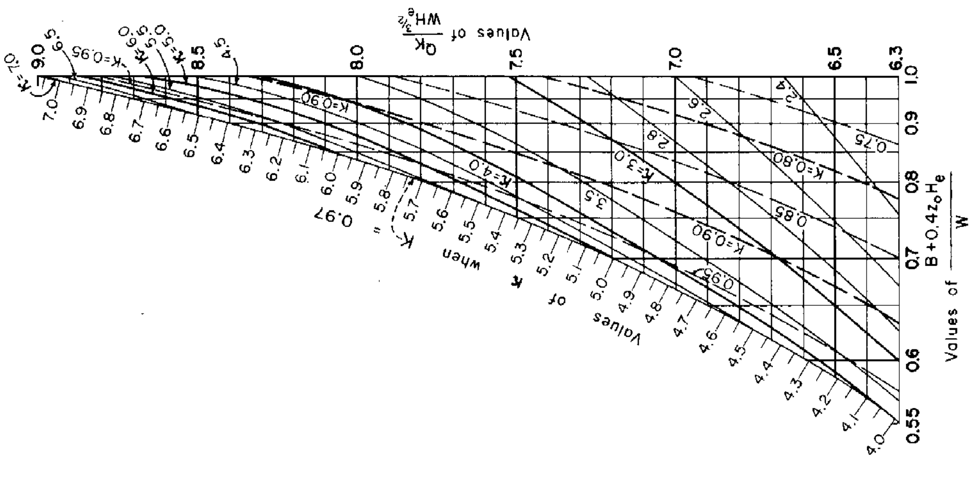




EQUATIONS:

$$K = \frac{W_c + 0.8 z_c H_e}{W}$$

$$Q_K = KQ$$



REFERENCE		
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 92 SHEET 10 OF 16 DATE 5-20-55

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Examples

EXAMPLE 1

Given: A flat-trapezoidal weir box inlet for a chute spillway. The inside dimensions are W = 10 ft, B = 6 ft, and D = 4 ft. The approach channel and the dike covering the headwall have no effect on the discharge of the inlet. $z_o = 3$.

Determine: 1. The head H_e over the crest at which the discharge Q begins to be affected by the dimension D; that is, the head H_e corresponding to impending submerged flow conditions at the crest.

2. The discharge corresponding to the head H_e determined in (1).

Solution: 1. Solving for the head H_e over the crest at which the discharge is affected by the dimension D. The value of $\frac{B}{W}$ is $\frac{6}{10} = 0.6$. The value of $\delta = \frac{D}{W}$ is $\frac{4}{10} = 0.4$. The point of intersection of the line having the value of $\frac{B}{W} = 0.6$ and the line $\delta = 0.4$, sheet 5, has a value $\gamma = \frac{H_e}{W} = 0.218$ or

$$H_e = 0.218\ (10) = 2.18 \text{ ft}$$

For heads over the crest greater than $H_e = 2.18$ ft, the discharge depends on the value of D = 4 ft as well as B, W, and H_e because submerged flow at the crest occurs.

2. Solving for the discharge corresponding to $H_e = 2.18$ ft. Since D is sufficiently large to insure no submergence of the crest, obtain from sheet 5 at the intersection of $\frac{B}{W} = 0.6$ and $\delta = \frac{D}{W} = 0.4$ the value $\frac{Q}{W^{5/2}} = 0.860$ or

$$Q = 0.860\ (10)^{5/2} = 272 \text{ cfs}$$

If the value of D had been greater than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.18$ ft remains the same; i.e., Q = 272 cfs. If the value of D had been less than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.18$ ft is not determinable from sheet 5 because the crest would be submerged as a result of a shallow box.

EXAMPLE 2

Given: A flat-trapezoidal weir box inlet. The inside dimensions are W = 5 ft, B = 2 ft, and $H_e = 3.5$ ft. The approach channel and the dike covering the headwall and the crest of the box inlet are sufficiently large to prevent any effect on the discharge of the inlet. $z_o = 3$.

Determine: 1. The actual discharge Q of the box inlet if flow at the crest is not submerged.

2. The depth D_r of the box inlet required to prevent submergence of the crest for this discharge.

3. The theoretical discharge Q_t of the box inlet as determined by the weir formula.

Solution: 1. Solving for the actual discharge of the box inlet. The value of $\frac{B}{W}$ is $\frac{2}{5} = 0.4$ and $\gamma = \frac{H_e}{W}$ is $\frac{3.5}{5} = 0.7$. The point of intersection of the lines having the values of $\frac{B}{W} = 0.4$ and $\gamma = \frac{H_e}{W} = 0.7$ corresponds to a value of $\frac{Q}{W^{5/2}} = 5.37$ and a value of $\delta = \frac{D_r}{W} = 1.38$.

$$Q = 5.37\ W^{5/2} = 5.37\ (5)^{5/2} = 300.2 \text{ cfs}$$

Concluded on Sheet 12

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Examples

Continuation from Sheet 11

2. Solving for the required depth D_r of the box inlet to prevent submergence

$$D_r = 1.38\ W = 1.38\ (5) = 6.90 \text{ ft}$$

3. Solving for the theoretical discharge of the box inlet as given by the weir formula

$$Q_t = 3.1\ (2\ B + W + 2.4\ H_e)\ H_e^{3/2}$$
$$= 3.1 \left[2\ (2) + 5 + 2.4\ (3.5)\right] (3.5)^{3/2}$$
$$Q_t = 353.2 \text{ cfs}$$

The stippled region shown on sheet 5 signifies the weir formula is not applicable in predicting the discharge for the points corresponding to the values of B, W, and H_e in this region. Therefore Part 3 is not a valid solution.

EXAMPLE 3

Given: A flat-trapezoidal weir box inlet for a chute spillway. The dimensions of the box inlet are W = 10 ft, B = 6 ft, D = 4.75 ft, h = 2.5 ft, and M = 4.5 ft. There is no effect on the discharge due to a narrow channel or dike. $z_o = 3$.

Determine: 1. The capacity without freeboard at the crest Q_{mh} in cfs.

2. The capacity without freeboard at the origin of the upper vertical curve Q_{mM} in cfs.

3. The capacity without freeboard of the box inlet Q_{mi} in cfs.

4. The capacity of the inlet Q_{si} if the total drop of the chute is Z = 25 ft.

Solution: No consideration of channel and dike effect will be required.

1. Solving for the capacity without freeboard at the crest Q_{mh}

$$\frac{B}{W} = \frac{6}{10} = 0.6 \qquad \delta = \frac{D}{W} = \frac{4.75}{10} = 0.475 \qquad \gamma = \frac{h}{W} = \frac{2.5}{10} = 0.25$$

At the intersection of lines (see sheet 5) $\frac{B}{W} = 0.6$ and $\gamma = 0.25$, read $\frac{Q_{mh}}{W^{5/2}} = 1.085$. Observe that the required value of δ is $0.468 < 0.475 = \frac{D}{W}$. If the value of $\delta = \frac{D_r}{W}$ read from the chart had been greater than 0.475, then the value of Q_{mh} is indeterminable from the chart.

$$Q_{mh} = 1.085\ W^{5/2} = 1.085\ (10)^{5/2} = 343.0 \text{ cfs}$$

2. The capacity without freeboard at the downstream end of the box inlet Q_{mM} may be read from Table 1, sheet 3, ES-88, for M = 4.50 ft and $q_{mM} = 35.16$ cfs/ft.

$$Q_{mM} = W\ q_{mM} = 10\ (35.16) = 351.6 \text{ cfs}$$

3. The capacity without freeboard of the box inlet Q_{mi} is the lesser of the values Q_{mh} and Q_{mM} or is $Q_{mh} = 343$ cfs.

4. The capacity of the inlet having the recommended freeboard is

$$Q_{si} = \frac{Q_{mi}}{(1.2 + 0.003\ Z)} = \frac{343}{1.2 + 0.003\ (25)} = 269 \text{ cfs}$$

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Examples

EXAMPLE 4

Given: A design discharge Q_r = 270 cfs for a chute of width W = 10 ft and a sidewall height over the crest h = 2 ft. The vertical drop of the chute from the crest of the inlet to the floor of the SAF outlet is Z = 30 ft. The slope of the box inlet is z_o = 3. No wave action is anticipated in the channel upstream from the inlet.

Determine: 1. The required capacity without freeboard Q_{fr}.

2. The required ratio of $\frac{B}{W}$ for a flat-trapezoidal weir if the approach channel and dike are to have no effect on the discharge equal to the design discharge without freeboard Q_{fr}.

3. The dimensions B, D, and M for the flat-trapezoidal weir box inlet if the approach channel and dike have no effect on the discharge Q_{fr}.

Solution: 1. Solving for the required capacity without freeboard Q_{fr}

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right] 270$$
$$Q_{fr} = 348.3 \text{ cfs}$$

2. When the discharge of the inlet is Q_{fr}, the value of B is to be determined such that the head over the crest is h = 2.0 ft. The value of $\frac{Q_{fr}}{W^{5/2}} = \frac{348.3}{(10)^{5/2}}$ = 1.101 and $\gamma = \frac{h}{W} = \frac{2.0}{10} = 0.20$. From sheet 5, read the value of $\frac{B}{W}$ = 1.26 for free-flow conditions.

3. (a) The required value of B is

$$B = W\left[\frac{B}{W}\right] = 10\ (1.26) = 12.60 \text{ ft}$$

Use B = 12.75 ft

(b) The required value of D_r to prevent submergence at the crest is obtained by reading the value of δ at the point of intersection of the lines γ = 0.20 and $\frac{Q_{fr}}{W^{5/2}}$ = 1.101 or δ = 0.479. The required value of D_r is

$$D_r = W\ \delta = 10\ (0.479) = 4.79 \text{ ft}$$

Use D = 5.0 ft

(c) The value of M may be read from Table 1, sheet 3, ES-88, when

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{348.3}{10} = 34.83 \text{ cfs/ft}$$

$$M = 4.50 \text{ ft}$$

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Examples

EXAMPLE 5

Given: A flat-trapezoidal weir box inlet with the dimensions B = 13.5 ft, W = 9 ft, h = 2.0 ft, and M = 4.00 ft; W_c = 35.2 ft and the headwall is extended across the channel. Thus no effect on the discharge is obtained by a dike. The side slope of the approach channel is 3 to 1; $z_c = 3$. The slope of the box inlet crest is $z_o = 3$.

