ENGINEERING
HANDBOOK

chute spillways

section 14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

United States Department of Agriculture

Soil Conservation Service

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Washington, D.C.
20013

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NATIONAL ENGINEERING HANDBOOK SECTION 14 (NEH-14)

210-VI
AMENDMENT 1

SUBJECT: ENG - REVISIONS TO NEH-14

Purpose. To transmit revised pages for National Engineering Handbook, Section 14 - Chute Spillways (NEH-14).

Effective Date. Effective when received.

Explanation of Changes. This amendment provides corrected pages for National Engineering Handbook, Section 14, "Chute Spillways." These pages correct the equations for ψ shown on pages 2.23 and 2.24 and on the corresponding ES-drawings. These equations are:

3.7e on page 2.23 and on ES-90 pages 2.33 and 2.34,
3.8e on page 2.23 and on ES-91 pages 2.57 and 2.58,
3.9e on page 2.23 and on ES-92 pages 2.81 and 2.82,
3.10e on page 2.24 and on ES-93 pages 2.97 and 2.98,

and

3.8d on page 2.23,
3.9d on page 2.23

The correct equations were used in the preparation of the charts showing the graphical relationship of the parameters, B/W, $Q/W^{5/2}$, D_r/W, and H_e/W. Therefore, no corrections are needed in the charts.

Filing Instructions. The following pages should be removed from NEH-14, and the enclosed corresponding pages should be inserted:

Pages 2.23/2.24, 2.33/2.34, 2.57/2.58, 2.81/2.82, 2.97/2.98

Distribution. This amendment should be distributed to all SCS offices that have copies of National Engineering Handbook, Section 14 - Chute Spillways. Additional copies may be ordered from Central Supply.

Paul M. Howard

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Deputy Chief
for Technology

Enclosure

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PREFACE

SECTION 14

CHUTE SPILLWAYS

The aim of this handbook is to present in brief and usable form information on the application of engineering principles to the problems of soil and water conservation. While this information will be sufficient for the solution of most problems, other sources of reference material should be used when applicable.

The scope of the handbook necessarily is limited to phases of engineering which pertain directly to the program of the Soil Conservation Service. Therefore, emphasis is given to problems involving the use, conservation, and disposal of water, and the design and use of structures most commonly used for water control. Typical problems in soil and water conservation are described, basic considerations are set forth, and step-by-step procedures are outlined to enable the engineer to understand a recommended solution. These solutions will help in training engineers and will promote nation-wide uniformity in procedures. Since some phases of the field of conservation engineering are relatively new, further experience may result in improved methods which will require revision of the handbook from time to time.

This section of the Engineering Handbook has been written by Paul D. Doubt, civil engineer. Richard M. Matthews and other members of the Design Section staff have helped materially with the calculations and in the preparation of charts and examples. This work was done under the general direction of M. M. Culp, Head, Design Section. A preliminary draft was submitted to field engineers and others for review. Their suggestions led to improvements in the text and are sincerely appreciated.

Many sources of information have been utilized in developing the material. Original contributions are acknowledged in the text.

PREFACE

REVISION OF OCTOBER 1977

This revision removes the references to concrete volumes which appeared in the original handbook. Concrete volumes for the elements of chute spillways may be obtained by using currently approved computer programs.

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SECTION 14

CHUTE SPILLWAYS

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SECTION 14

CHUTE SPILLWAYS

1. INTRODUCTION

Definitions. Chute spillways are defined as open channels with steep slopes, in which flow has supercritical velocities. They usually consist of an inlet, vertical curve section, channel, and outlet. The major part of the drop in water surface takes place in a channel. Flow passes through the inlet and down a paved, steeply sloped channel to the floor of the outlet. (See ES-78, page 2.143.) Various designs and proportions are in use. Further research and systematic evaluations of experience with existing structures will lead to continued improvement in design and proportions. However, confidence can be placed in the design principles contained herein, for they are conservative when available information does not permit them to be stated precisely.

The word "chute" will be used to mean chute spillway.

Component Parts. As mentioned before, a chute is generally composed of four component parts, namely:

a. Inlet
b. Vertical curve section
c. Paved, steeply sloped channel
d. Outlet

In most instances, these component parts are structurally independent. Five types of inlets are in common use, three of which are treated in this section. The five types are:

a. Straight inlet (See ES-82, page 2.13.)
b. Box inlet (See ES-90, ES-91, ES-92, and ES-93, pages 2.31, 2.55, 2.79, and 2.95.)
c. Side-channel inlet (See ES-85, page 2.113.)
d. Culvert inlet (See Fig. 1a, page 1.2.)
e. Drop inlet or box-culvert inlet (See Fig. 1b, page 1.2.)

Culverts and drop inlets will be considered in the Engineering Handbook sections on Culverts and Drop Inlets. Figures 1a and 1b are schematic drawings. No inference concerning the proper proportioning of such inlets is to be made from these drawings.

Material. Reinforced concrete is by far the most widely used material for chute construction, and has proved to be satisfactory from the standpoints of long life and low construction and maintenance costs. This section considers only chutes constructed of reinforced concrete.

Purposes. Chutes are used for the following purposes:

a. To control the gradient in either natural or constructed channels.
b. To serve as reservoir spillways for flood-control and water-conservation structures, and sediment-collecting structures.

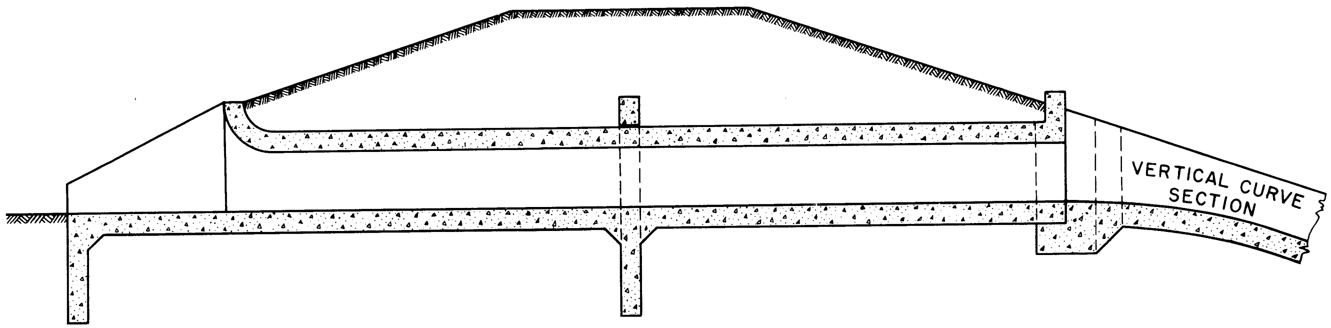


FIGURE – 1a

CULVERT INLET

(NON-PRESSURE FLOW)

SECTION ALONG CENTER-LINE

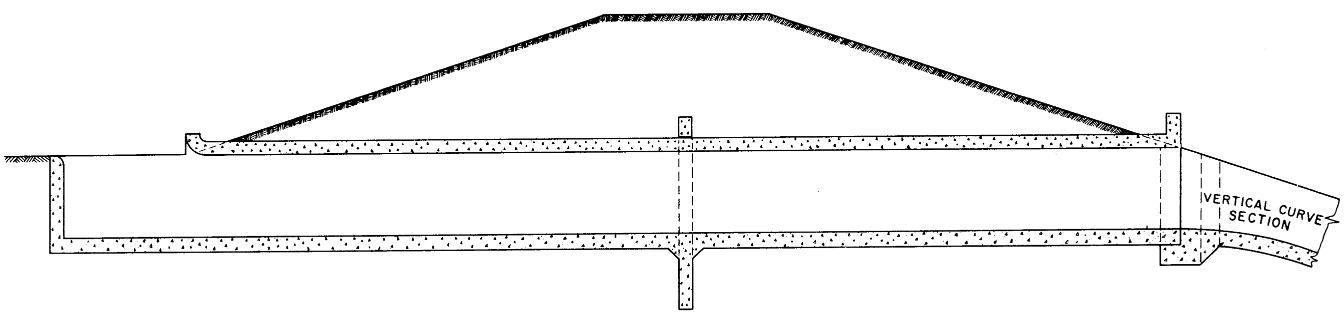


FIGURE – 1b

BOX-CULVERT INLET

(NON-PRESSURE FLOW)

SECTION ALONG CENTER-LINE

Methods of determining discharges and hydrographs from watersheds are discussed in the Engineering Handbook, Section 4, Hydrology. Determination of the rate of runoff or the hydrograph of runoff into the reservoir associated with the chute should be related to:

a. Expected life of the structure, which depends on the quality and type of material used.

b. Type and amount of damage that would result from various runoff rates through the chute that are greater than its capacity.

c. Probability or frequency of partial or complete failure as a result of the lack of spillway capacity.

The capacity-cost relationship of a chute is such that increasing the capacity of a chute causes a smaller rate of increase in the cost for concrete. Thus, insurance against failure because of a lack of capacity can be obtained for a relatively small increase in the total cost of the structure. The initial cost of a chute is usually much lower than the cost of replacing a chute that has failed completely.

The discharge the spillway is expected to convey is determined from hydrologic data and possibly reservoir routing and economic considerations. This discharge Q_r is the design discharge. Throughout the Chute Spillway Section, Q_r will be the symbol used to designate design discharge and the symbol q_r will be used to designate the design discharge per foot width of chute. When routing is considered, the design discharge is dependent in part on the relationship of the discharge head over the crest of the spillway itself. See Engineering Handbook, Section 5, Hydraulics, for methods of routing floods through reservoirs.

2. HYDRAULIC DESIGN

The hydraulic design of any structure is based on the purposes or objectives it is to accomplish. The purposes for which chutes are used have been listed. The explicit objective of chutes is to convey all discharges equal to or less than a given design discharge Q_r from one elevation to a lower elevation in a manner which will not cause erosion between the two elevations. To accomplish this objective, the various component parts of the chute need to be properly proportioned to perform certain functions. These functions and the hydraulic design of the components are considered in this part. Sometimes chutes are designed to fulfill additional objectives besides the one explicitly stated above.

Functions of Inlets. The inlet of a chute has several functions. They are:

a. Convey and guide all discharges equal to or less than a given design discharge to the vertical-curve section or steep, paved channel in a manner that will not cause any appreciable waves in the steep channel of the chute.

b. Provide a positive cutoff of flow by piping under and around the chute channel.

c. Permit all discharges equal to or less than a given design discharge to pass safely through the inlet between the spillway crest and top of the sidewalls.

Further explanatory remarks are made concerning these functions before the hydraulic design of the three types of inlets are considered.

Standing Waves. Flow of water through the inlet to the steep, vertical-curve section passes from subcritical to supercritical. (See Engineering Handbook, Section 5, Hydraulics.) A phenomenon known as "standing waves" can occur when flow is supercritical. The standing waves can attain heights several times the average depth of flow and persist downstream, sometimes almost undiminished in height, through the length of the steep channel. Standing waves can occur when any one of the following conditions exists in the steep channel:

a. The walls of the steep channel are not parallel; i.e., the walls converge or diverge.

b. The walls of the steep channel are not straight; i.e., the chute is curved in a longitudinal direction.

c. The sidewalls of the steep channel are not vertical; i.e., the sidewall has a side slope.

d. The bottom of the steep channel is not level in a direction perpendicular to the axis of the channel; i.e., the channel bottom has a cross slope.

e. The direction of flow in the steep channel is not parallel to the sidewalls.

f. The flow has an appreciably unequal distribution of velocities (or energy) in a channel cross section.

g. The flow has an appreciably unequal distribution of discharge in ` channel cross section.

h. An irregularity or obstruction exists in the channel.

An example of a standing wave is shown by several photographs. Figure 2 shows a plan view of a reinforced concrete spillway and the approximate directions in which subsequent photographs were taken. Observe that the spillway crest is level and is a segment of a circular arc. All flow downstream from the crest is supercritical. Figure 2a shows the flow of water over the crest. The head on the crest is approximately 3.5 ft and the discharge over the crest is approximately 4000 cfs. The direction of flow at the crest is variable and at any point is in the direction toward the center of curvature of the crest. Figure 2b shows a standing wave reflected diagonally from the far wall. Observe that no flow occurs on a small area along the near wall. Every condition except conditions (c) and (h), page 2.1, contributes to the development of this standing wave. The channel walls immediately below the spillway crest are neither parallel nor straight. The channel bottom immediately below the crest is a warped surface. Flow over the crest is not in a direction parallel to the sidewalls. The discharge per foot length over the crest is uniform, but is not presented to the steep channel uniformly; thus, unequal distribution of velocities and discharge are present in the channel. Figure 2c shows the poor flow conditions through the channel and overtopping of the left wall by a discharge which is less than 30 percent of the design discharge.

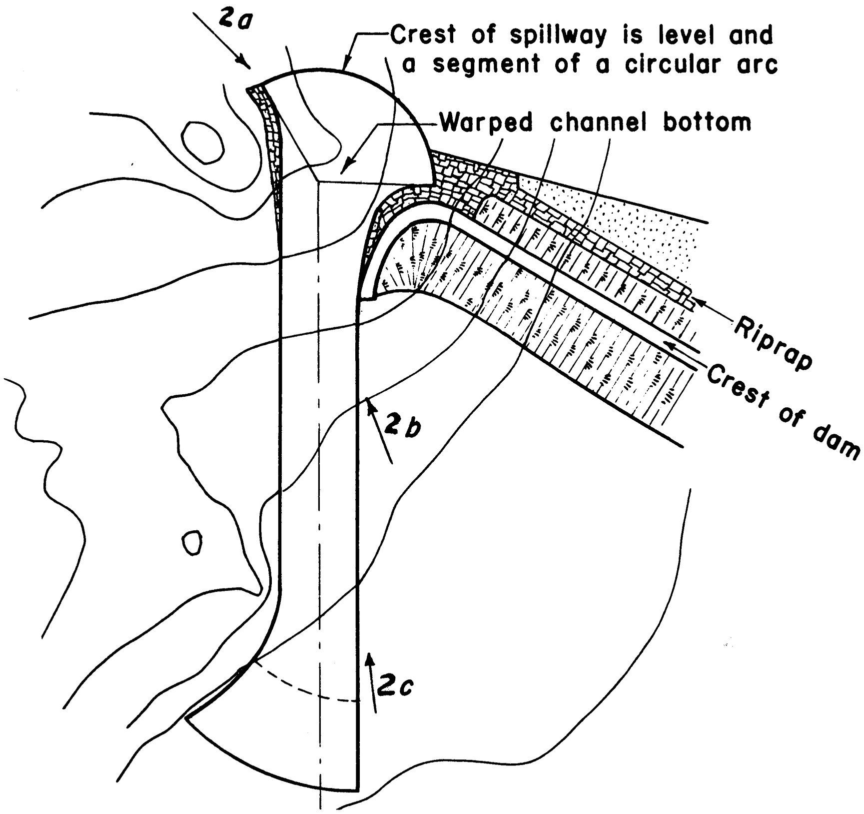
A sharp corner in the sidewall or irregularity or obstruction in the channel where supercritical flow exists will have no effect on flow upstream from any such obstruction as long as the obstruction does not induce subcritical flow. The effect of any such obstruction in supercritical flow is to cause a standing wave to occur diagonally from the obstruction downstream to the sidewall. This standing wave will then be reflected diagonally downstream again and again from the sidewalls. These statements are made on the assumption that no other obstructions are placed to "cancel out" the standing wave. It is not to be implied that steep channels having curvature in their alignment or having a cross slope in their bottoms cannot be designed to function properly. In general, the design of such channels should be checked by hydraulic model studies.