Determine: 1. The capacity without freeboard at the crest of this inlet Q_{mh} when the effect of the narrow approach channel is not considered, and the value of $\delta = \frac{D}{W}$ is sufficiently large to prevent submergence of the crest.

2. The capacity without freeboard at the origin of the vertical curve Q_{mM}.

3. The value of K.

4. The capacity without freeboard at the crest of this inlet $(Q_K)_{mh}$ when the effect of the narrow approach channel is considered, and the value of $\delta = \frac{D}{W}$ is sufficiently large to prevent submergence of the crest.

5. The required depth of the box inlet D_r to insure free-flow conditions at the crest corresponding to the discharge $(Q_K)_{mh}$.

6. The capacity without freeboard of this inlet $(Q_K)_{mi}$ when the effect of the narrow approach channel is considered.

Solution: 1. Solving for the capacity without freeboard at the crest Q_{mh} of the box inlet when the width of the approach channel is sufficiently great to prevent an effect on the capacity of the inlet and the depth D is sufficiently large to prevent submergence of the crest. The capacity Q_{mh} of the box inlet is equal to the discharge of the box inlet with a head h over the crest.

$$\frac{B}{W} = \frac{13.5}{9} = 1.5 \qquad \text{and} \qquad \gamma = \frac{h}{W} = \frac{2}{9} = 0.222$$

At the intersection of $\frac{B}{W} = 1.5$ and $\gamma = 0.222$, sheet 5, read the value $\frac{Q_{mh}}{W^{5/2}} = 1.47$

$$Q_{mh} = 1.47\ W^{5/2} = 1.47\ (9)^{5/2} = 357 \text{ cfs}$$

This is the capacity without freeboard Q_{mh} at the crest of the box inlet if D and the channel width W_c are both sufficiently great.

2. Solving for the capacity without freeboard Q_{mM} at the origin of the vertical curve section. This is read from Table 1, sheet 3, ES-88. When M = 4.00 ft, then q_{mM} = 29.47 cfs/ft.

$$Q_{mM} = W\ q_{mM} = 9\ (29.47) = 265.2 \text{ cfs}$$

3. Solving for the ratio

$$\kappa = \frac{W_c + 0.8\ z_c\ h}{W} = \frac{35.2 + 0.8\ (3)(2)}{9} = \frac{40}{9} = 4.444$$

From sheet 9, the corresponding value of K when $\kappa = 4.444$ and $\frac{B + 0.4\ z_o\ h}{W} = \frac{13.5 + 0.4\ (3)(2)}{9}$ = 1.77 is K = 0.770.

4. Solving for the capacity without freeboard $(Q_K)_{mh}$ at the crest of the box inlet when the narrow channel effects are considered and free-flow conditions exist at the crest.

$$(Q_K)_{mh} = K\ Q_{mh} = 0.770\ (357) = 275 \text{ cfs}$$

Concluded on Sheet 15

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Examples

Continuation from Sheet 14

This could also be obtained from sheet 9 when $\kappa = 4.444$ and $\frac{B + 0.4\ z_o\ h}{W} = 1.77$, read $\frac{(Q_K)_{mh}}{W\ h^{3/2}} = 10.82$ or

$$(Q_K)_{mh} = 10.82\ W\ h^{3/2}$$
$$= 10.82\ (9)(2)^{3/2}$$
$$(Q_K)_{mh} = 275 \text{ cfs}$$

5. Solving for the required depth D_r of the box inlet having the five given dimensions is read on sheet 5 at the intersection of the lines $\frac{(Q_K)_{mh}}{W^{5/2}} = \frac{275}{(9)^{5/2}} = 1.132$ and $\frac{B}{W} = 1.5$ or

$$\delta = \frac{D_r}{W} = 0.490 \qquad \text{and} \qquad D_r = 0.490\ (9) = 4.41 \text{ ft}$$

The depth D_r is required to prevent submergence of the crest when $W_c = 35.2$ ft, and the discharge is $(Q_K)_{mh} = 275$ cfs. A value of $D > 4.41$ ft will not increase the capacity without freeboard of this channel and box inlet. The capacity of the channel and box inlet for a $D < 4.41$ ft is not determinable by these charts; such a value will cause submergence at the crest. See Ex. 1. For construction purposes D will generally be chosen to be the next size larger than D_r when D is a multiple of 3 inches, or D = 4.50 ft.

6. The smaller of the two values $(Q_K)_{mh} = 275$ cfs or $Q_{mM} = 265.2$ cfs is the capacity without freeboard $(Q_K)_{mi}$ of the box inlet when the narrow approach channel effect is considered.

$$(Q_K)_{mi} = (Q_K)_{mM} = 265.2 \text{ cfs}$$

EXAMPLE 6

Given: The problem of designing a flat-trapezoidal weir box inlet for the design discharge $Q_r = 200$ cfs. The approach channel to the inlet has a width of $W_c = 24.6$ ft. The vertical drop from the crest of the inlet to the floor of the outlet is Z = 30 ft. The width W of the chute is 8 ft and the dimension h is 2.25 ft. The headwall is to extend across this channel and thus no consideration of dike effect is required. The side slopes of the approach channel are 3 to 1; $z_c = 3$. The slope of the box inlet crest is $z_o = 3$.

Determine: 1. The required capacity without freeboard Q_{fr} and q_{fr}.

2. The value of B when the effect on the discharge of the narrow approach channel is neglected.

3. The value of K.

4. The value of B when the effect of the narrow channel on the discharge is considered.

5. The value of D_r required to prevent submerged flow conditions at the crest when the effect of the narrow channel is considered.

6. The capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the capacity of the approach channel and the dimension of B obtained in (4).

7. The dimension M of the box inlet.

8. The capacity of the box inlet without freeboard $(Q_K)_{mi}$ when considering the effect of the narrow approach channel.

Solution: 1. Solving for the required capacity without freeboard is

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right]\ 200$$
$$Q_{fr} = 258 \text{ cfs}$$

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{258}{8} = 32.25 \text{ cfs/ft}$$

Concluded on Sheet 16

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS; Examples

Continuation from Sheet 15

2. The value B when the effect on the discharge of the narrow approach channel is neglected may be obtained from sheet 5. At the intersection of lines $\frac{Q_{fr}}{W^{5/2}} = \frac{258}{8^{5/2}} = 1.425$ and $\gamma = \frac{h}{W} = \frac{2.25}{8} = 0.281$, read $\frac{B}{W} = 0.710$

$$B = 0.710\ W = 0.710\ (8) = 5.68\ \text{ft}$$

3. The value of K may be read from sheet 9 at the intersection of the lines $\frac{Q_{fr}}{W\ h^{3/2}} = \frac{258}{8\ (2.25)^{3/2}} = 9.56$ and $\kappa = \frac{W_c + 0.8\ z_c\ h}{W} = \frac{24.6 + 0.8\ (3)(2.25)}{8} = 3.75$. Read K = 0.745.

4. The value of B when the effect of the narrow channel on the discharge is considered is again obtained at the intersection of lines $\kappa = 3.75$ and $\frac{Q_{fr}}{W\ h^{3/2}} = 9.56$, read $\frac{B + 0.4\ z_o\ h}{W} = 1.575$ or

$$B = 1.575\ W - 0.4\ z_o\ h = (1.575)\ 8 - 0.4\ (3)(2.25) = 9.90\ \text{ft}$$

Use B = 10.0 ft

5. The value of D_r may be obtained on sheet 5 at the intersection of the lines $\frac{Q_{fr}}{W^{5/2}} = \frac{258}{8^{5/2}} = 1.425$ and $\frac{B}{W} = \frac{9.90}{8} = 1.238$. This reads

$$\delta = \frac{D_r}{W} = 0.569 \quad \text{or} \quad D_r = 0.569\ W = 0.569\ (8) = 4.55\ \text{ft}$$

Use D = 4.75 ft

6. Solving for the capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the narrow approach channel. From sheet 5 when $\frac{B}{W} = \frac{10}{8} = 1.25$ and $\gamma = \frac{h}{W} = \frac{2.25}{8} = 0.281$, read

$$\frac{Q_{mh}}{W^{5/2}} = 1.93$$

$$Q_{mh} = 1.93\ W^{5/2} = 1.93\ (8)^{5/2} = 349\ \text{cfs}$$

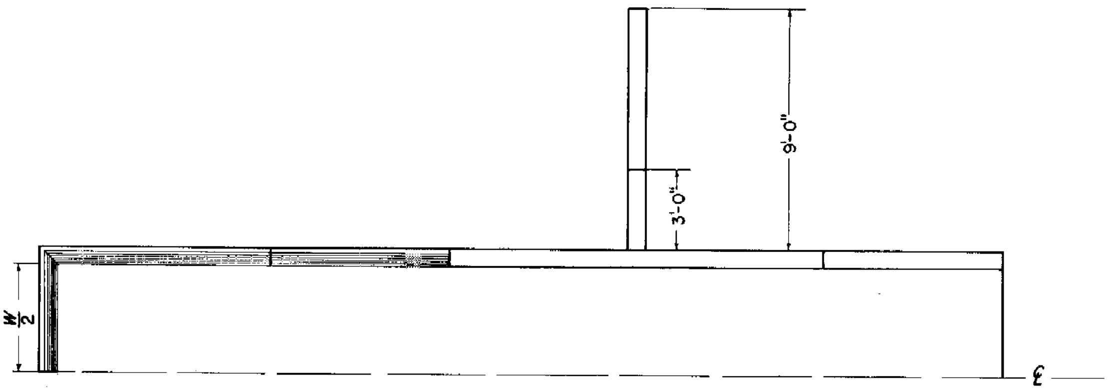
$$(Q_K)_{mh} = K\ (Q_{mh}) = 0.745\ (349) = 260\ \text{cfs}$$

7. Solving for the dimension M at the origin of the vertical curve section. Given $q_{fr} = 32.25$, see Step 1. Read from Table 1, sheet 3, ES-88, the value M = 4.25 when $q_{mM} = 32.27$ and $Q_{mM} = W\ q_{mM} = (8)\ 32.27 = 258.16$ cfs.