General Criteria to Accomplish Functions of Inlets. The first listed function of the inlet can be accomplished if the inlet conveys the water so that velocity and discharge distribution are uniform at the entrance to the vertical curve, and the direction of flow is parallel to the axis of the chute. Uniform velocity and discharge distribution at the entrance of the vertical curve section require that both the water surface and floor at this section be level transversely. Uniform discharge distribution requires that this section be rectangular. The transverse water-surface profile can be made level by one of the following methods:

a. Providing sufficient length of a level prismatic channel upstream from this section. (See ES-82, page 2.13, for example.)

b. Providing a level cross weir of sufficient height at this section. (See ES-85, page 2.113, for example.)

Flow by piping can be prevented by construction of an adequate antiseep collar.



PLAN VIEW

Arrows indicate directions photographs were taken.

FIGURE 2

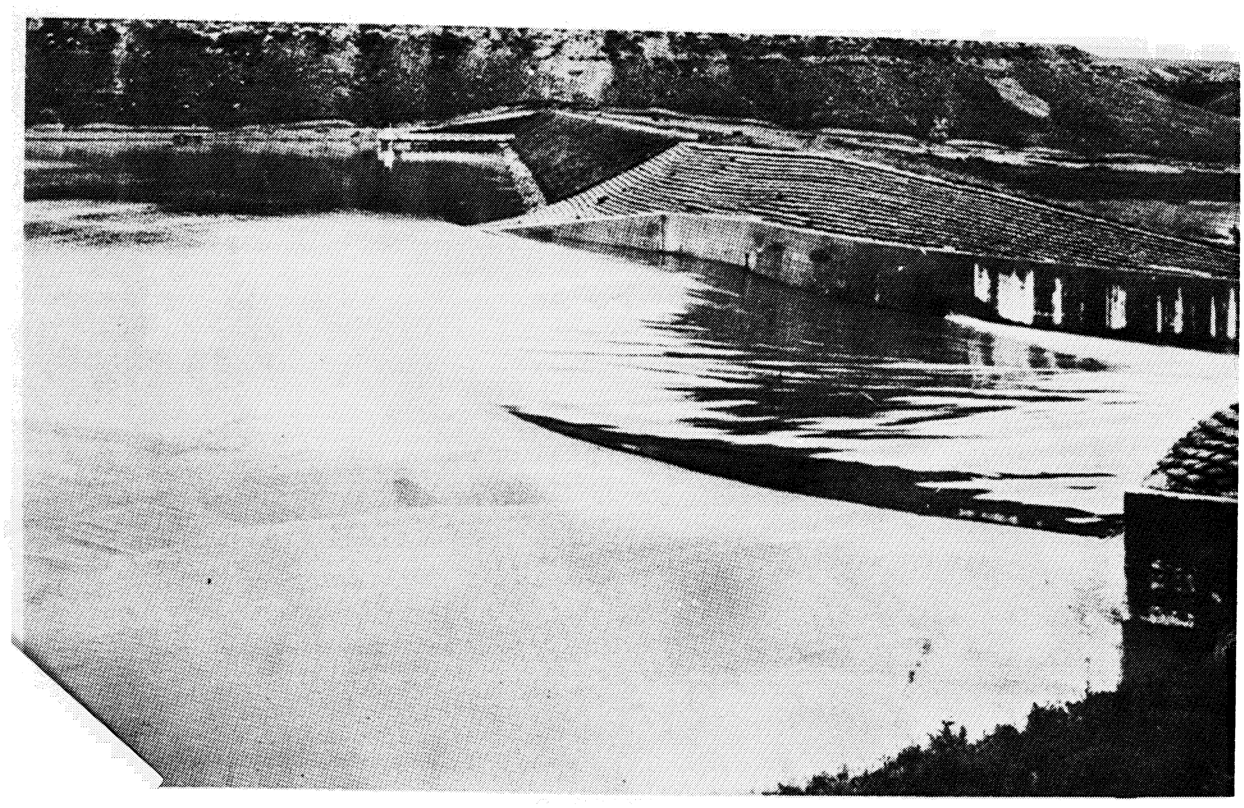


FIGURE 2a

FIGURE 2b

FIGURE 2c

All the factors presented by the third function are not recognized by some engineers. Ignoring that the distance between the elevation of the spillway crest and a maximum water-surface elevation at the inlet is a determinable quantity can lead to appreciably higher structural costs by improper choice of inlet type or chute dimensions. Selection of the type of inlet is not an arbitrary choice nor is the width of the chute. The type of inlet is determined on the factual basis of:

a. Functional uses
b. Physical conditions of a site
c. Economy

A detailed explanation of methods to determine the type of inlet and its dimensions is given in part 3. A few limited explanatory remarks in the form of examples suggesting some of the elements which are involved in this determination will be made here.

Some inlets are designed for additional functional uses. For example, a culvert inlet is used to provide a crossing for vehicles, equipment, pedestrians, or livestock. As will be seen later, culvert inlets may be used for other reasons.

An illustration of how the pnysical conditions of a site determines the type of inlet follows. A site may require that the head over the crest be restricted to prevent inundation of certain areas or objects. (See page 2.6 for definition of head over the crest.) Whenever the head over the crest is reduced, the length of the inlet crest must be increased to prevent lowering the capacity of the inlet. A physical condition which requires that the head over the crest be small may determine the type of inlet and its dimensions. A physical condition of this type might dictate that a box inlet be used.

In another example, a site which requires that the spillway be placed adjacent to or in a steep bank might dictate the use of a side-channel spillway.

An example in which economics might dictate that a box inlet be used follows. Frequently a chute is associated with a high or long embankment. The amount of head required over the crest of the inlet for a given design discharge has an important influence on the cost of the associated embankment. The amount of head over the crest of the inlet can always be decreased without decreasing the inlet capacity by increasing the length of the crest. When the head over the crest is decreased, the height of the embankment can be decreased by the same amount. If the associated embankment yardage is of considerable height or length, a large decrease in embankment yardage is made by choosing a smaller head over the crest. The saving in cost of embankment yardage may be greater by this choice than the cost of additional concrete yardage required for a chute with a box inlet.

One other example will be given which involves the use of a box-culvert inlet. Spillways of reservoirs having large surface areas must be designed with wave freeboards. When this freeboard becomes large, it might be more economical to build a box-culvert inlet instead of a box inlet or a straight-culvert inlet.

All chutes should be designed with the proper type of inlet and a set of dimensions in accordance with the basic facts presented by the particular site. These basic facts are a matter for field determination.

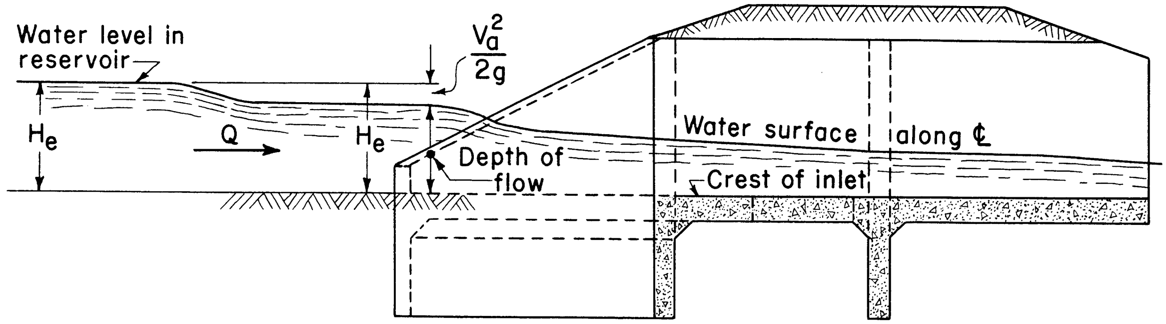


FIGURE 3

Head over the crest of an inlet is the sum of the depth of water above the crest and the velocity head at the section near the entrance of the inlet at which the head over the crest H_e is measured. (See Fig. 3.) This head is the specific energy head referenced to the crest and is measured in feet. Spillways for reservoirs have a head over the crest H_e equal to the difference in elevation of the water surface in the reservoir near the entrance of the inlet and the elevation of the crest if friction losses between the reservoir and inlet entrance are negligible. The head over the crest corresponding to the design discharge Q_r (see part 1) is the design head over the crest h_r.

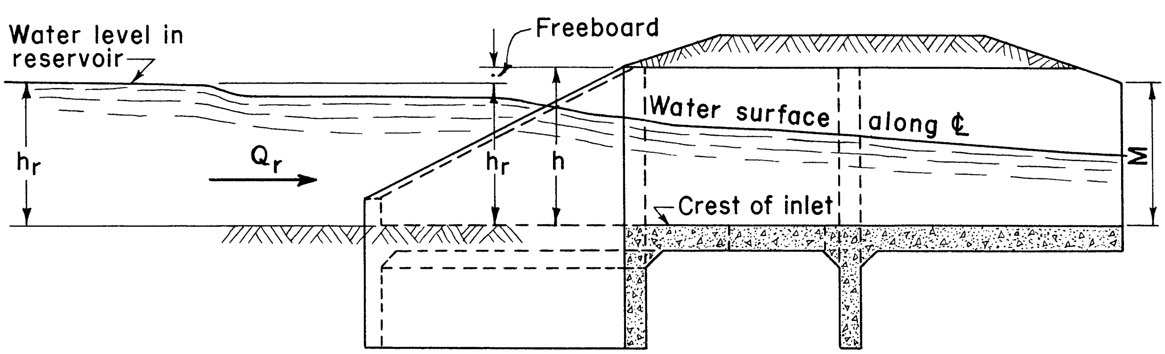


FIGURE 4

Freeboard of an inlet is the difference in the sidewall height h above the crest and the design head h_r over the crest of the inlet. (See Fig. 4.) It is measured in feet and is a safety factor to prevent overtopping of the inlet. The overtopping could be a result of one or more causes. Among the causes are wave action, inability to predict closely the capacity of the inlet, decreased capacity of the inlet due to some unpredicted condition (see definition of capacity, page 2.7), and a larger discharge requirement than the design discharge Q_r due to inability to predict runoff with precision.

Since it is possible to estimate wave heights by Stephenson's equation or a modification of that equation, the freeboard requirement for wave action will be considered separately from freeboard requirement for other causes.

These other causes are common to all structures. The freeboard requirement of structures in which wave action is anticipated will be the sum of the freeboard requirement for wave actions and the freeboard requirements for the other causes. Freeboard requirement for these other causes is known as no-wave freeboard.

Recommended No-wave Freeboard. Where no wave action is anticipated, it is convenient to express freeboard in terms of design discharge. It is logical that the freeboard should be dependent on the design discharge Q_r and the vertical drop Z from the crest of the inlet to the floor of the outlet. The recommended freeboard f_r for inlets having no wave action expressed in units of discharge is

$$f_r = (0.20 + 0.003\ Z)\ Q_r = Q_{mi} - Q_{si} \qquad 2.1$$

where Q_r = design discharge in cfs
Z = vertical drop from the crest of the inlet to the floor of the outlet in ft
f_r = recommended freeboard expressed as a discharge in cfs

The choice of this safety factor, or freeboard, is somewhat an arbitrary quantity and for this reason, as well as convenience, capacities of various component parts of the chute will be given without freeboard.

Recommended Wave Freeboard for Inlets. For inlets in which wave heights are approximated, an additional freeboard is required. The wave heights may be approximated by one of the four formulas, 3.8, 3.9, 3.10, or 3.11, page 3.8, Engineering Handbook, Section 11, Drop Spillways. The recommended total freeboard for inlets of chutes is the sum of the approximated wave heights and the freeboard recommended for inlets in which no wave action is anticipated.

Capacities With and Without Freeboard. (See next section, Symbols.) The distinction in the meanings of the words "design discharge," "capacity," and "required capacity" is important. The design discharge Q_r is the discharge that the inlet (or chute) is required to convey and is determined by hydrological and reservoir-routing considerations. The capacity Q_{si} of the inlet is the discharge that the inlet is capable of conveying with the recommended freeboard (see page 2.11) and is determined in part by the dimensions of the inlet. This capacity will be used infrequently in this Chute Spillway Section of the Handbook. The capacity without freeboard Q_{mi} of the inlet is the discharge that the inlet is capable of conveying without freeboard. It is greater than the capacity Q_{si} and is determined solely by the dimensions of the inlet. The difference in the capacity Q_{si} of the inlet with the recommended freeboard and the capacity without freeboard Q_{mi} is the recommended freeboard of the inlet expressed in discharge cfs instead of feet. The required capacity without freeboard Q_{fr} is the design discharge Q_r increased by the recommended freeboard expressed as a discharge. The required capacity without freeboard becomes

$$Q_{fr} = Q_r + f_r$$

or by Eq. 2.1

$$Q_{fr} = (1.20 + 0.003\ Z)\ Q_r \qquad 2.2$$

where Q_{fr} = required capacity without freeboard in cfs
Q_r = design discharge in cfs
Z = vertical distance from crest of inlet to floor of outlet in ft

The chute spillway is designed to have a capacity without freeboard as great as the required capacity without freeboard Q_{fr}; thus, the capacity without freeboard Q_{mi}, $Q_{m\nu}$, Q_{mc}, and Q_{mo} of the various component parts will all be at least as large as Q_{fr}. This gives each component part approximately the same factor of safety. The capacity without freeboard usually will be slightly larger than the required capacity, because only component parts of even dimensions are considered. A component part of a given size or set of dimensions will have associated with it a maximum discharge which it is capable of conveying without freeboard. This maximum discharge is the capacity without freeboard Q_m of that component part which is equal to or slightly greater than the required capacity without freeboard Q_{fr}, because the next smaller component part has a capacity without freeboard less than Q_{fr}.

Symbols. The symbol Q with subscripts is being used for both discharge and capacity. For instance, the symbol Q with the subscript m is used to designate the capacity of the chute without freeboard Q_m. The capacity of the chute without freeboard is dependent upon the size of the chute or on the various dimensions of the chute. The subscript i is added to the subscript m to designate the capacity of the inlet without freeboard Q_{mi}. Likewise, the subscript ν is added to denote the vertical curve section, the subscript c to designate the channel, and the subscript o is added to m to signify the outlet. For example, Q_{mi}, $Q_{m\nu}$, Q_{mc}, Q_{mo}, and Q_m are respectively the capacity without freeboard of the inlet, the vertical curve section, the channel, the outlet, and the chute as a whole. The capacity without freeboard of the chute as a whole Q_m is equal to the smallest of the values Q_{mi}, $Q_{m\nu}$, Q_{mc}, and Q_{mo}.

The symbol Q_s designates the capacity of the chute with the recommended freeboard. The value of Q_s is dependent on the dimensions of the chute and the recommended freeboard. The subscripts i, ν, c, and o will have the same meaning as before and Q_{si}, $Q_{s\nu}$, Q_{sc}, Q_{so}, and Q_s are respectively the capacity with the recommended freeboard of the inlet, vertical curve section, channel, outlet, and the chute as a whole. The capacity with the recommended freeboard of the chute Q_s is equal to the smallest of the values Q_{si}, $Q_{s\nu}$, Q_{sc}, and Q_{so}. Observe that an inlet with given dimensions will have a definite capacity without freeboard regardless of the recommended freeboard. The capacity of this inlet with the recommended freeboard is dependent not only on the dimensions of the inlet but also on the recommended freeboard.

The dimensions of the straight inlet, namely h, M, and W will be used to determine the capacity without freeboard of the inlet Q_{mi}. The dimensions M, N, $\mathfrak{z}$, and W will be used to determine the capacity without freeboard of the vertical curve section. The dimensions N and W are used for determining Q_{mc}; J, L_B, Z, and W are used to determine Q_{mo} These determinations will be given where the discussions of the various component parts are made. Since the width of the chute W is used in determining the capacity without freeboard for each of the component parts, the symbol q will be used to denote the discharge per foot width. Likewise, the symbols q_{mi}, q_{mv}, q_{mc}, q_{mo}, and q_m are used to designate respectively the capacity without freeboard per foot width of the inlet, vertical curve section, channel, outlet, and the chute as a whole.

The discharge Q through a chute can be any quantity ranging in value from zero to the capacity without freeboard Q_m. If Q is greater than Q_m, then the chute is overtopped and the discharge relationships given for component parts are not applicable.

The design discharge Q_r is that discharge the chute and each of its component parts is required to convey with the recommended freeboard. The required capacity without freeboard Q_{fr} of the chute and each of its component parts is obtained by use of Q_r in Eq. 2.1. Thus the capacity without freeboard of each of the component parts Q_{mi}, Q_{mv}, Q_{mc}, and Q_{mo} will be equal to or slightly larger than the required capacity without freeboard Q_{fr} because only even dimensioned component parts are considered in evaluating Q_{mi}, Q_{mv}, Q_{mc}, and Q_{mo}.

The definition of the few additional symbols will be considered at their first appearance.

STRAIGHT INLETS

Design Criteria of Straight Inlet. The straight inlet terminates in the downstream direction at the origin of the upper curve. (See Fig. 5.) The actual depth of flow at the origin of the vertical curve if positive floor pressures are maintained on the vertical curve is between d_c and 0.715 d_c.[1] The depth is governed by entrance conditions to the vertical curve and will generally be between 0.80 d_c and 0.715 d_c. If no vertical curve were provided downstream from the inlet--that is, a sharp break in grade existed at the downstream end of the inlet--the depth of flow could be less than 0.715 d_c because of the occurrence of negative floor pressures immediately downstream from the break in grade. The critical depth of flow occurs at a section approximately 3 d_c upstream from the vertical curve which provides positive floor pressures. Supercritical flow exists in the portion of the inlet downstream from the section at which critical depth occurs. This portion of the inlet will be a prismatic channel to insure favorable flow conditions at the vertical curve section. The floor (or crest) of the straight inlet where supercritical flow exists should be paved for two reasons:

a. Earth channel bottoms are unstable in regions of supercritical flow and will cause disturbed flow conditions in the steep chute.

b. A concrete floor along with the anti-seep collar provides a means of constructing a cutoff of flow by piping.

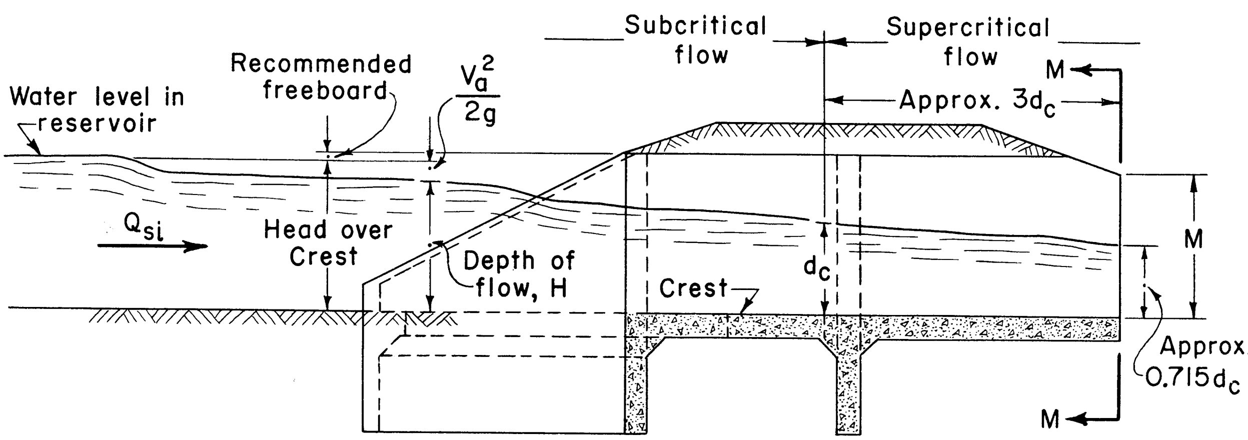


FIGURE 5

Discharge-Head Relationship for a Straight Inlet. The discharge-head relationship of a straight inlet is given by the weir formula

$$Q = 3.1\ W \left[H + \frac{v_a^2}{2g}\right]^{3/2} = 3.1\ W\ H_e^{3/2} \qquad 2.4$$

where Q = discharge of inlet in cfs

W = width of chute or inlet in ft

[1] M. R. Carstens, Free Overflow has Rapidly Varying Characteristics, Civil Engineering, June 1955, Page 64.

H = depth of flow over the crest (or floor) of inlet in ft (See Fig. 5.)
H_e = specific energy head referenced to the crest of the inlet or the head over the crest of the inlet in ft
v_a = mean velocity of approach at which the depth H is measured in ft/sec
g = 32.16 ft/sec^2

The coefficient 3.1 will vary for various entrance conditions to the vertical curve section. Its value is slightly larger when the channel conveying water to the inlet is wider than the width of the inlet. The value 3.1 is conservative and its use is predicated on the assumption that H_e and v_a are measured in a section having subcritical flow.

Capacity of a Straight Inlet. The capacity without freeboard Q_{mi} of a straight inlet is determined by the dimensions h, M, and W of the inlet. The value of h will determine the capacity without freeboard at the crest q_{mh} per foot width of chute. The value of M will determine the capacity without freeboard q_{mM} at the downstream section of the inlet. The lower value of q_{mh} and q_{mM} is the capacity of the inlet without freeboard q_{mi}.

The capacity without freeboard at the crest q_{mh} of the inlet is given by Eq. 2.4, page 2.10, when the head over the crest is equal to the height of the sidewalls.

$$q_{mh} = 3.1\ h^{3/2} \qquad 2.5$$

where q_{mh} = the capacity at the crest of the inlet without freeboard in cfs/ft
h = height of sidewalls over the crest in ft

Values of q_{mh} for various values of h are given by Table 1, ES-82, page 2.14.

The section at the downstream end of the straight inlet has a sidewall height M equal to the height of the sidewall of the vertical curve section at this section. The criteria for determining the capacity q_{mM} is given in the discussion of Vertical Curve Sections, page 2.121. Values of q_{mM} for various values of M are given by Table 1, ES-88, page 2.125.

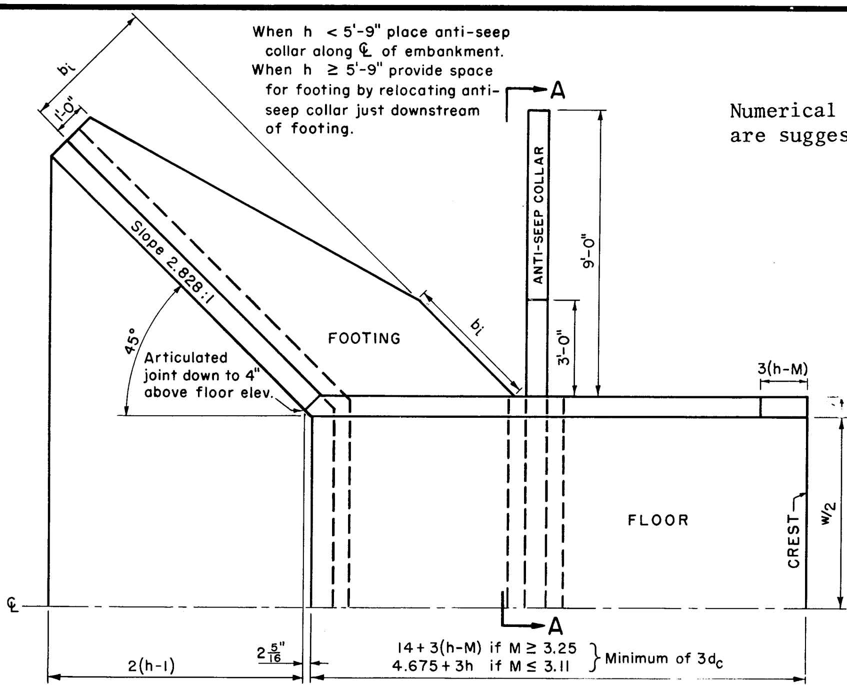
As stated before, capacity of the inlet without freeboard q_{mi} is equal to or slightly greater than the required capacity without freeboard q_{fr}. Two types of straight inlets are given in the drawing of ES-82, page 2.13. The essential difference of the two types of inlets is the length of the inlet. For inlets having a capacity without freeboard of q_{mi} = 20.196 cfs/ft, the value of M is 3.108 ft. When the capacity of the inlet without freeboard is equal to or less than q_{mi} = 16.108 cfs/ft, the value of M is equal to h. Values of q_{mi} are given by Table 2, ES-82, page 2.14. The capacities of inlets without freeboard Q_{mi} can be read from the graph of ES-82, page 2.15. The capacity q_{si} of the inlet can be determined by the relations

$$q_{mi} = (1.20 + 0.003\ Z)\ q_{si} \qquad 2.6$$

The capacity q_{si} of inlets will be equal to or slightly larger than the design discharge q_r.

CHUTE SPILLWAYS: STRAIGHT INLETS
The General Layout Drawing

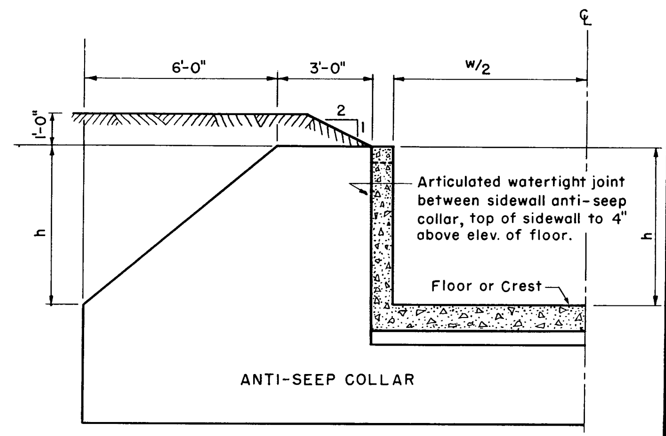
Numerical values shown are suggested minimums.



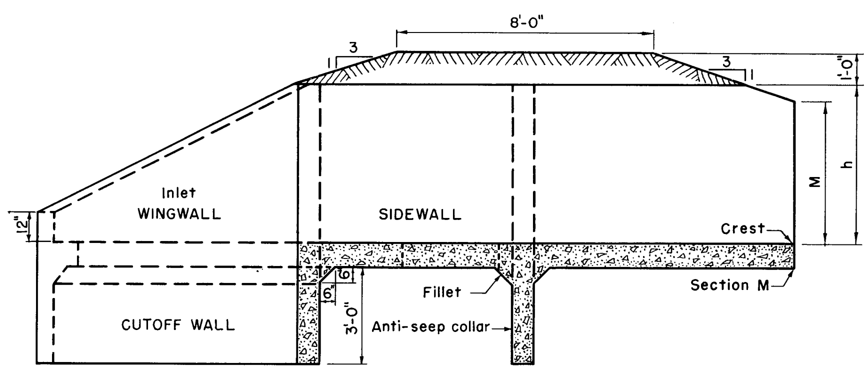
HALF-PLAN VIEW

Note-
Hydraulic criteria and formulas are given on sheet 2 of this drawing.

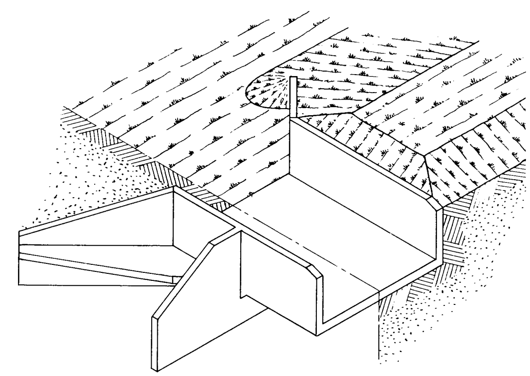
Note-
Capacities for this structure are given on sheet 3 of this drawing.