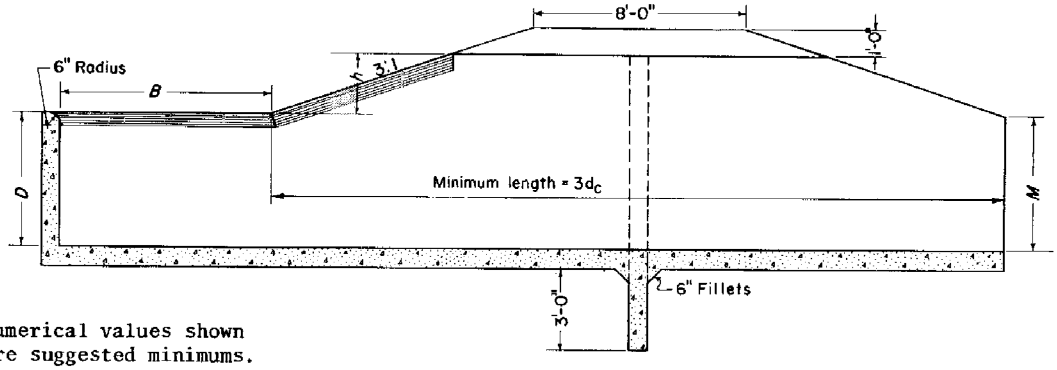
8. Solving for the capacity without freeboard of the box inlet $(Q_K)_{mi}$ considering the effect of the narrow channel and free-flow conditions. The value of $(Q_K)_{mi}$ is equal to the smaller of the values $(Q_K)_{mh}$ and Q_{mM}.

$$(Q_K)_{mi} = Q_{mM} = 258.16\ \text{cfs}$$

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLET; General layout.



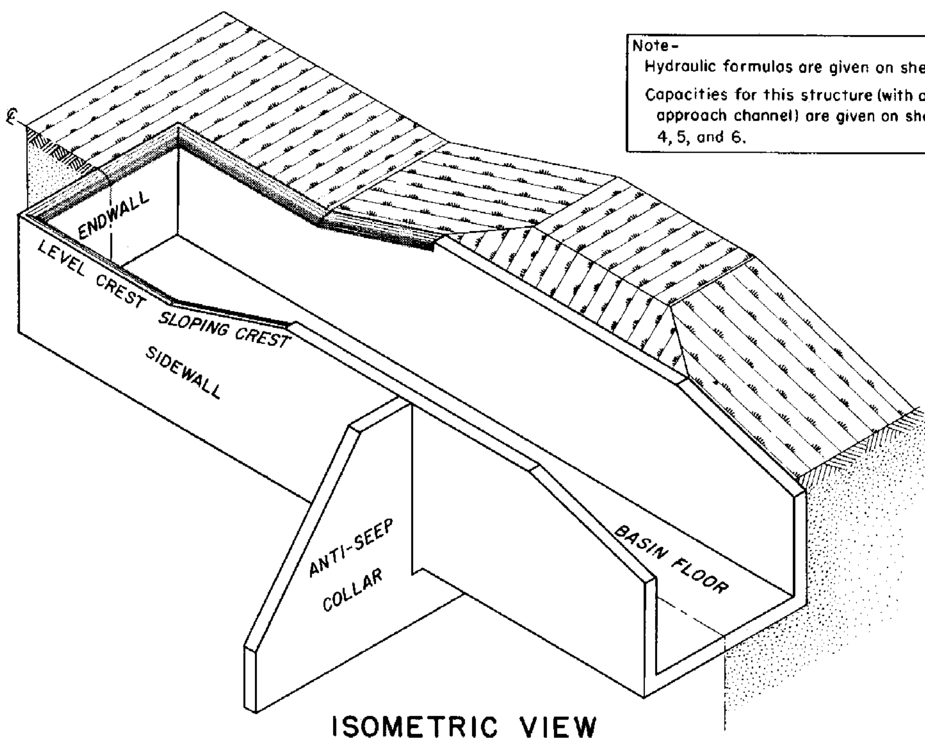
HALF PLAN



Numerical values shown are suggested minimums.

SECTION ALONG CENTER-LINE

Note-
Hydraulic formulas are given on sheet 4.
Capacities for this structure (with a wide approach channel) are given on sheets 4, 5, and 6.

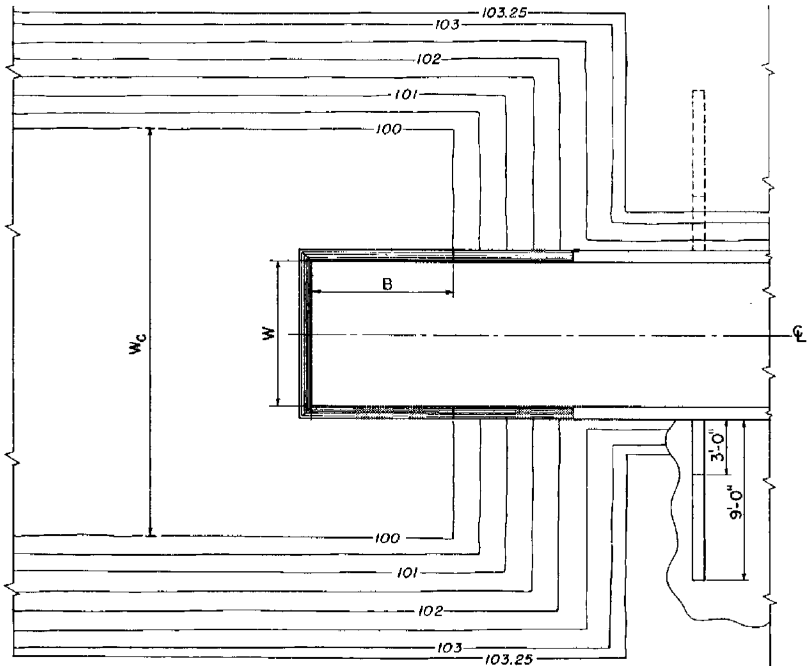


ISOMETRIC VIEW

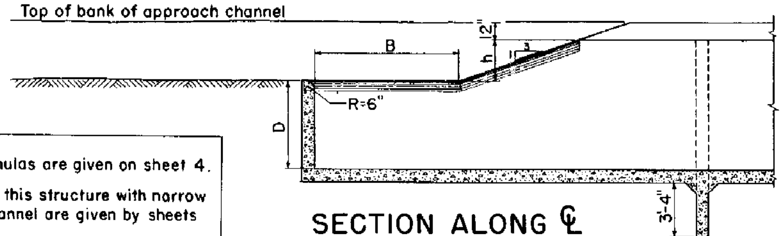
REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-93 SHEET 1 OF 16 DATE 2-23-55

Revised 10/77

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLET; Effect of narrow channels on discharge.



PLAN



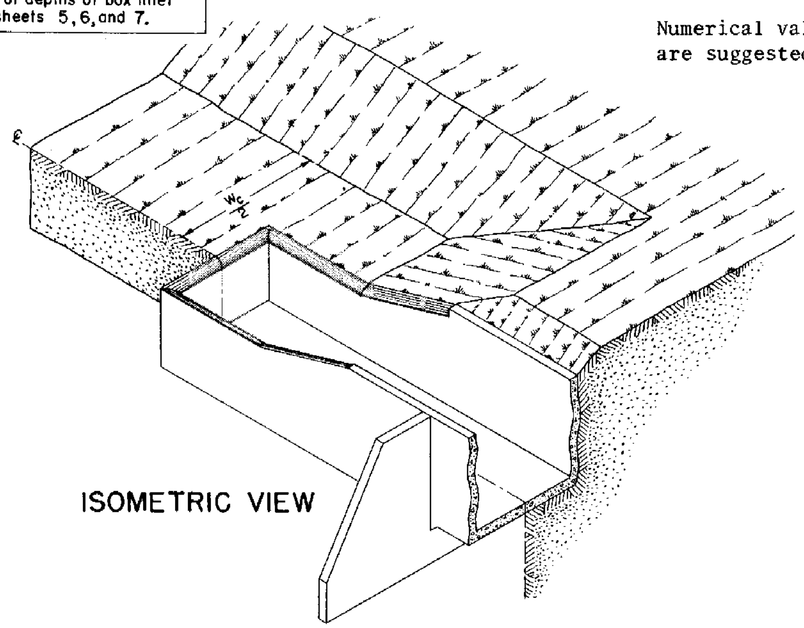
SECTION ALONG ℄

Note -
Hydraulic formulas are given on sheet 4.

Capacities for this structure with narrow approach channel are given by sheets 9 and 10.

Required values of depths of box inlet are given by sheets 5, 6, and 7.

Numerical values shown are suggested minimums



ISOMETRIC VIEW

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 93 SHEET 2 OF 16 DATE 2-23-55

Revised 10/77

CHUTE SPILLWAYS : ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Definition of symbols

DEFINITION OF SYMBOLS

B = Inside length of the box inlet measured from the downstream face of the endwall to the upstream face of the headwall in ft

D = Depth (i.e., distance from the crest to the floor) of the box inlet in ft

D_r = Required depth of box inlet to prevent submergence at the crest when the discharge is Q in ft

h = Height of sidewalls above the crest of the box inlet in ft

H_e = Specific energy head above the crest of the inlet corresponding to any discharge Q the inlet is capable of conveying in ft

K = $\frac{Q_K}{Q}$

L = Length of developed crest = $2\ B + W + 0.4\ z_o\ H_e + 2$

M = Height of sidewall above the floor of the box inlet at the junction with the vertical curve section in ft

q = Discharge per unit width W or $q = \frac{Q}{W}$ in cfs/ft

Q = Discharge corresponding to the head H_e of a box inlet having no narrow approach channel or dike effect in cfs

Q_r = Design discharge in cfs

Q_{fr} = Required capacity without freeboard in cfs

Q_{si} = Capacity of inlet in cfs

Q_{mi} = Capacity of inlet without freeboard in cfs

Q_{mh} = Capacity of inlet without freeboard at the crest in cfs; the discharge $Q = Q_{mh}$ when $H_e = h$

Q_{mM} = Capacity of inlet without freeboard at the origin of the upper vertical curve in cfs

$(Q_K)_{mh}$ = Capacity without freeboard of a box inlet at the crest when a narrow approach channel is considered in cfs; the discharge $Q = (Q_K)_{mh}$ when $H_e = h$

Q_K = Discharge corresponding to the head H_e of a box inlet having a narrow approach channel in cfs

$(Q_K)_{mi}$ = Capacity without freeboard of a box inlet and narrow approach channel of width W_c and downstream end section having a sidewall height M in cfs

W = Width of inlet in ft

W_c = Bottom width of the approach channel for the box inlet in ft

z_c = Side slope (horizontal distance per vertical foot) of approach channel

z_o = Side slope (horizontal distance per vertical foot) of spillway crest

Z = Vertical drop from the crest of the inlet to the floor of the SAF outlet in ft

κ = Ratio $\frac{W_c + 0.8\ z_c\ H_e}{W + 1}$

$\psi = \frac{1.2\ g^{1/3}\ W^{2/3}}{Q^{2/3}} D_r$ where $\psi > 1$ (see equations, sheet 4)

γ = Ratio $\frac{H_e}{W + 1}$

δ = Ratio $\frac{W^{2/3}}{(W + 1)^{5/3}} D_r$

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-93 SHEET 3 OF 16 DATE 6-4-55

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Formulas

FORMULAS

The relationship of the discharge-head over the crest for a rounded-trapezoidal weir box inlet having a wide approach channel and no dike effect is

$$Q = 3.1\,(2\,B + W + 2 + 0.8\,z_o\,H_e)\,H_e^{3/2} \qquad \text{when}$$

$$0 < H_e \leqq \frac{0.49\,W}{1 - 0.016\,z_o} + \frac{0.04\,B}{1 - 0.016\,z_o} + \frac{0.51}{1 - 0.016\,z_o}\,; \quad (W \geqq 4\text{ ft}) \qquad \text{and}$$

$$0 < Q \leqq 5.5\,(W + 1)^{5/2} \qquad \text{and}$$

$$\psi^3 - 3\,\psi + 2\left[\frac{W + 1}{2\,B + W + 2 + 0.8\,z_o\,H_e}\right]^2 = 0 \qquad \text{where}$$

$$\frac{1.2\,g^{1/3}\,W^{2/3}\,D_r}{Q^{2/3}} = \psi > 1$$

These relations are expressed in graphical form by sheets 5, 6, and 7 where $z_o = 3$ and

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}}\,D_r \qquad \text{and} \qquad \gamma = \frac{H_e}{W + 1}$$

values of $H_e^{3/2}$, $(W + 1)^{5/2}$, and $\frac{W^{2/3}}{(W + 1)^{5/3}}$ are given on sheet 8.

When $H_e > 0.51\,W + 0.04\,B + 0.53$, no algebraic relationship is given. The last two relations are a requirement of the value of D to prevent submergence of the crest. The relationship of the discharge-head over the crest of a rounded-trapezoidal weir box inlet having a narrow channel effect but no dike effect is

$$Q_K = K\,Q$$

where the value of K is obtained from sheets 9 and 10. The value of Q_K may be obtained from sheets 9 and 10 without determining the value of K. The value of κ is

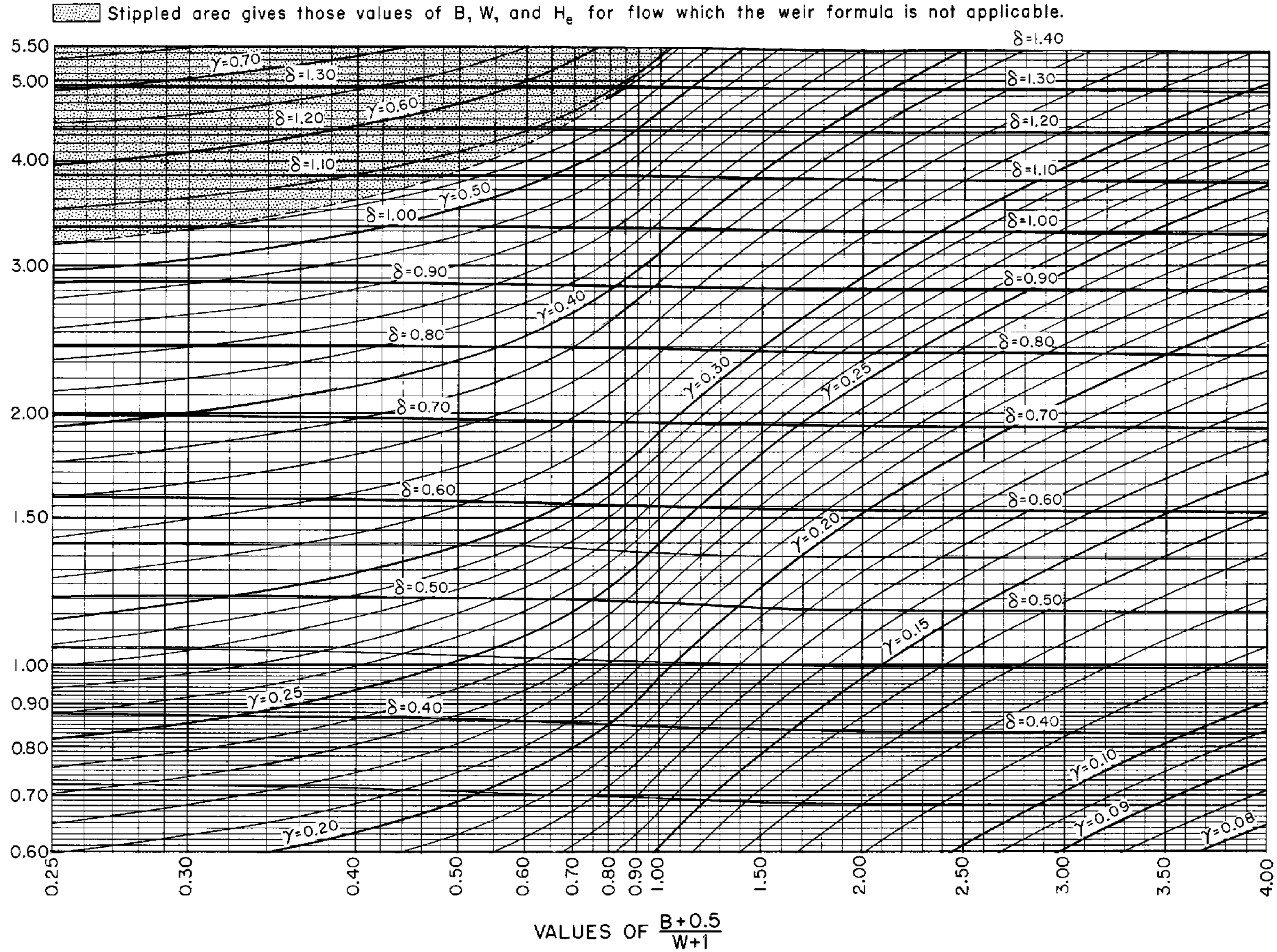
$$\kappa = \frac{W_c + 0.8\,z_c\,H_e}{W + 1}$$

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-93 SHEET 4 OF 16 DATE 6-4-55

CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-TRAPEZOIDAL weir box inlet with free-flow conditions at the crest and no narrow channel effects, $z_o = 3:1$

$\delta = \frac{W^{2/3}}{(W+1)^{5/3} D_r}$

$\gamma = \frac{H_e}{W+1}$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

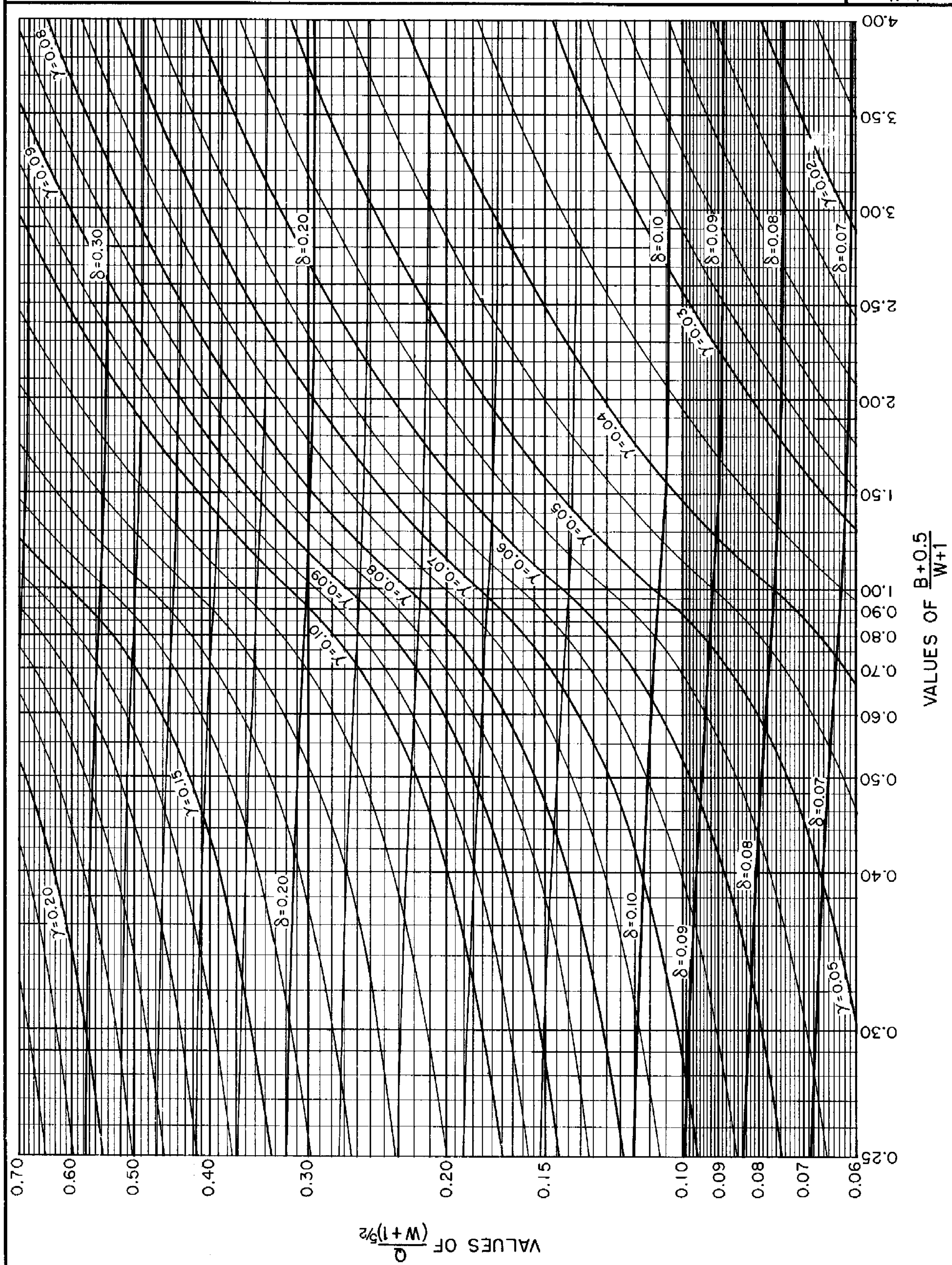
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-93
SHEET 5 OF 16
DATE 5-28-55

CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-TRAPEZOIDAL weir box inlet with free-flow conditions at the crest and no narrow channel effects, $z_o = 3:1$

$\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D_r$

$\gamma = \frac{H_e}{W+1}$

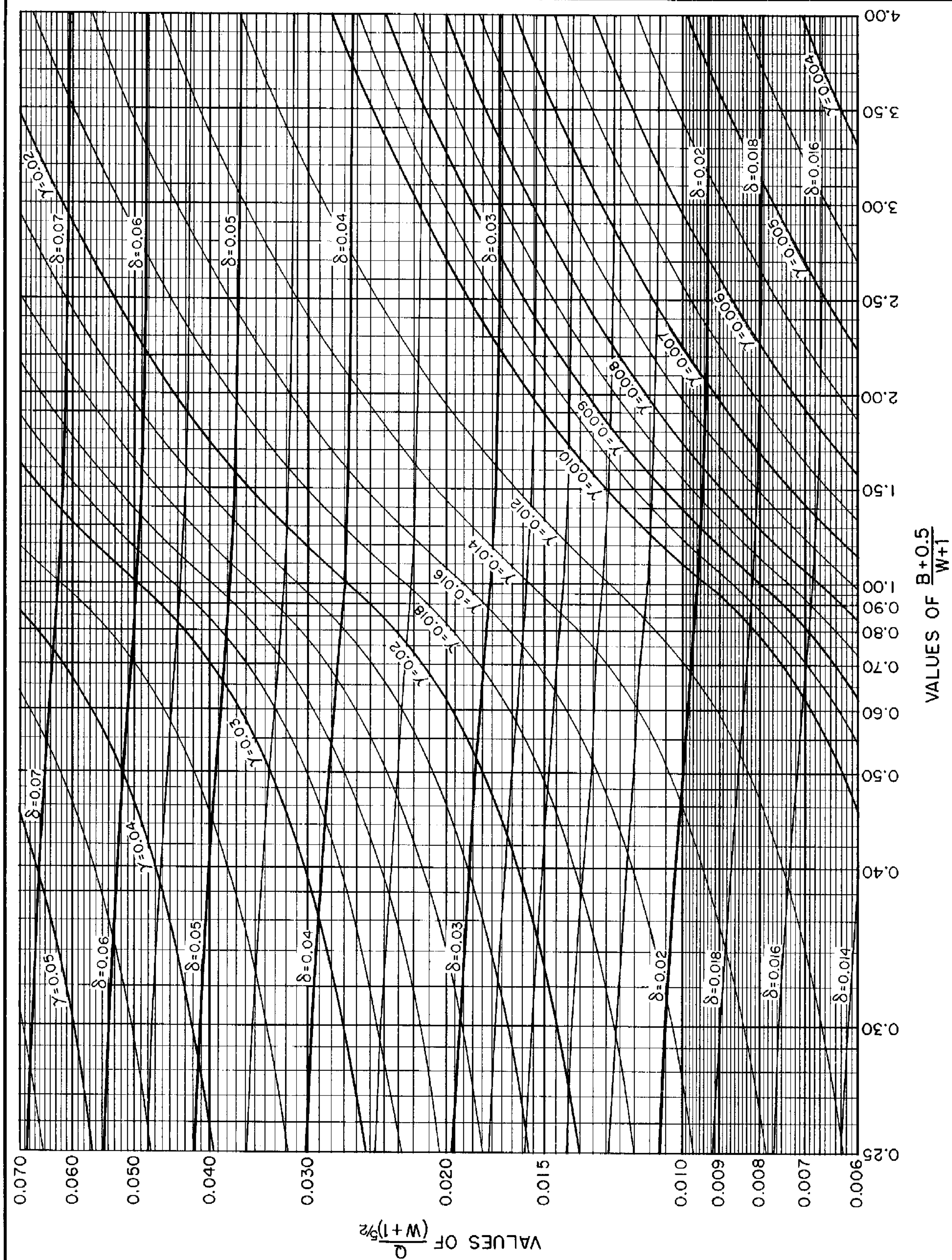


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE	STANDARD DWG. NO.
This chart was developed by Paul D. Doubt of the Design Section.	SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	ES-93 SHEET 6 OF 16 DATE 5-28-55

CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-TRAPEZOIDAL weir box inlet with free-flow conditions at the crest and no narrow channel effects, $z_o = 3:1$

$\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D_r$

$\gamma = \frac{H_e}{W+1}$



REFERENCE
This chart was developed by Paul D. Doubt of the Design Section.

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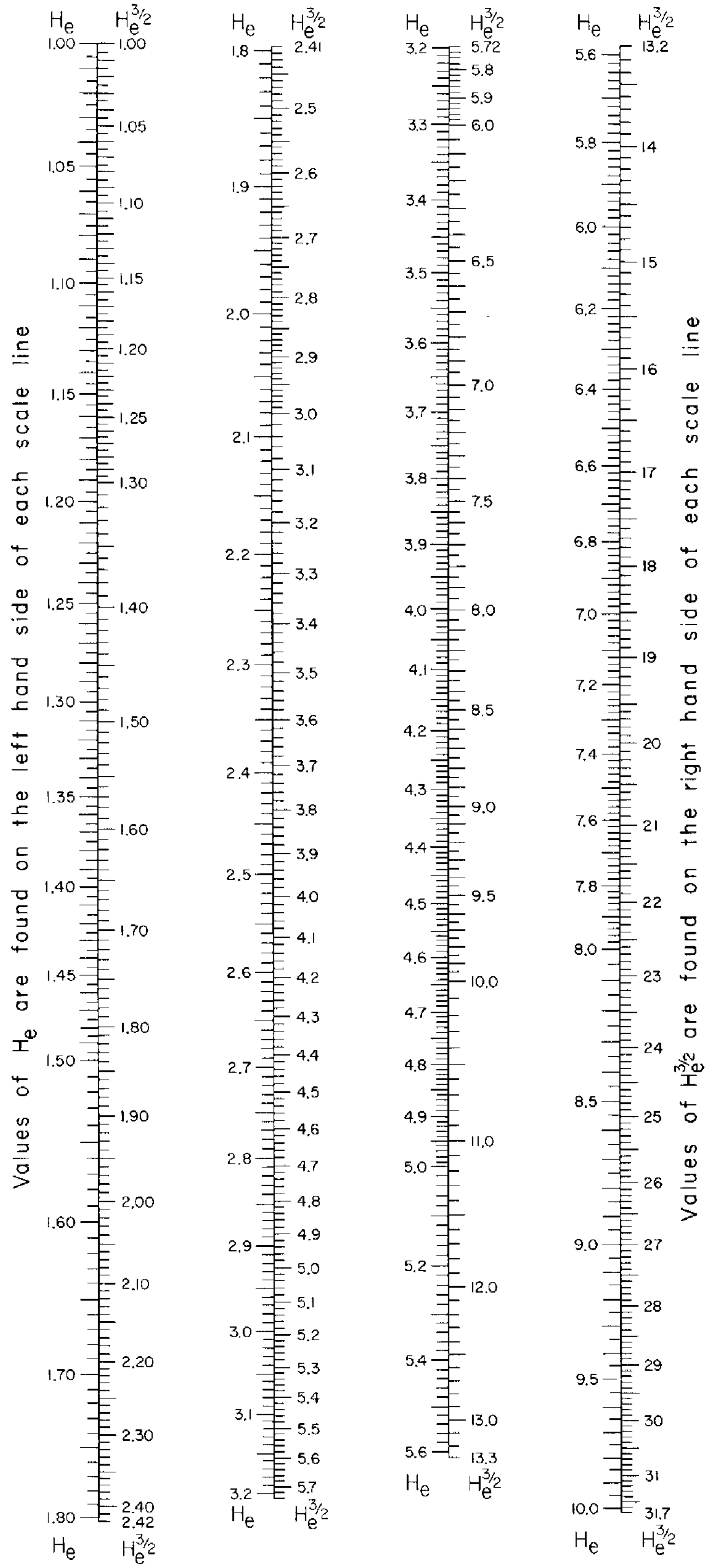
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-93
SHEET 7 OF 16
DATE 5-28-55