SECTION A-A
SHOWING ANTI-SEEP COLLAR



SECTION ON CENTER LINE



ISOMETRIC VIEW

REFERENCE

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

STANDARD DWG. NO.
ES-82
SHEET 1 OF 4
DATE 2-2-54

CHUTE SPILLWAYS: STRAIGHT INLETS

Definition of symbols, Formulas, Dimensions, and Capacities

HYDRAULIC FORMULA

Capacity of straight inlet without freeboard

$$Q_{mi} = Q_{si}\ (1.20 + 0.003\ Z) = 3.1\ Wh^{3/2}$$

Table 1
Capacities at
Crest of Inlet

h	q_{mh}
2.00	8.768
2.25	10.462
2.50	12.254
2.75	14.137
3.00	16.108
3.25	18.162
3.50	20.298
3.75	22.511
4.00	24.800
4.25	27.161
4.50	29.592
4.75	32.092
5.00	34.659
5.25	37.290
5.50	39.986
5.75	42.742
6.00	45.560
6.25	48.437
6.50	51.372
6.75	54.364
7.00	57.412
7.25	60.515
7.50	63.672
7.75	66.882

DEFINITION OF SYMBOLS

- h = Height of sidewalls and wingwalls above floor in ft
- h_r = Specific energy head at the crest of the inlet corresponding to design discharge Q_r in ft
- h_{fr} = Specific energy head at the crest of the inlet corresponding to the discharge Q_{fr} in ft
- M = Height of sidewall above floor at junction with vertical curve section in ft
- b_i = Required width of footing at junction of sidewall and wingwall in ft
- W = Width of inlet in ft
- Z = Vertical drop from crest of inlet and floor of SAF outlet in ft
- H_e = Specific energy head at crest of inlet corresponding to any discharge Q the inlet is capable of conveying in ft
- Q_1 = 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
- Q_{mM} = Capacity of inlet without freeboard at the origin of the upper vertical curve in cfs
- Q = Discharge in cfs
- q_{si} = Capacity per foot width of inlet in cfs/ft
- q_{mi} = Capacity per foot width of inlet without freeboard in cfs/ft

Table 2
Dimensions and Capacities

h	M	q_{mi}
2.00	2.00	8.768
2.25	2.25	10.462
2.50	2.50	12.254
2.75	2.75	14.137
3.00	3.00	16.108
3.25	3.11	18.162
3.50	3.11	20.196
3.50	3.25	20.298
3.75	3.25	21.580
3.75	3.50	22.511
4.00	3.50	24.120
4.00	3.75	24.800
4.25	3.75	26.740
4.25	4.00	27.161
4.50	4.00	29.470
4.50	4.25	29.592
4.75	4.25	32.092
5.00	4.25	32.27
5.00	4.50	34.659
5.25	4.50	35.16
5.25	4.75	37.290
5.50	4.75	38.130
5.50	5.00	39.986
5.75	5.00	41.180
5.75	5.25	42.742
6.00	5.25	44.310
6.00	5.50	45.560
6.25	5.50	47.510
6.25	5.75	48.437
6.50	5.75	50.78
6.50	6.00	51.372
6.75	6.00	54.140
6.75	6.25	54.364
7.00	6.25	57.412
7.25	6.25	57.56
7.25	6.50	60.515
7.50	6.50	61.08
7.50	6.75	63.672
7.75	6.75	64.59
7.75	7.00	66.882

REFERENCE

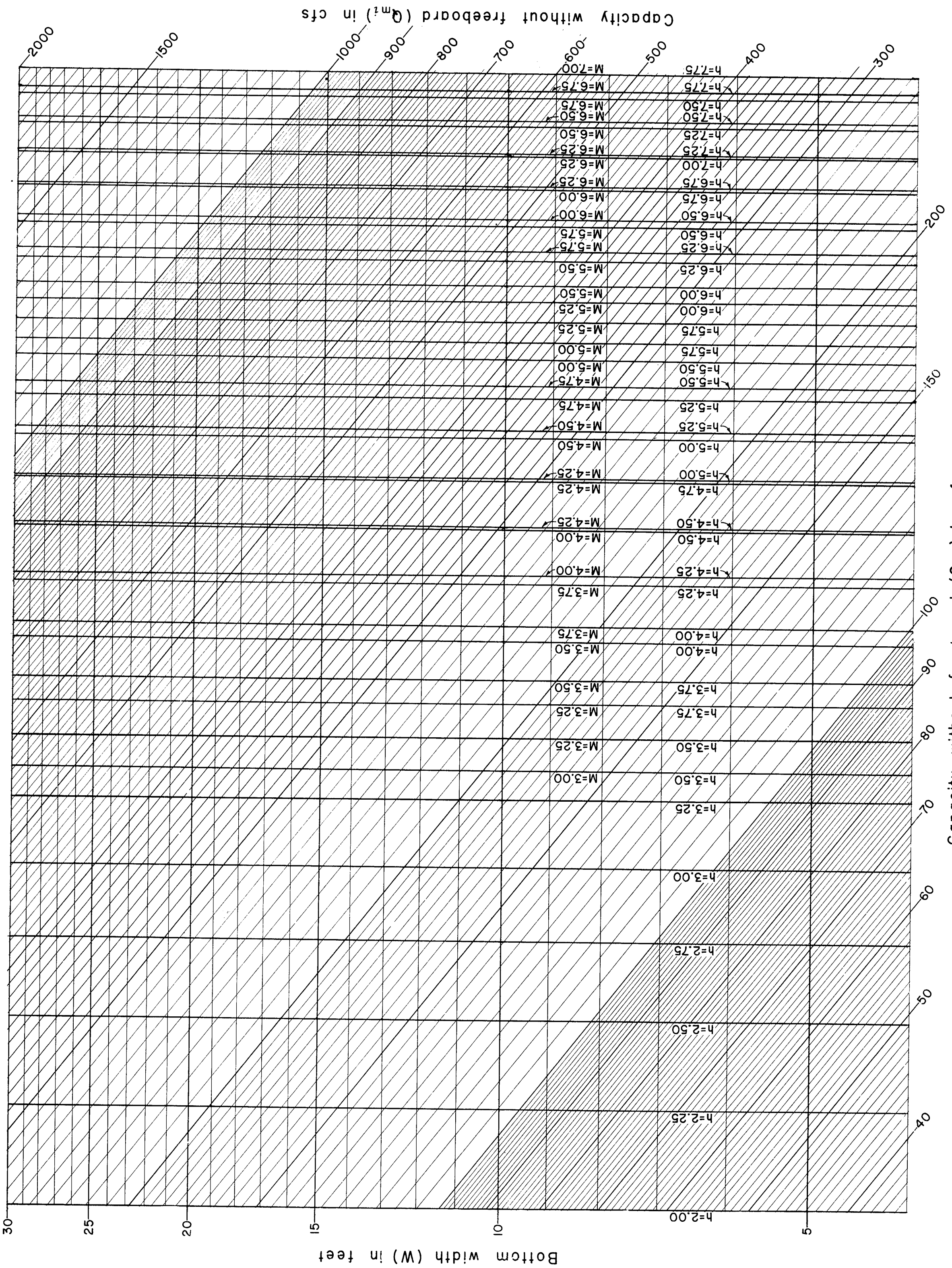
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES-82
SHEET 2 OF 4
DATE February 1954

Revised 10/77

CHUTE SPILLWAYS: STRAIGHT INLETS

Capacities without freeboard in cfs; Q_{mi}



REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-82 SHEET 3 OF 4 DATE 2-3-54 Rev. 11-1-54

CHUTE SPILLWAYS: STRAIGHT INLETS; Example

EXAMPLE

Given: Design discharge Q_r = 320 cfs for a chute width of W = 12 ft. The vertical drop of the chute from the crest of the inlet to the floor of the SAF outlet is 31 ft. No wave action is anticipated in the channel upstream from the inlet.

Determine:
1. Dimensions of straight inlet for this chute
2. Recommended freeboard in ft
3. Actual freeboard in ft
4. Capacity of this inlet in cfs

Solution: 1. The discharge Q_{fr} the inlet is required to convey without freeboard is

$$Q_{fr} = (1.20 + 0.003\ Z)\ Q_r$$

$$Q_{fr} = [1.20 + (0.003)(31)]\ (320) = 413.76 \text{ cfs}$$

a. The available inlet having a width of W = 12 ft capable of conveying this discharge without freeboard as read from sheet 3 is h = 5.00 ft; M = 4.50 ft. This inlet is capable of conveying 416 cfs without freeboard

b. This calculation can also be made by determining the value of $q_r = \frac{Q_r}{W}$, then

$$q_{fr} = (1.20 + 0.003\ Z)\ q_r$$

$$q_{fr} = [1.20 + (0.003)(31)] \left(\frac{320}{12}\right) = 34.48 \text{ cfs/ft width}$$

The available inlet capable of conveying this discharge according to table 2 sheet 2 is again h = 5.00 ft; M = 4.50 ft

2. The recommended freeboard is the difference in the specific energy heads at the crest required to discharge Q_{fr} and Q_r. The specific energy head h_r at the crest required to discharge the design discharge Q_r is

$$Q_r = 3.1\ Wh_r^{3/2}$$

$$h_r = \left[\frac{Q_r}{3.1\ W}\right]^{2/3} = \left[\frac{320}{(3.1)(12)}\right]^{2/3} = 4.20 \text{ ft}$$

The specific energy head h_{fr} at the crest required to discharge the recommended freeboard discharge Q_{fr} is

$$h_{fr} = \left[\frac{Q_{fr}}{3.1\ W}\right]^{2/3} = \left[\frac{413.76}{(3.1)(12)}\right]^{2/3} = 4.97 \text{ ft}$$

The recommended freeboard is $h_{fr} - h_r = 4.97 - 4.20 = 0.77$ ft

3. The actual freeboard is the difference in the height of the sidewall above the crest and the specific energy head h_r at the crest required to discharge the design discharge Q_r

$$h - h_r = 5.0 - 4.20 = 0.80 \text{ ft}$$

4. The capacity of the inlet Q_{si} is the discharge the inlet is capable of discharging with the recommended freeboard

$$Q_{mi} = 3.1\ Wh^{3/2}$$

$$Q_{mi} = (3.1)(12)(5)^{3/2} = 415.9 \text{ cfs}$$

$$Q_{mi} = (1.20 + 0.003\ Z)\ Q_{si}$$

$$Q_{si} = \frac{415.9}{1.20 + 0.003\ (31)} = 321 \text{ cfs}$$

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.

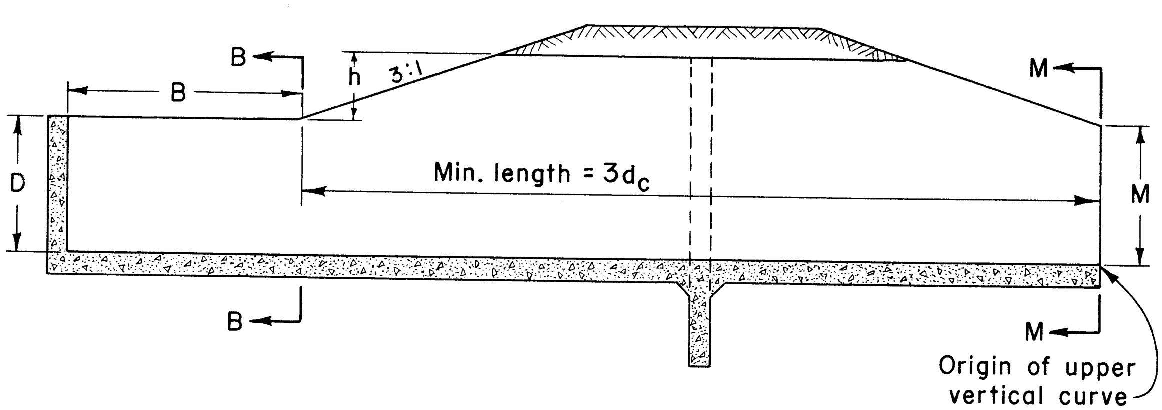


FIGURE 5A

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 + l) 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 (2 B + W) or (2 B + 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

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

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

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

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

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

(3.7)

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

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

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

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

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

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

(3.8)

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

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

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

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

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

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

(3.9)

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

$$Q = 3.1\ (2\ B + W + 2 + 0.8\ z_o\ H_e)\ H_e^{3/2} \qquad \text{when} \qquad 3.10a$$

$$0 < H_e \leq \frac{0.49\ W}{1 - 0.016\ z_o} + \frac{0.04\ B}{1 - 0.016\ z_o} + \frac{0.51}{1 - 0.016\ z_o}$$

$$(W \geq 4\ \text{ft}) \qquad \text{and} \qquad 3.10b$$

$$0 < Q \leq 5.5\ W^{5/2} \qquad \text{and} \qquad 3.10c$$

$$\psi^3 - 3\ \psi + 2\left[\frac{W + 1}{2\ B + W + 0.8\ z_o\ H_e + 2}\right]^2 = 0 \qquad \text{where} \qquad 3.10d$$

$$\frac{1.2\ g^{1/3}\ W^{2/3}\ D_r}{Q^{2/3}} = \psi \geq 1 \qquad 3.10e$$

(Equations 3.10a–3.10e together: 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:

ia. 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 Υ_1 and $\frac{\overline{\eta}_2}{W}$

iia. Find the values of Υ_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 Υ_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

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

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

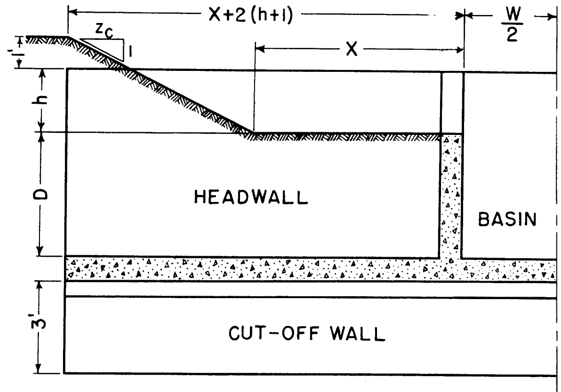
$$B = \beta_1 + \beta_2 + \cdot\ \cdot\ \cdot + \beta_i$$

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

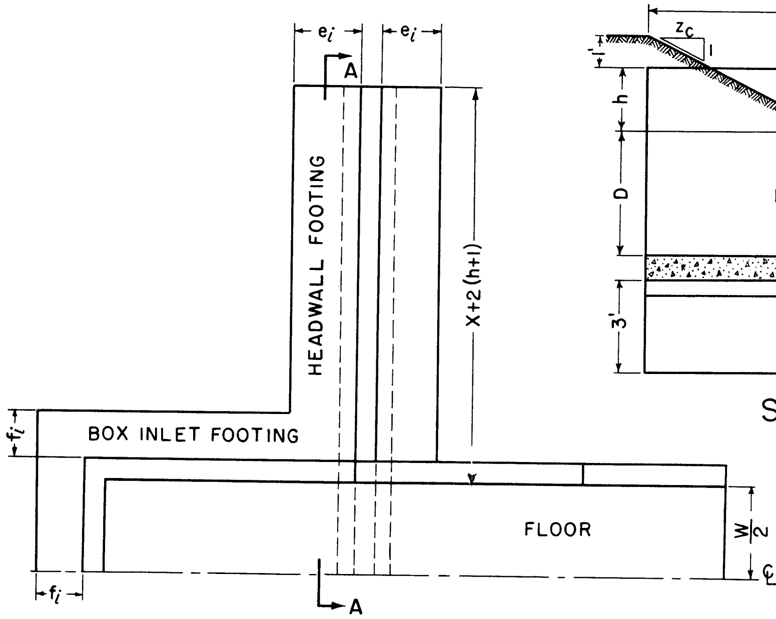
$$H_{ei} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdot\ \cdot\ \cdot \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

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.



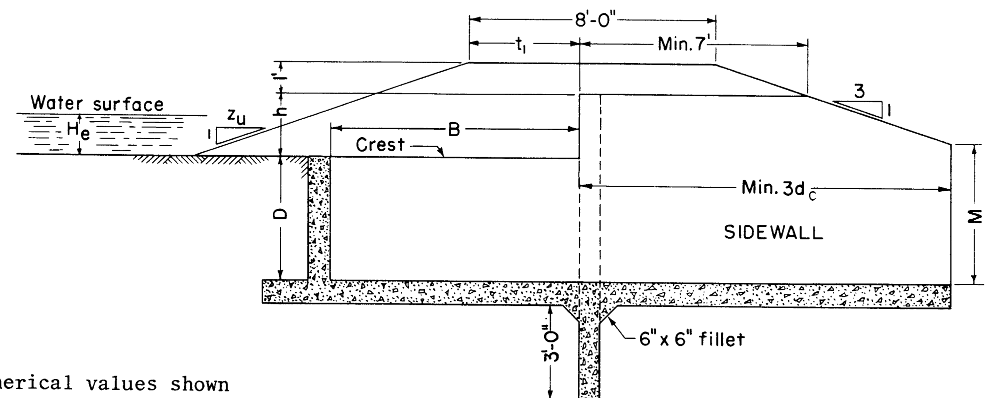
SECTION A-A



HALF-PLAN

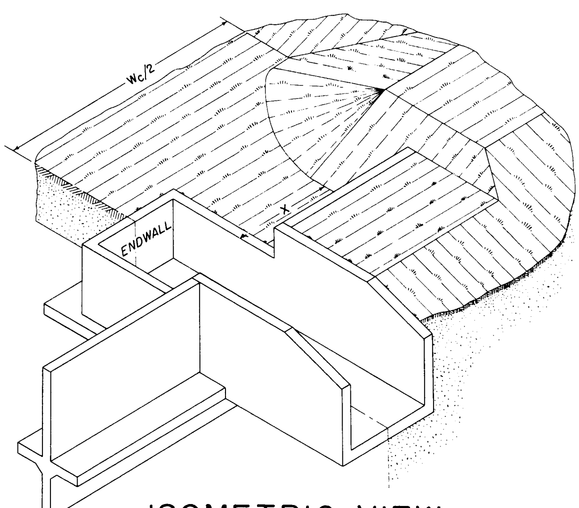
Note–
Hydraulic formulas are given on sheet 4

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

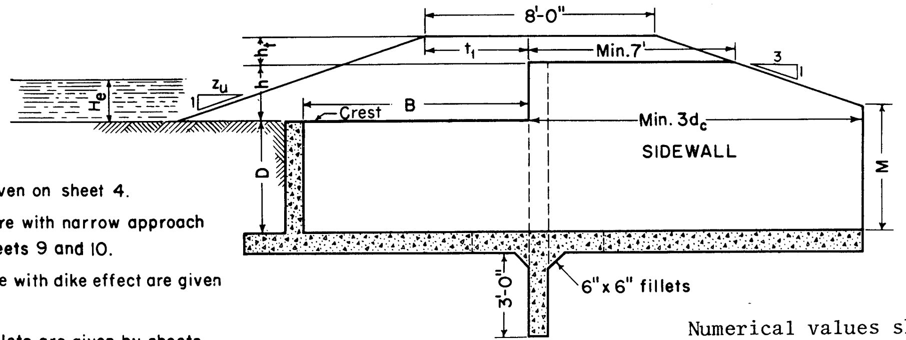


ISOMETRIC VIEW

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.

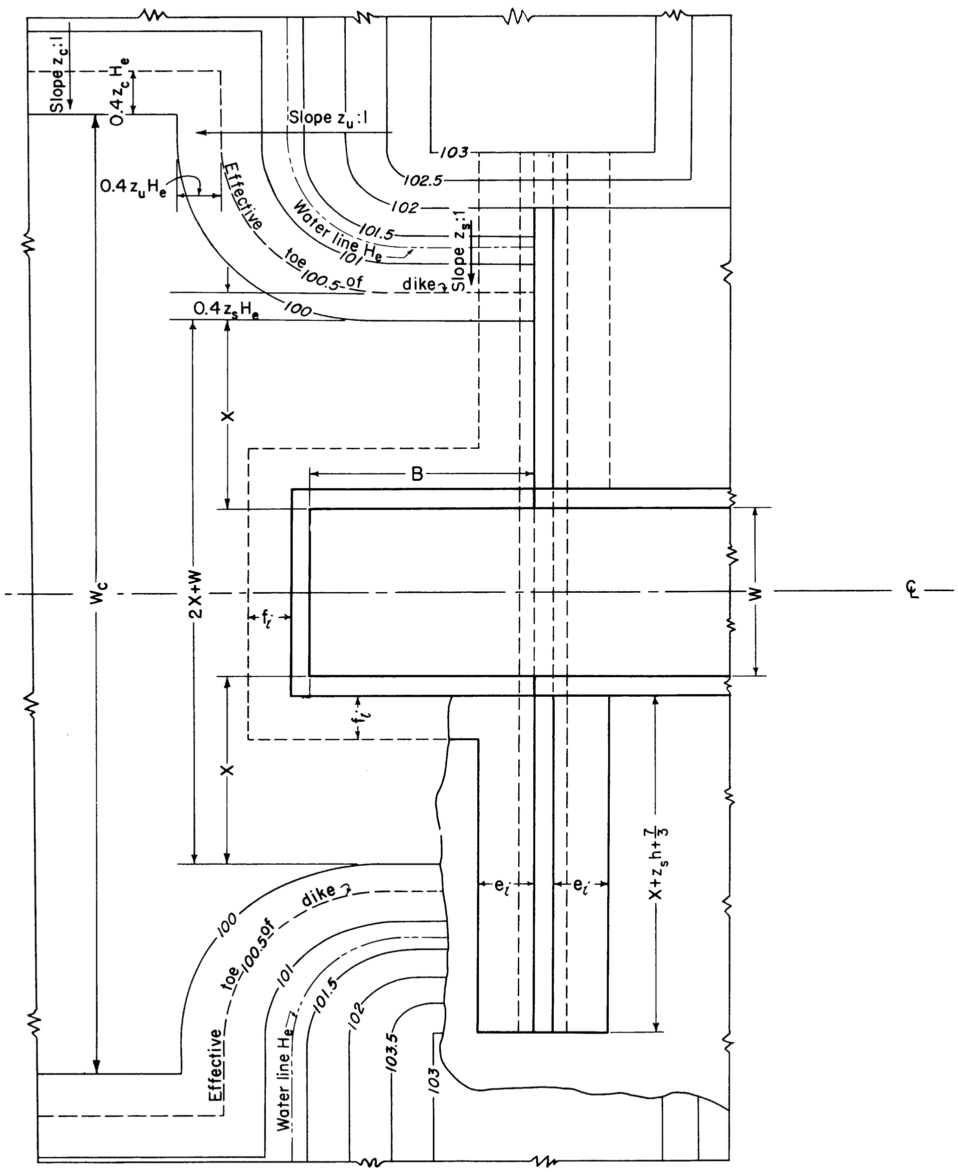
Capacities of this structure with dike effect are given by sheets 11, 12, and 13.

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 SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	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

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

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 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

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

The actual discharge Q_λ is

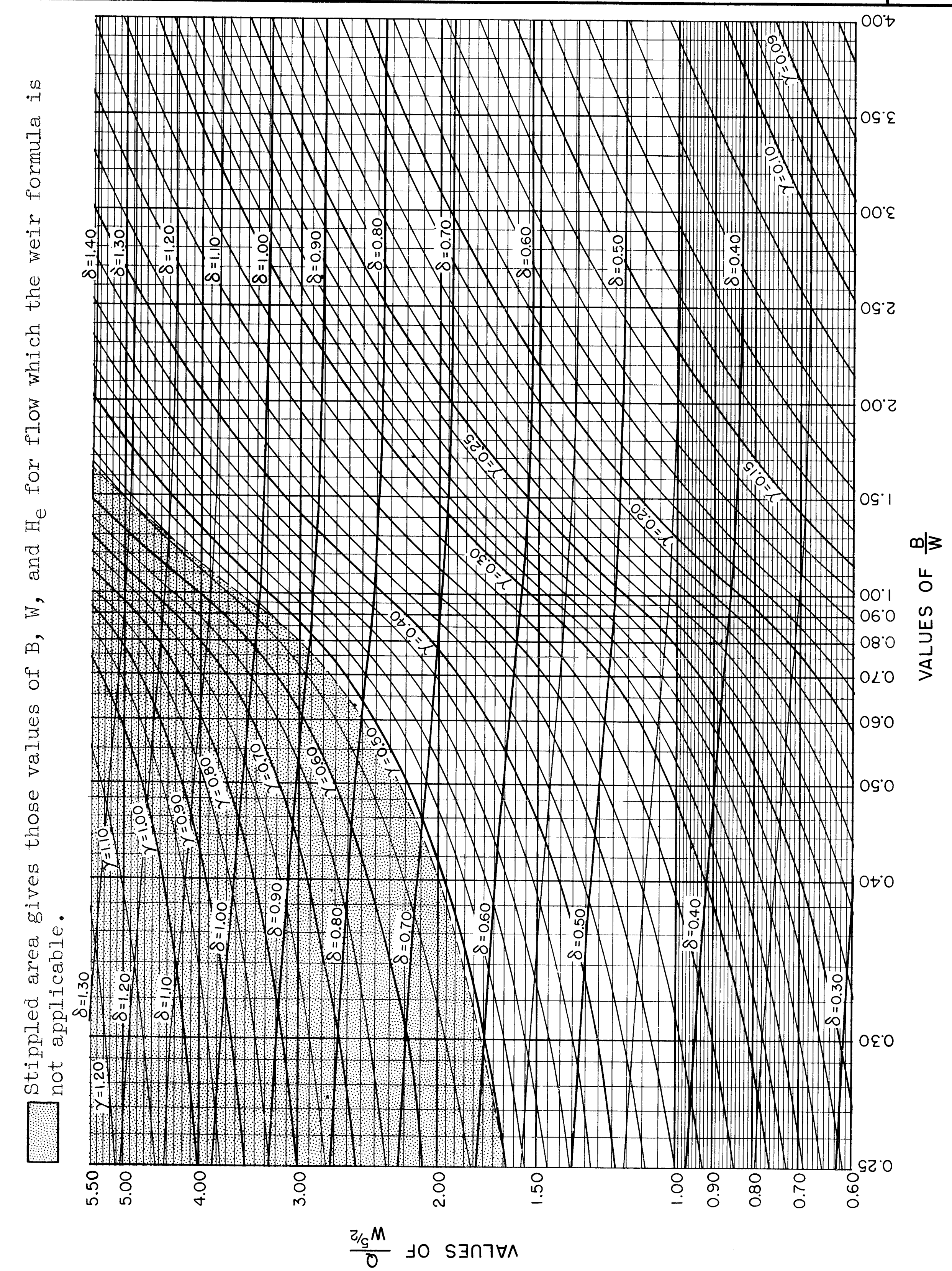
$$T_n + 3.09 = \frac{Q_\lambda}{W\ H_e^{3/2}}$$

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.

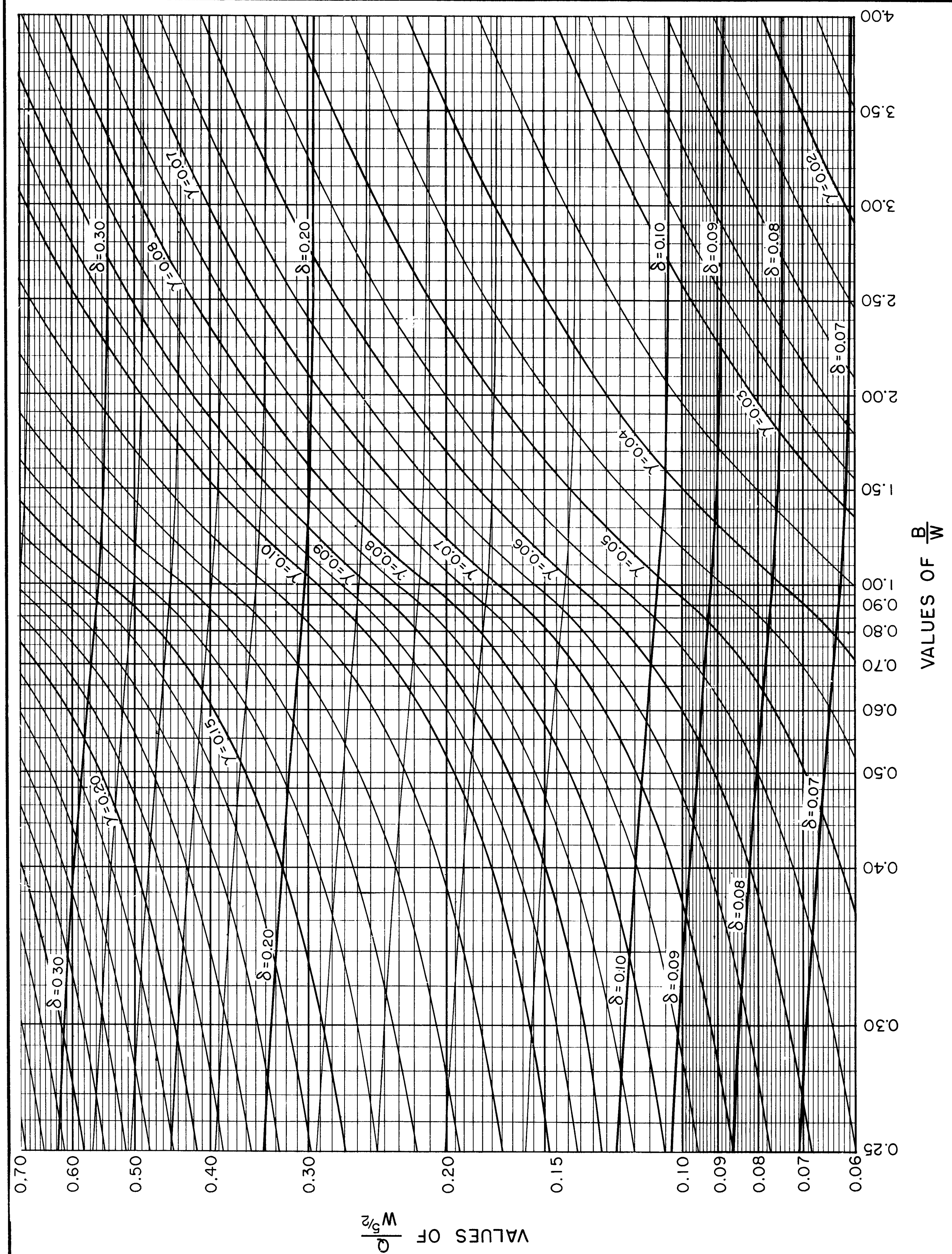
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

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.