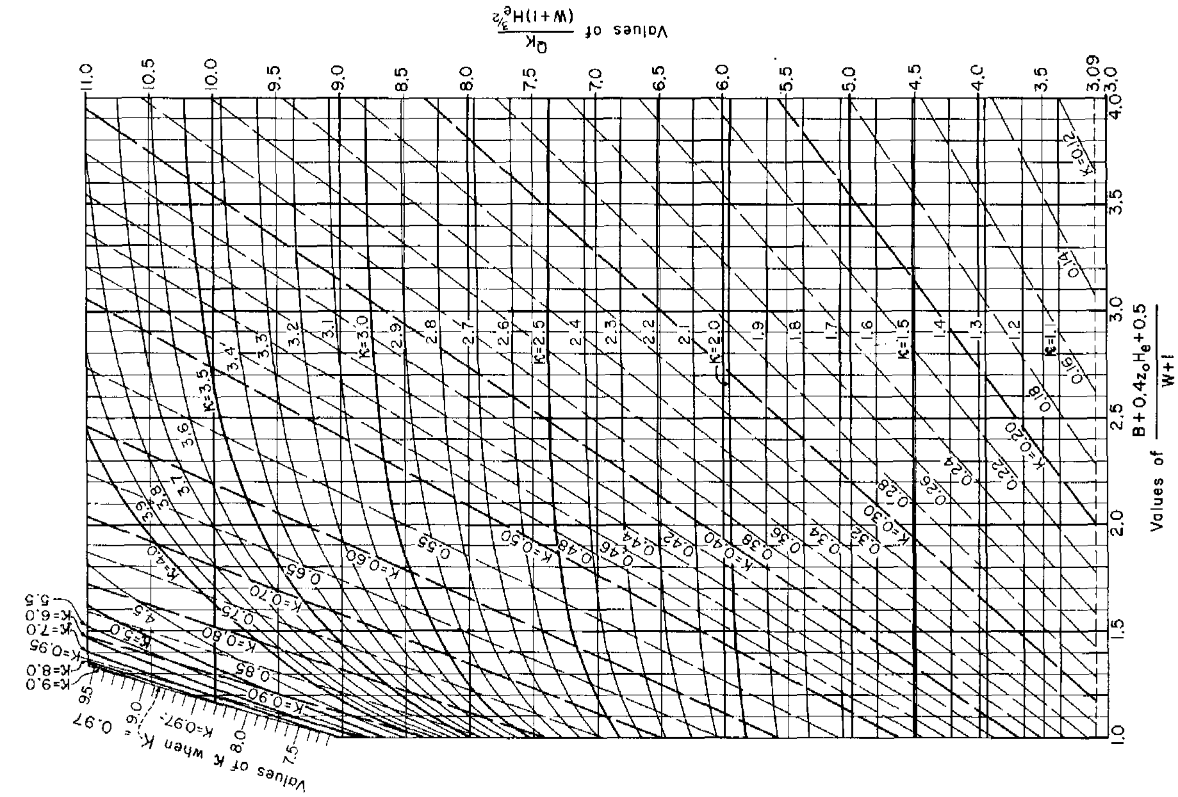
CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS.

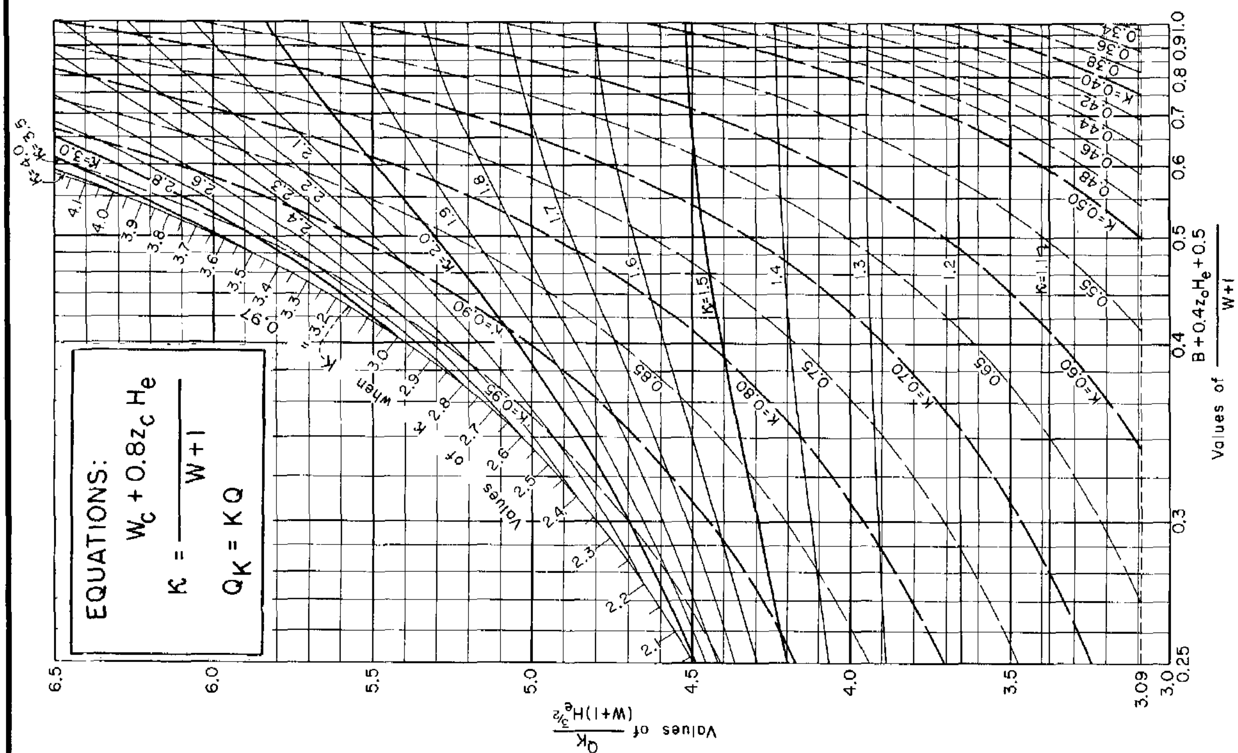
W-ft	$(W + 1)^{5/2}$	$\frac{W^{2/3}}{(W + 1)^{5/3}}$
3.0	32.000	0.2064
3.5	42.957	0.1918
4.0	55.902	0.1724
4.5	70.943	0.1591
5.0	88.182	0.1476
5.5	107.72	0.1376
6.0	129.64	0.1289
6.5	154.05	0.1212
7.0	181.02	0.1144
7.5	210.64	0.1082
8.0	243.00	0.1027
8.5	278.17	0.09774
9.0	316.23	0.09321
9.5	357.25	0.08909
10.0	401.31	0.08532
10.5	448.48	0.08184
11.0	498.83	0.07864
11.5	552.43	0.07568
12.0	609.34	0.07293
12.5	669.63	0.07037
13.0	733.36	0.06799
13.5	800.61	0.06576
14.0	871.42	0.06367
14.5	945.87	0.06171
15.0	1024.0	0.05987
15.5	1105.9	0.05813
16.0	1191.6	0.05649
16.5	1281.1	0.05494
17.0	1374.6	0.05348
17.5	1472.1	0.05209
18.0	1573.6	0.05077
18.5	1679.1	0.04951
19.0	1788.9	0.04832
19.5	1902.8	0.04718
20.0	2020.9	0.04609
20.5	2143.4	0.04506
21.0	2270.2	0.04407
21.5	2401.4	0.04312
22.0	2537.0	0.04221
22.5	2677.1	0.04134
23.0	2821.8	0.04050
23.5	2971.1	0.03970
24.0	3125.0	0.03893
24.5	3283.6	0.03818
25.0	3446.9	0.03747
25.5	3615.1	0.03678
26.0	3788.0	0.03612
26.5	3965.8	0.03548
27.0	4148.5	0.03486
27.5	4336.2	0.03426
28.0	4528.9	0.03369
28.5	4726.7	0.03313
29.0	4929.5	0.03259
29.5	5137.5	0.03208
30.0	5350.6	0.03156
30.5	5569.0	0.03106
31.0	5792.6	0.03060
31.5	6021.6	0.03014
32.0	6255.8	0.02969
32.5	6497.2	0.02925
33.0	6740.6	0.02883
33.5	6991.1	0.02842
34.0	7247.2	0.02802
34.5	7508.8	0.02764
35.0	7776.0	0.02726
35.5	8048.8	0.02690
36.0	8327.3	0.02654
36.5	8611.5	0.02619
37.0	8901.4	0.02585
37.5	9197.1	0.02552
38.0	9498.6	0.02520
38.5	9806.0	0.02488
39.0	10,119	0.02458
39.5	10,439	0.02428
40.0	10,764	0.02399



REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-93 SHEET 8 OF 16 DATE 6-10-55

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS;
Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.

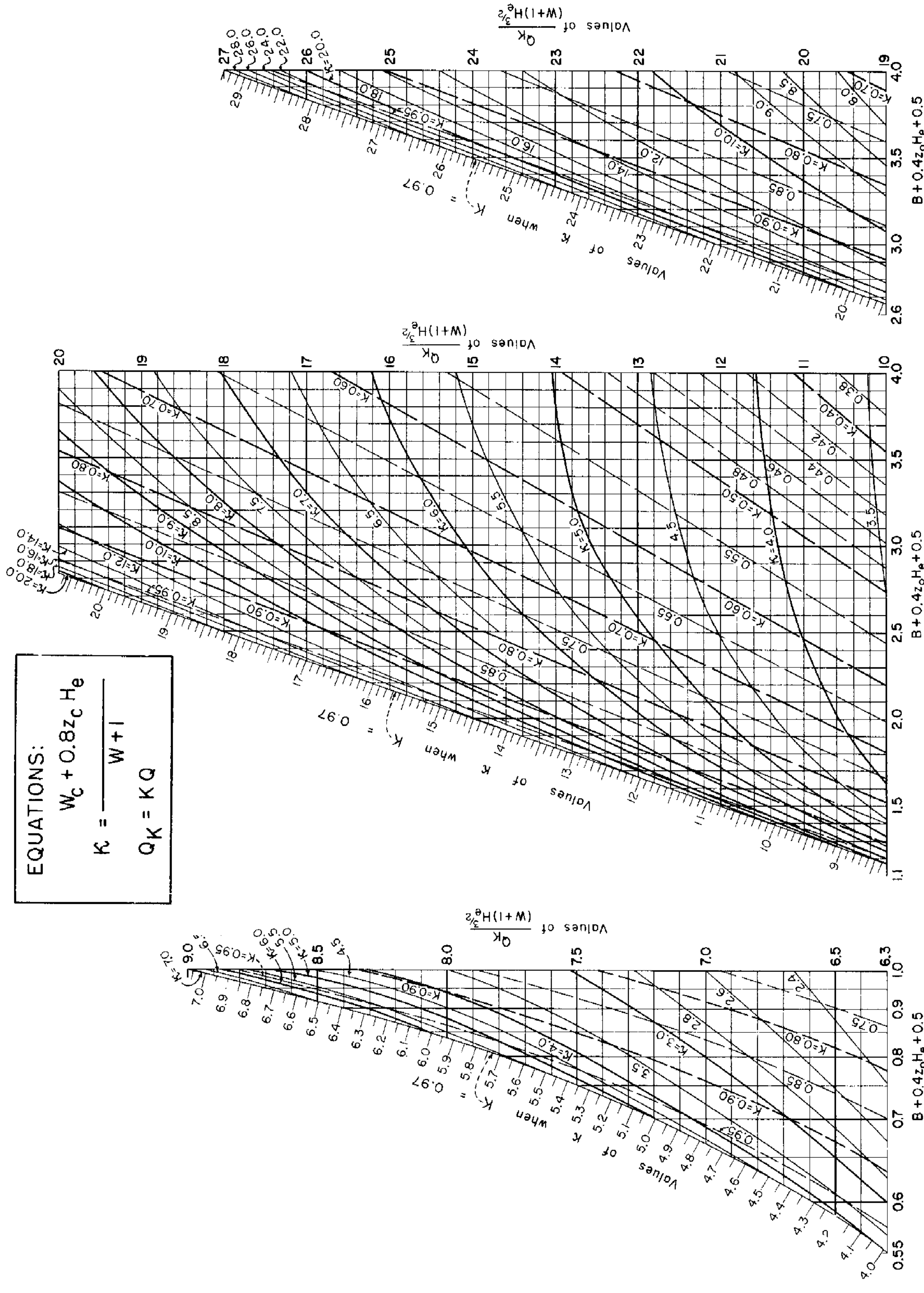




REFERENCE	U. S. DEPARTMENT OF AGRICULTURE	STANDARD DWG. NO.
This chart was developed by Paul D. Doubt of the Design Section.	SOIL CONSERVATION SERVICE	ES- 93
	ENGINEERING DIVISION · DESIGN SECTION	SHEET 9 OF 16
		DATE 5-20-55.