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

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

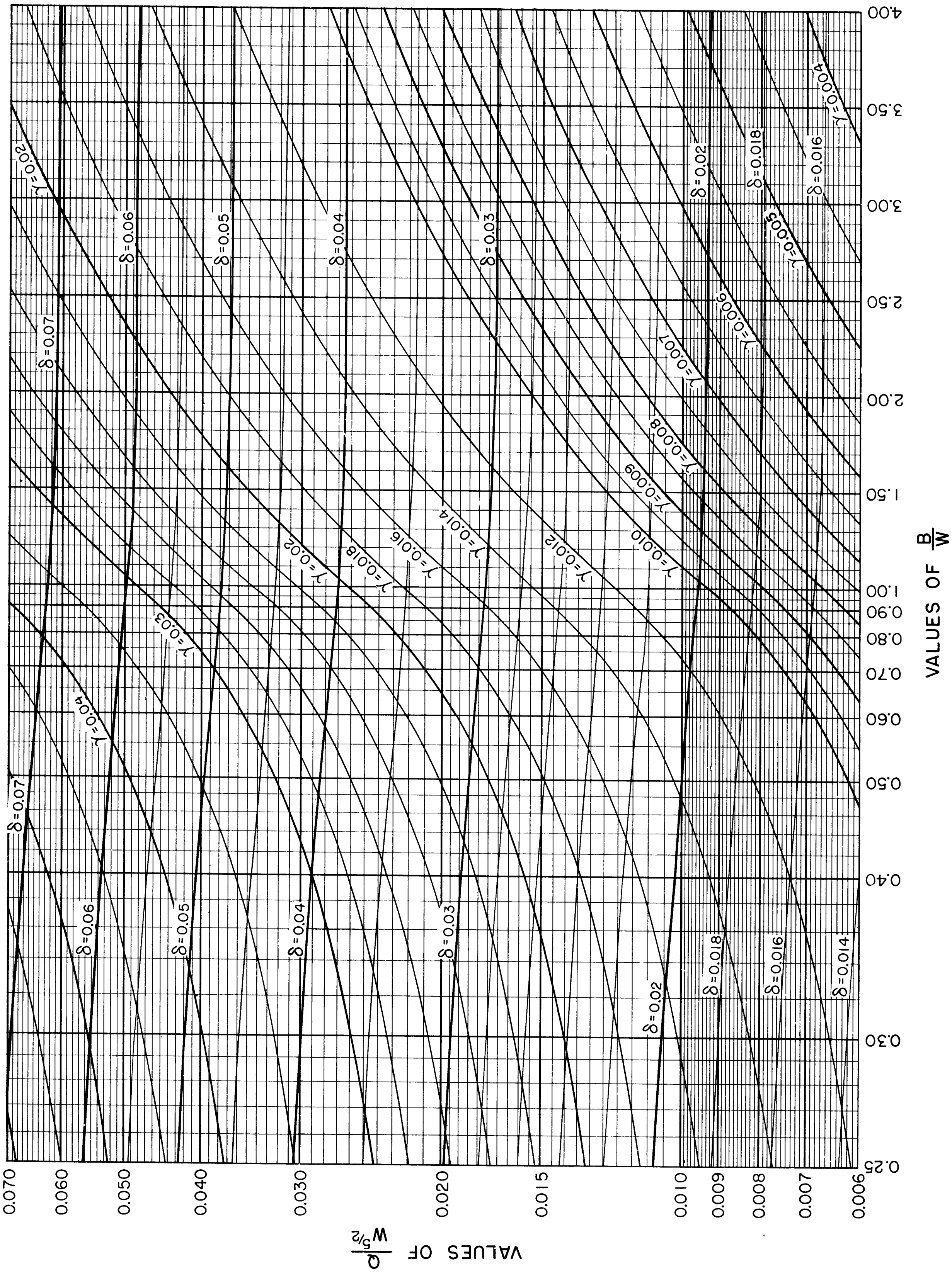


REFERENCE		
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 6 OF 24 DATE 4-5-55

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

U. S. DEPARTMENT OF AGRICULTURE
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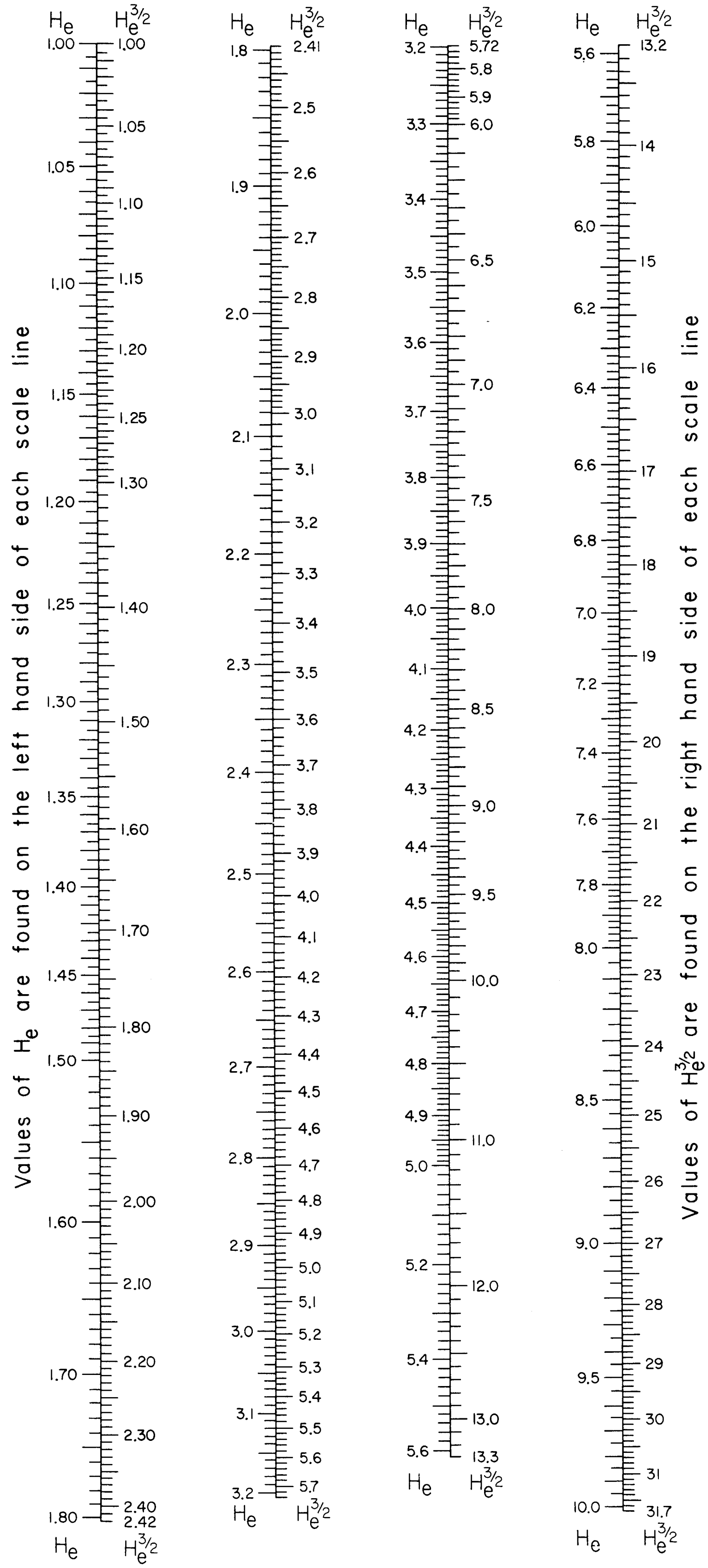
STANDARD DWG. NO.
ES-90
SHEET 7 OF 24
DATE 4-5-55

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

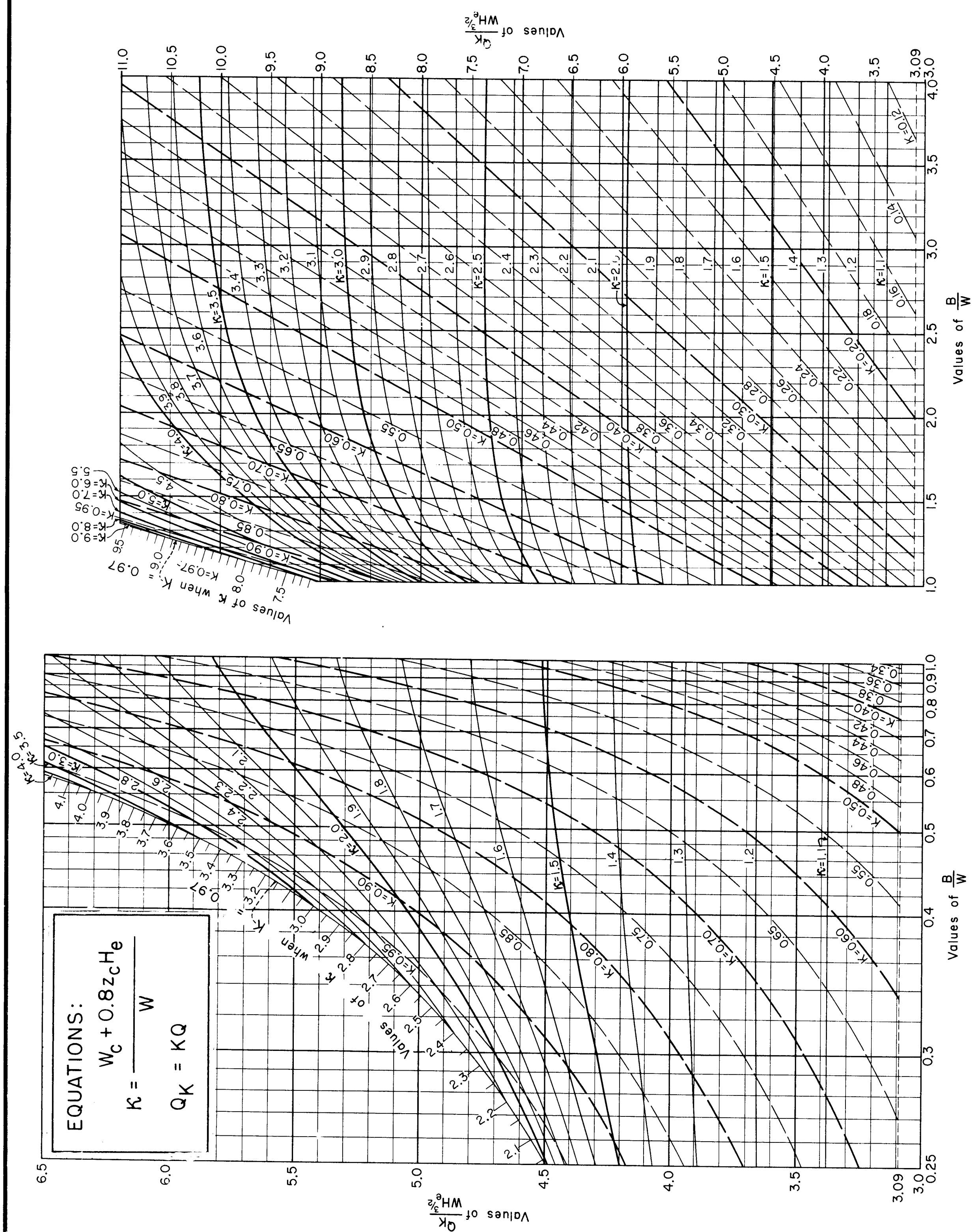


REFERENCE

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.



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

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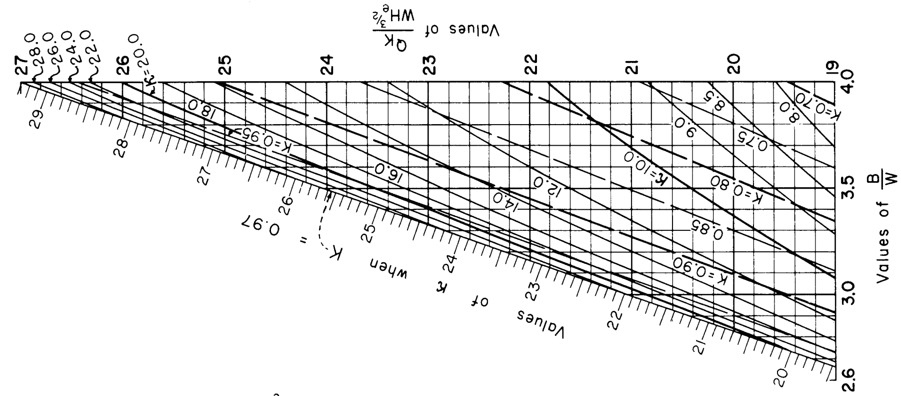
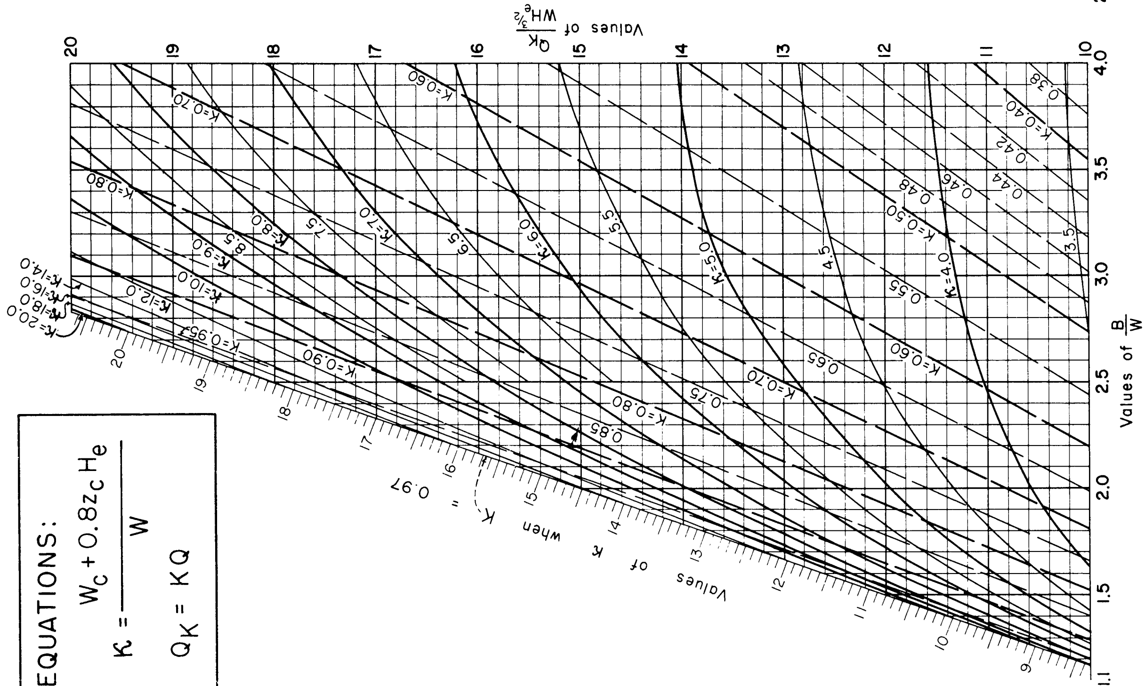
STANDARD DWG. NO.
ES- 90
SHEET 9 OF 24
DATE 5-20-55

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS;

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

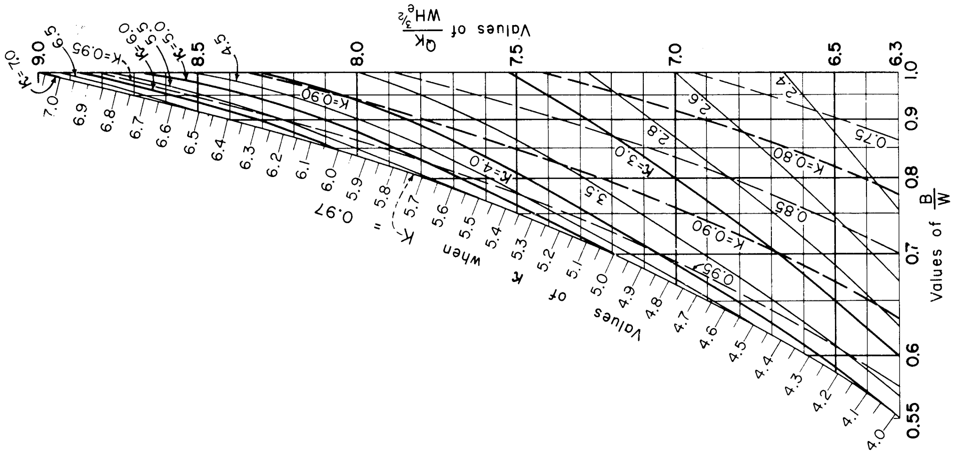




EQUATIONS:

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

$$Q_K = KQ$$



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.