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS;

Effect of narrow approach channels on discharge or capacities when free-flow conditions exist at the crest.



REFERENCE		STANDARD DWG. NO.
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	ES-93 SHEET 10 OF 16 DATE 5-20-55

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Examples

EXAMPLE 1

Given: A rounded-trapezoidal weir box inlet for a chute spillway. The inside dimensions are W = 10 ft, B = 6 ft, and D = 4 ft. The approach channel and the dike covering the headwall have no effect on the discharge of the inlet. $z_o = 3$.

Determine: 1. The head H_e over the crest at which the discharge Q begins to be affected by the dimension D; that is, the head H_e corresponding to impending submerged flow conditions at the crest.

2. The discharge corresponding to the head H_e determined in (1).

Solution: 1. Solving for the head H_e over the crest at which the discharge is affected by the dimension D. The value of $\frac{B + 0.5}{W + 1}$ is $\frac{6.5}{11} = 0.591$. The value of $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D$ is $\frac{(10)^{2/3}}{(10 + 1)^{5/3}} 4 = 0.341$. The point of intersection of the line having the value of $\frac{B + 0.5}{W + 1} = 0.591$ and the line $\delta = 0.341$, sheet 5, has a value $\gamma = \frac{H_e}{W + 1} = 0.190$ or

$$H_e = 0.190\ (10 + 1) = 2.09\text{ ft}$$

For heads over the crest greater than $H_e = 2.09$ ft, the discharge depends on the value of D = 4 ft as well as B, W, and H_e because submerged flow at the crest occurs.

2. Solving for the discharge corresponding to $H_e = 2.09$ ft. Since D is sufficiently large to insure no submergence of the crest, obtain from the chart at the intersection of $\frac{B + 0.5}{W + 1} = 0.591$ and $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D = 0.341$ the value $\frac{Q}{(W + 1)^{5/2}} = 0.675$ or

$$Q = 0.675\ (10 + 1)^{5/2} = 271\text{ cfs}$$

If the value of D had been greater than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.09$ ft remains the same; i.e., Q = 271 cfs. If the value of D had been less than 4 ft, the discharge corresponding to a head over the crest $H_e = 2.09$ ft is not determinable from the chart because the crest would be submerged as a result of a shallow box.

EXAMPLE 2

Given: A rounded-trapezoidal weir box inlet. The inside dimensions are W = 5 ft, B = 2 ft, and $H_e = 3.5$ ft. The approach channel and the dike covering the headwall and the crest of the box inlet are sufficiently large to prevent any effect on the discharge of the inlet. $z_o = 3$.

Determine: 1. The actual discharge Q of the box inlet if flow at the crest is not submerged.

2. The depth D_r of the box inlet required to prevent submergence of the crest for this discharge.

3. The theoretical discharge Q_t of the box inlet as determined by the weir formula.

Solution: 1. Solving for the actual discharge of the box inlet. The value of $\frac{B + 0.5}{W + 1}$ is $\frac{2.5}{6} = 0.417$ and $\gamma = \frac{H_e}{W + 1}$ is $\frac{3.5}{6} = 0.583$. The point of intersection of the lines having the values of $\frac{B + 0.5}{W + 1} = 0.417$ and $\gamma = \frac{H_e}{W + 1} = 0.583$ corresponds to a value of $\frac{Q}{(W + 1)^{5/2}} = 4.28$ and a value of $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 1.18$.

$$Q = 4.28\ (W + 1)^{5/2} = 4.28\ (5 + 1)^{5/2} = 377.4\text{ cfs}$$

2. Solving for the required depth D_r of the box inlet to prevent submergence

$$D_r = 1.18\ \frac{(W + 1)^{5/3}}{W^{2/3}} = 1.18\ \frac{(5 + 1)^{5/3}}{5^{2/3}} = 8.00\text{ ft}$$

Concluded on Sheet 12

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Examples

Continuation from Sheet 11

3. Solving for the theoretical discharge of the box inlet as given by the weir formula

$$Q_t = 3.1 \left[2\ (B + 0.5) + (W + 1) + 2.4\ H_e\right] H_e^{3/2}$$
$$= 3.1 \left[2\ (2 + 0.5) + (5 + 1) + 2.4\ (3.5)\right] 3.5^{3/2}$$
$$Q_t = 393.8 \text{ cfs}$$

The stippled region shown on sheet 5 signifies the weir formula is not applicable in predicting the discharge for the points corresponding to the values of B, W, and H_e in this region. Therefore Part 3 is not a valid solution.

EXAMPLE 3

Given: A rounded-trapezoidal weir box inlet for a chute spillway. The dimensions of the box inlet are W = 10 ft, B = 6 ft, D = 5.0 ft, h = 2.5 ft, and M = 4.50 ft. There is no effect on the discharge due to a narrow channel or dike. $z_o = 3$.

Determine:
1. The capacity without freeboard at the crest Q_{mh} in cfs.
2. The capacity without freeboard at the origin of the upper vertical curve Q_{mM} in cfs.
3. The capacity without freeboard of the box inlet Q_{mi} in cfs.
4. The capacity of the inlet Q_{si} if the total drop of the chute is Z = 25 ft.

Solution: No consideration of channel and dike effect will be required.

1. Solving for the capacity without freeboard at the crest Q_{mh}

$$\frac{B + 0.5}{W + 1} = \frac{6.5}{11} = 0.591\ ; \quad \delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D = \frac{10^{2/3}}{(10 + 1)^{5/3}} 5.0 = 0.427\ ; \quad \gamma = \frac{h}{W + 1} = \frac{2.5}{11} = 0.227$$

At the intersection of lines (see sheet 5) $\frac{B + 0.5}{W + 1} = 0.591$ and $\gamma = 0.227$, read $\frac{Q_{mh}}{(W + 1)^{5/2}} = 0.910$.

Observe that the required value of δ is $0.417 < 0.427 = \frac{W^{2/3}}{(W + 1)^{5/3}} D$. If the value of $\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r$ read from the chart had been greater than 0.427, then the value of Q_{mh} is indeterminable from the chart.

$$Q_{mh} = 0.910\ (W + 1)^{5/2} = 0.910\ (10 + 1)^{5/2} = 365 \text{ cfs}$$

2. The capacity without freeboard at the downstream end of the box inlet Q_{mM} may be read from Table 1, sheet 3, ES-88, for M = 4.50 ft and $q_{mM} = 35.16$ cfs/ft.

$$Q_{mM} = W\ q_{mM} = 10\ (35.16) = 351.6 \text{ cfs}$$

3. The capacity without freeboard of the box inlet Q_{mi} is the lesser of the values Q_{mh} and Q_{mM} or is $Q_{mM} = 351.6$ cfs.

4. The capacity of the inlet having the recommended freeboard is

$$Q_{si} = \frac{Q_{mi}}{(1.2 + 0.003\ Z)} = \frac{351.6}{1.2 + 0.003\ (25)} = 276 \text{ cfs}$$

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Examples

EXAMPLE 4

Given: A design discharge Q_r = 270 cfs for a chute of width W = 10 ft and a sidewall height over the crest h = 2 ft. The vertical drop of the chute from the crest of the inlet to the floor of the SAF outlet is Z = 30 ft. No wave action is anticipated in the channel upstream from the inlet. $z_o = 3$.

Determine: 1. The required capacity without freeboard Q_{fr}.

2. The required ratio of $\frac{B + 0.5}{W + 1}$ for a rounded-trapezoidal weir if the approach channel and dike are to have no effect on the discharge equal to the design discharge without freeboard Q_{fr}.

3. The dimensions B, D, and M for the rounded-trapezoidal weir box inlet if the approach channel and dike have no effect on the discharge Q_{fr}.

Solution: 1. Solving for the required capacity without freeboard Q_{fr}

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right] 270$$
$$Q_{fr} = 348.3 \text{ cfs}$$

2. When the discharge of the inlet is Q_{fr}, the value of B is to be determined such that the head over the crest is h = 2.0 ft. The value of $\frac{Q_{fr}}{(W + 1)^{5/2}} = \frac{348.3}{(10 + 1)^{5/2}} = 0.868$ and $\gamma = \frac{h}{W + 1} = \frac{2.0}{11} = 0.182$. From sheet 5, read the value of $\frac{B + 0.5}{W + 1} = 1.082$ for free-flow condi-conditions.

3. (a) The required value of B is

$$B = (W + 1)\left[\frac{B + 0.5}{W + 1}\right] - 0.5 = (10 + 1)(1.082) - 0.5 = 11.40 \text{ ft}$$

Use B = 11.50 ft

(b) The required value of D_r to prevent submergence at the crest is obtained by reading the value of δ at the point of intersection of the lines $\gamma = 0.182$ and $\frac{Q_{fr}}{(W + 1)^{5/2}} = 0.868$ or $\delta = 0.408$. The required value of D_r is

$$D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.408\ (10 + 1)^{5/3}}{(10)^{2/3}} = 4.78 \text{ ft}$$

Use D = 5.0 ft

(c) The value of M may be read from Table 1, sheet 3, ES-88, when

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{348.3}{10} = 34.83 \text{ cfs/ft}$$

$$M = 4.50 \text{ ft}$$

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Examples

EXAMPLE 5

Given: A rounded-trapezoidal weir box inlet with the dimensions B = 13.5 ft, W = 9 ft, h = 2.0 ft, and M = 4.25 ft; W_c = 35.2 ft and the headwall is extended across the channel. Thus no effect on the discharge is obtained by a dike. The side slope of the approach channel is 3 to 1; $z_c = 3$. The slope of the box inlet crest is $z_o = 3$.

Determine: 1. The capacity without freeboard at the crest of this inlet Q_{mh} when the effect of the narrow approach channel is not considered, and the value of $\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D$ is sufficiently large to prevent submergence of the crest.

2. The capacity without freeboard at the origin of the vertical curve Q_{mM}.

3. The value of K.

4. The capacity without freeboard at the crest of this inlet $(Q_K)_{mh}$ when the effect of the narrow approach channel is considered, and the value of $\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D$ is sufficiently large to prevent submergence of the crest.

5. The required depth of the box inlet D_r to insure free-flow conditions at the crest corresponding to the discharge $(Q_K)_{mh}$

6. The capacity without freeboard of this inlet $(Q_K)_{mi}$ when the effect of the narrow approach channel is considered.

Solution: 1. Solving for the capacity without freeboard at the crest Q_{mh} of the box inlet when the width of the approach channel is sufficiently great to prevent an effect on the capacity of the inlet and the depth D is sufficiently large to prevent submergence of the crest. The capacity Q_{mh} of the box inlet is equal to the discharge of the box inlet with a head h over the crest.

$$\frac{B+0.5}{W+1} = \frac{14}{10} = 1.4 \qquad \text{and} \qquad \gamma = \frac{h}{W+1} = \frac{2}{10} = 0.20$$

At the intersection of $\frac{B+0.5}{W+1} = 1.4$ and $\gamma = 0.20$, sheet 5, read the value $\frac{Q_{mh}}{(W+1)^{5/2}} = 1.18$

$$Q_{mh} = 1.18\ (W+1)^{5/2} = 1.18\ (9+1)^{5/2} = 373 \text{ cfs}$$

This is the capacity without freeboard Q_{mh} at the crest of the box inlet if D and the channel width W_c are both sufficiently great.

2. Solving for the capacity without freeboard Q_{mM} at the origin of the vertical curve section. This is read from Table 1, sheet 3, ES-88. When M = 4.25 ft, then q_{mM} = 32.27 cfs/ft.

$$Q_{mM} = W\ q_{mM} = 9\ (32.27) = 290.4 \text{ cfs}$$

3. Solving for the ratio

$$\kappa = \frac{W_c + 0.8\ z_c\ h}{(W+1)} = \frac{35.2 + 0.8\ (3)(2)}{10} = \frac{40}{10} = 4.0$$

From sheet 9, the corresponding value of K when $\kappa = 4.0$ and $\frac{B + 0.4\ z_o\ h + 0.5}{(W+1)} = 1.64$ is K = 0.757.

Concluded on Sheet 15

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Examples

Continuation from Sheet 14

4. Solving for the capacity without freeboard $(Q_K)_{mh}$ at the crest of the box inlet when the narrow channel effects are considered and free-flow conditions exist at the crest.

$$(Q_K)_{mh} = K\ Q_{mh} = 0.757\ (373) = 283 \text{ cfs}$$

This could also be obtained from sheet 9 when $\kappa = 4.0$ and $\frac{B + 0.4\ z_o\ h + 0.5}{(W + 1)} = 1.64$, read $\frac{(Q_K)_{mh}}{(W + 1)\ h^{3/2}} = 10.02$ or

$$(Q_K)_{mh} = 10.02\ (W + 1)\ h^{3/2}$$
$$= 10.02\ (10)(2)^{3/2}$$
$$(Q_K)_{mh} = 283 \text{ cfs}$$

5. Solving for the required depth D_r of the box inlet having the five given dimensions is read on sheet 5 at the intersection of the lines $\frac{(Q_K)_{mh}}{(W + 1)^{5/2}} = \frac{283}{(10)^{5/2}} = 0.895$ and $\frac{B + 0.5}{W + 1} = 1.4$ or

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 0.418 \qquad \text{and} \qquad D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.418\ (9 + 1)^{5/3}}{9^{2/3}} = 4.48 \text{ ft}$$

The depth D_r is required to prevent submergence of the crest when $W_c = 35.2$ ft, and the discharge is $(Q_K)_{mh} = 283$ cfs. A value of $D > 4.48$ ft will not increase the capacity without freeboard of this channel and box inlet. The capacity of the channel and box inlet for a $D < 4.48$ ft is not determinable by these charts; such a value will cause submergence at the crest. See Ex. 1. For construction purposes D will generally be chosen to be the next size larger than D_r when D is a multiple of 3 inches, or D = 4.50 ft.

6. The smaller of the two values $(Q_K)_{mh} = 283$ cfs or $Q_{mM} = 290.4$ cfs is the capacity without freeboard $(Q_K)_{mi}$ of the box inlet when the narrow approach channel effect is considered.

$$(Q_K)_{mi} = (Q_K)_{mh} = 283 \text{ cfs}$$

EXAMPLE 6

Given: The problem of designing a rounded-trapezoidal weir box inlet for the design discharge $Q_r = 200$ cfs. The approach channel to the inlet has a width of $W_c = 24.6$ ft. The vertical drop from the crest of the inlet to the floor of the outlet is Z = 30 ft. The width W of the chute is 8 ft and the dimension h is 2.25 ft. The headwall is to extend across this channel and thus no consideration of dike effect is required. The side slopes of the approach channel are 3 to 1; $z_c = 3$. The slope of the box inlet crest is $z_o = 3$.

Determine: 1. The required capacity without freeboard Q_{fr} and q_{fr}.

2. The value of B when the effect on the discharge of the narrow approach channel is neglected.

3. The value of K.

4. The value of B when the effect of the narrow channel on the discharge is considered.

5. The value of D_r required to prevent submerged flow conditions at the crest when the effect of the narrow channel is considered.

6. The capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the capacity of the approach channel and the dimension of B obtained in (4).

7. The dimension M of the box inlet.

8. The capacity of the box inlet without freeboard $(Q_K)_{mi}$ when considering the effect of the narrow approach channel.

Concluded on Sheet 16

CHUTE SPILLWAYS: ROUNDED-TRAPEZOIDAL WEIR BOX INLETS; Examples

Continuation from Sheet 15

Solution: 1. Solving for the required capacity without freeboard is

$$Q_{fr} = (1.2 + 0.003\ Z)\ Q_r$$
$$= \left[1.2 + 0.003\ (30)\right] 200$$
$$Q_{fr} = 258 \text{ cfs}$$
$$q_{fr} = \frac{Q_{fr}}{W} = \frac{258}{8} = 32.25 \text{ cfs/ft}$$

2. The value of B when the effect on the discharge of the narrow approach channel is neglected may be obtained from sheet 5. At the intersection of lines $\frac{Q_{fr}}{(W + 1)^{5/2}} = \frac{258}{(8 + 1)^{5/2}} = 1.062$ and $\gamma = \frac{h}{W + 1} = \frac{2.25}{(8 + 1)} = 0.250$, read $\frac{B + 0.5}{W + 1} = 0.575$.

$$B = 0.575\ (W + 1) - 0.5 = 0.575\ (8 + 1) - 0.5 = 4.68 \text{ ft}$$

3. The value of K may be read from sheet 9 at the intersection of the lines $\frac{Q_{fr}}{(W + 1)\ h^{3/2}} = \frac{258}{(8 + 1)(2.25)^{3/2}} = 8.49$ and $\kappa = \frac{W_c + 0.8\ z_c\ h}{W + 1} = \frac{24.6 + 0.8\ (3)(2.25)}{8 + 1} = 3.33$.

Read K = 0.774.

4. The value of B when the effect of the narrow channel on the discharge is considered is again obtained at the intersection of lines $\kappa = 3.33$ and $\frac{Q_{fr}}{(W + 1)\ h^{3/2}} = 8.49$, read

$\frac{B + 0.4\ z_o\ h + 0.5}{W + 1} = 1.275$ or

$$B = 1.275\ (W + 1) - 0.4\ z_o\ h - 0.5 = 1.275\ (8 + 1) - 0.4\ (3)(2.25) - 0.5 = 8.275 \text{ ft}$$

Use B = 8.5 ft

5. The value of D_r may be obtained on sheet 5 at the intersection of the lines $\frac{Q_{fr}}{(W + 1)^{5/2}} = \frac{258}{(8 + 1)^{5/2}} = 1.062$ and $\frac{B + 0.5}{W + 1} = \frac{8.275 + 0.5}{8 + 1} = 0.975$. This reads

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 0.466 \quad \text{or} \quad D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.466\ (8 + 1)^{5/3}}{(8)^{2/3}} = 4.54 \text{ ft}$$

Use D = 4.75 ft

6. Solving for the capacity of the box inlet without freeboard $(Q_K)_{mh}$ at the crest considering the effect of the narrow approach channel. From sheet 5 when $\frac{B + 0.5}{W + 1} = \frac{8.5 + 0.5}{8 + 1} = 1.0$ and $\gamma = \frac{h}{W + 1} = \frac{2.25}{8 + 1} = 0.250$, read

$$\frac{Q_{mh}}{(W + 1)^{5/2}} = 1.40$$
$$Q_{mh} = 1.40\ (W + 1)^{5/2} = 1.40\ (8 + 1)^{5/2} = 340 \text{ cfs}$$
$$(Q_K)_{mh} = K\ (Q_{mh}) = 0.774\ (340) = 263 \text{ cfs}$$

7. Solving for the dimension M at the origin of the vertical curve section. Given $q_{fr} = 32.25$, see step 1. Read from Table 1, sheet 3, ES-88, the value M = 4.25 when $q_{mM} = 32.27$ and $Q_{mM} = W\ q_{mM} = (8)\ 32.27 = 258.16$ cfs.

8. Solving for the capacity without freeboard of the box inlet $(Q_K)_{mi}$ considering the effect of the narrow channel and free-flow conditions. The value of $(Q_K)_{mi}$ is equal to the smaller of the values $(Q_K)_{mh}$ and Q_{mM}.

$$(Q_K)_{mi} = Q_{mM} = 258.16 \text{ cfs}$$