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

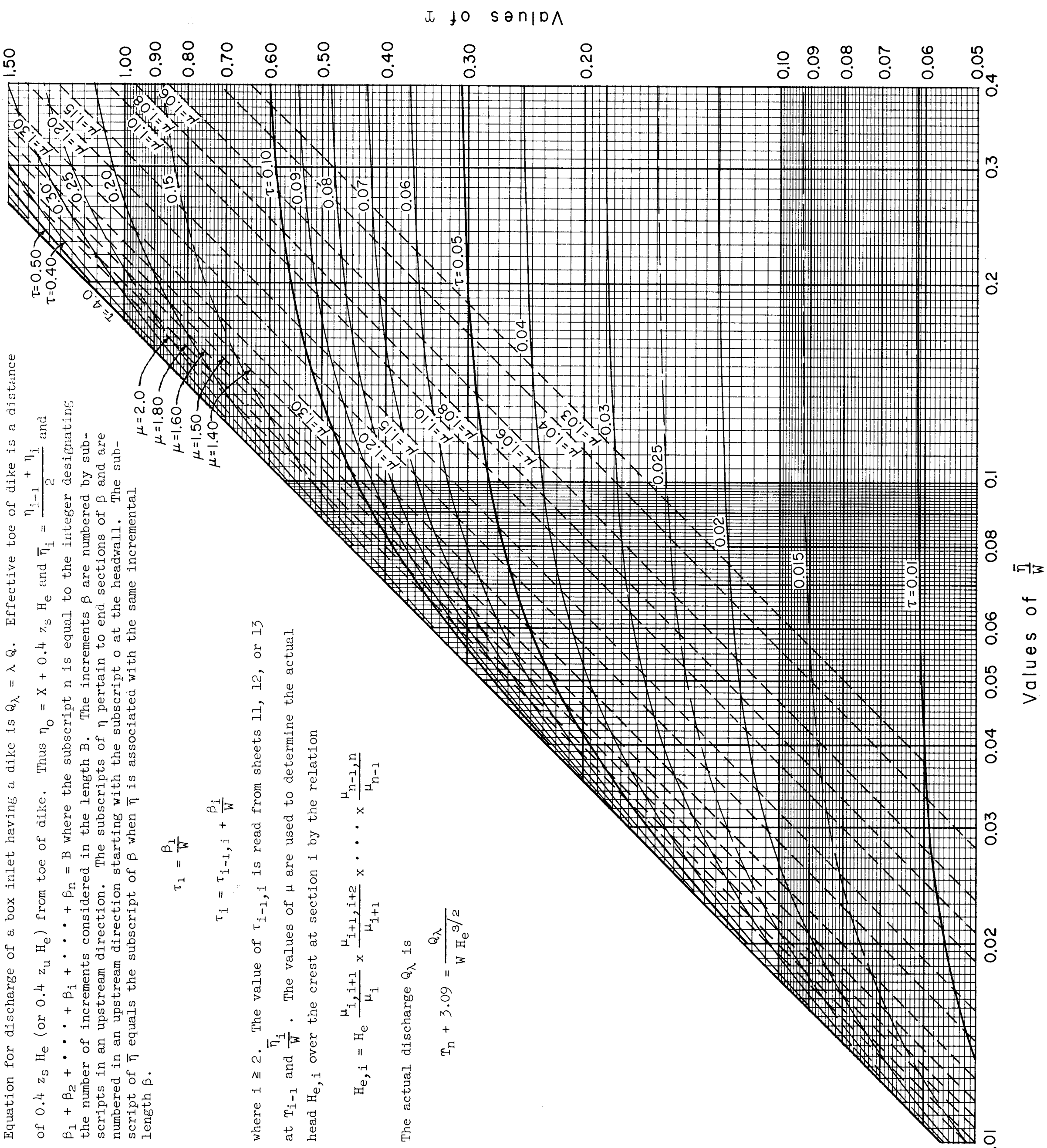
$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W}$$

where $i \geqq 2$. 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

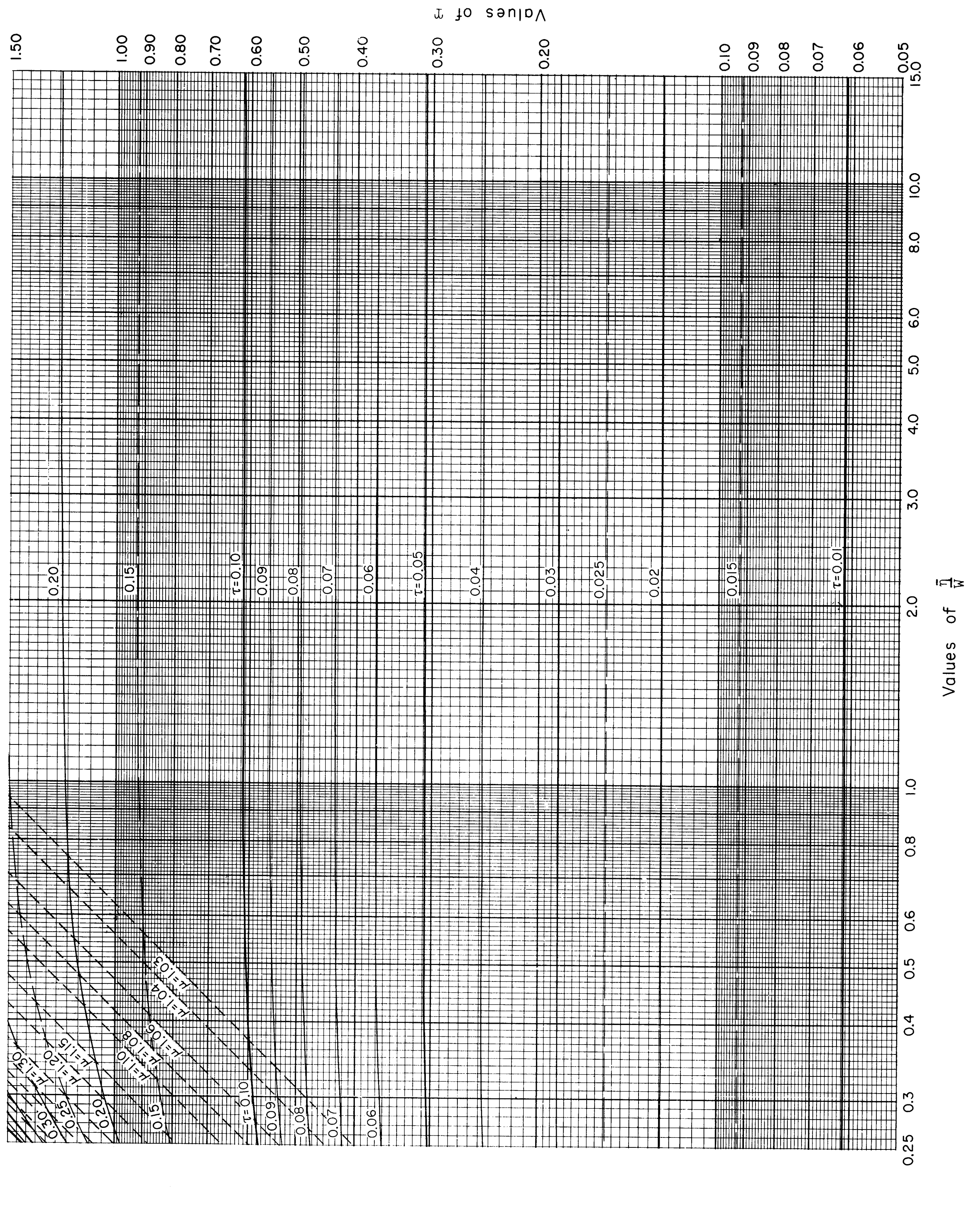
$$H_{e,i} = H_e \frac{\mu_{i,i+1}}{\mu_i} \times \frac{\mu_{i+1,i+2}}{\mu_{i+1}} \times \cdots \times \frac{\mu_{n-1,n}}{\mu_{n-1}}$$

The actual discharge Q_λ is

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



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



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

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SOIL CONSERVATION SERVICE
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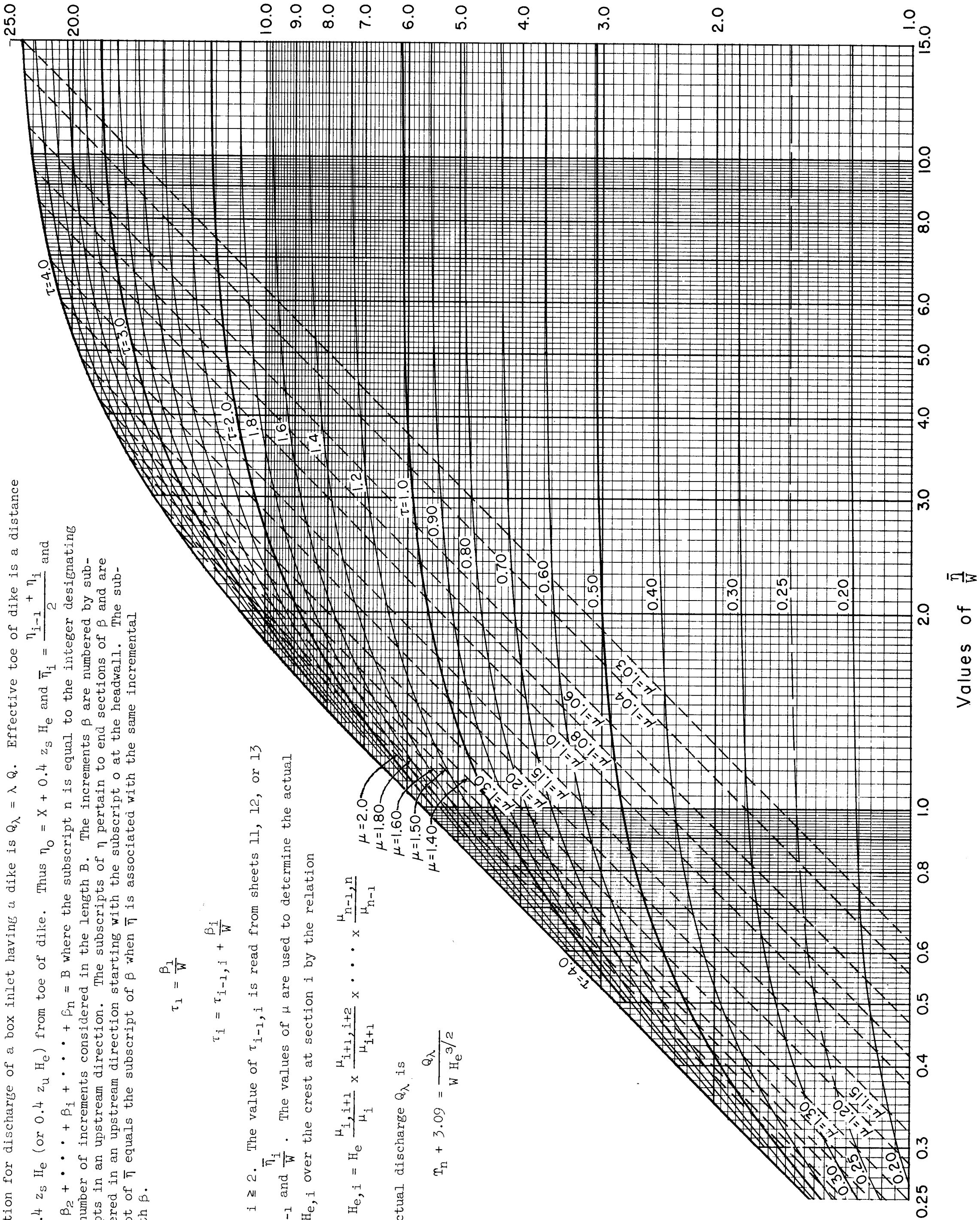
STANDARD DWG. NO.
ES- 90
SHEET 12 OF 24
DATE 6-14-55

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

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

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

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STANDARD DWG. NO.
ES- 90
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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

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

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

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

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

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

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 $\frac{Q_{mh}}{W^{5/2}} = 1.94$

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

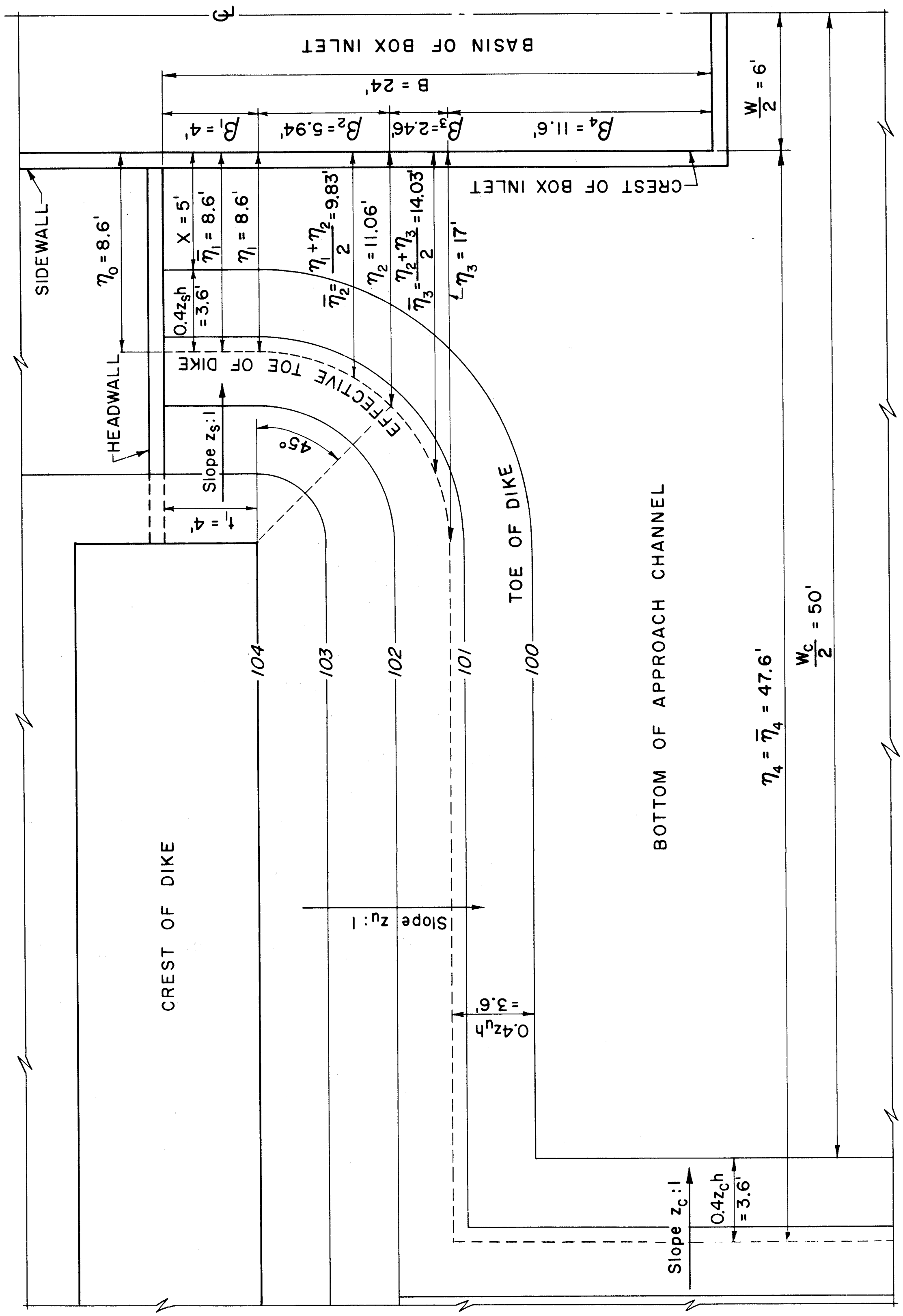
This is the capacity without freeboard Q_{mh} at the crest of the box inlet if D, W_c, and X are all sufficiently large.

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^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 $\bar{\eta}_i$ 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 μ_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 τ_2 = 0.821 and $\frac{\bar{\eta}_2}{W}$ = 0.819 and obtain T_2 = 3.64 and μ_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 τ_3 = 0.883 and $\frac{\bar{\eta}_3}{W}$ = 1.169 and obtain T_3 = 4.40 and μ_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 τ_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 $\bar{\eta}_i$ and $\frac{\bar{\eta}_i}{W}$. The result of the computations are illustrated on sheet 24 and shown in the following tabulation.

i	$H_{e,i}$	β_i	$\bar{\eta}_i$	$\frac{\beta_i}{W}$	$\frac{\bar{\eta}_i}{W}$
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 $\frac{\bar{\eta}_1}{W} = 0.606$ and obtain $T_1 = 1.80$.

b. Read the intersection of $T_1 = 1.80$ and $\frac{\bar{\eta}_2}{W} = 0.695$ 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 $\frac{\bar{\eta}_2}{W} = 0.695$ and obtain $T_2 = 3.32$.

b. Read the intersection of $T_2 = 3.32$ and $\frac{\bar{\eta}_3}{W} = 1.1$ 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 $T_3 = 4.25$.

b. Read the intersection of $T_3 = 4.25$ 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 $T_4 = 9.3$.

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

$$\frac{(Q_\lambda)_{mh}}{W\ h^{3/2}} = 3.09 + T_4$$

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

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

Use $D = 7.50$ 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.

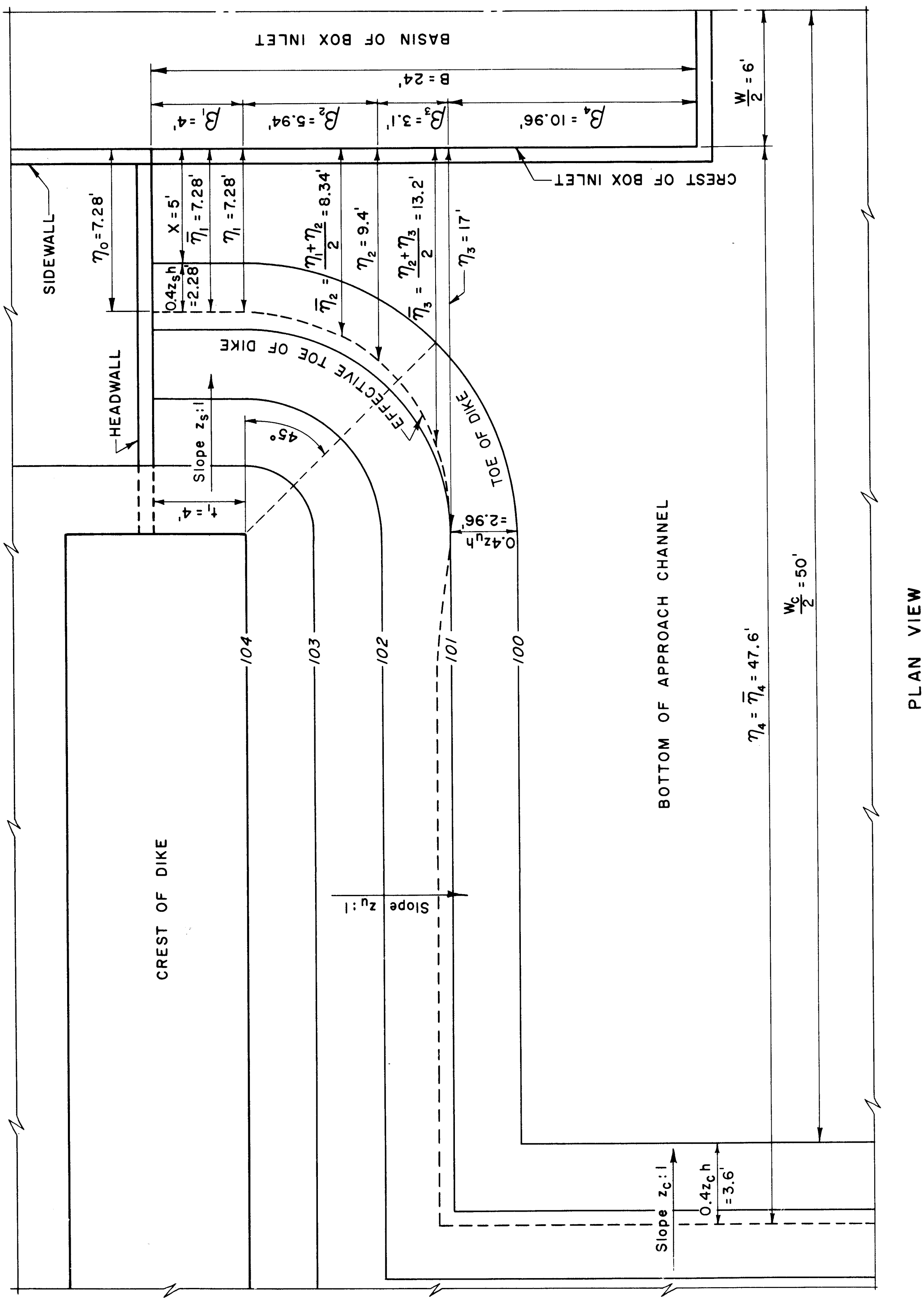
$$(Q_\lambda)_{mi} = (Q_\lambda)_{mh} = 773 \text{ cfs}$$

7. The value of λ is determined by the relation

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

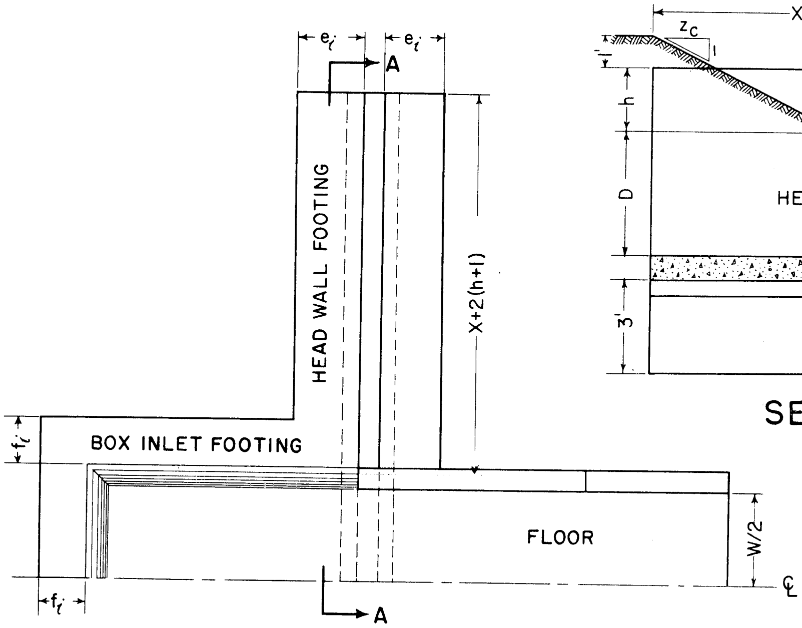
$$\lambda = \frac{(Q_\lambda)_{mh}}{Q_{mh}} = \frac{773}{968} = 0.799$$

CHUTE SPILLWAYS: FLAT-RECTANGULAR WEIR BOX INLETS; Examples

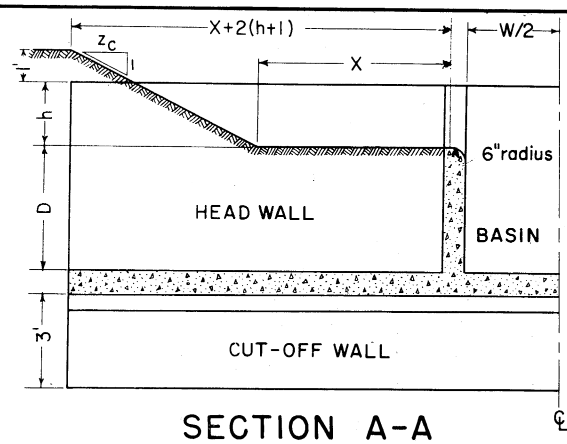


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-90 SHEET 24 OF 24 DATE 6-14-55

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

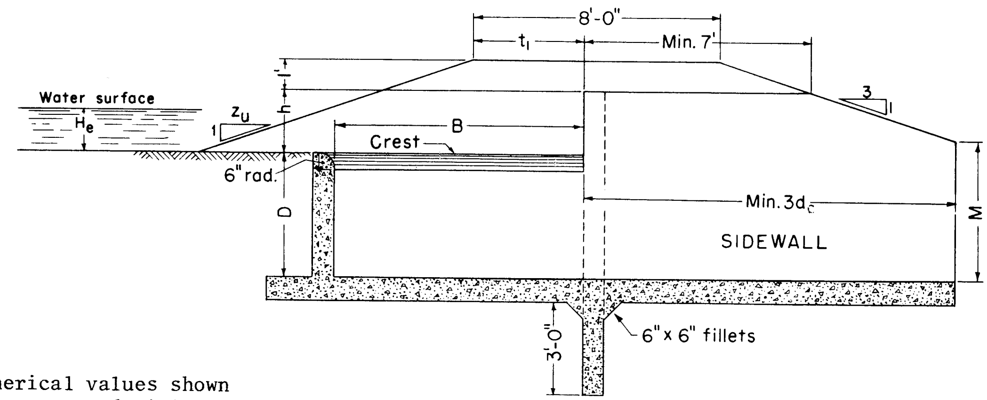


HALF-PLAN



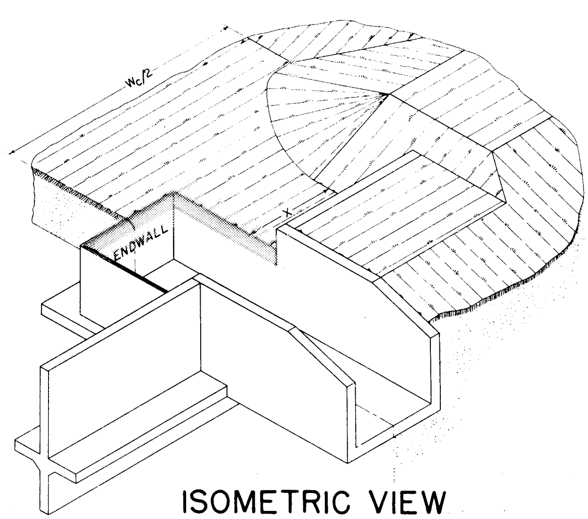
SECTION A-A

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

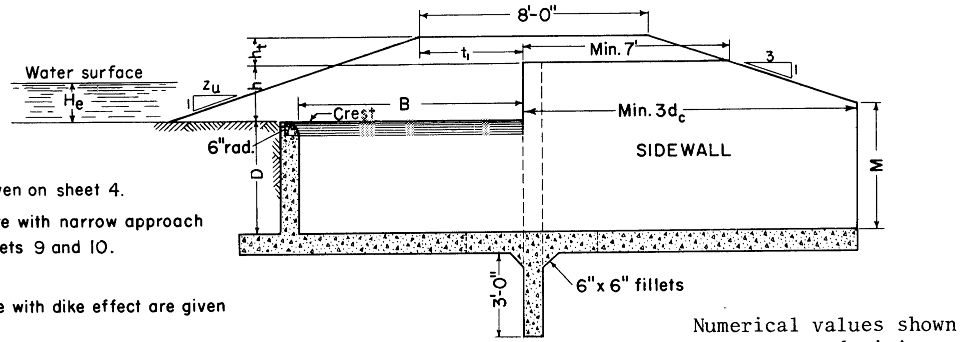


ISOMETRIC VIEW

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.

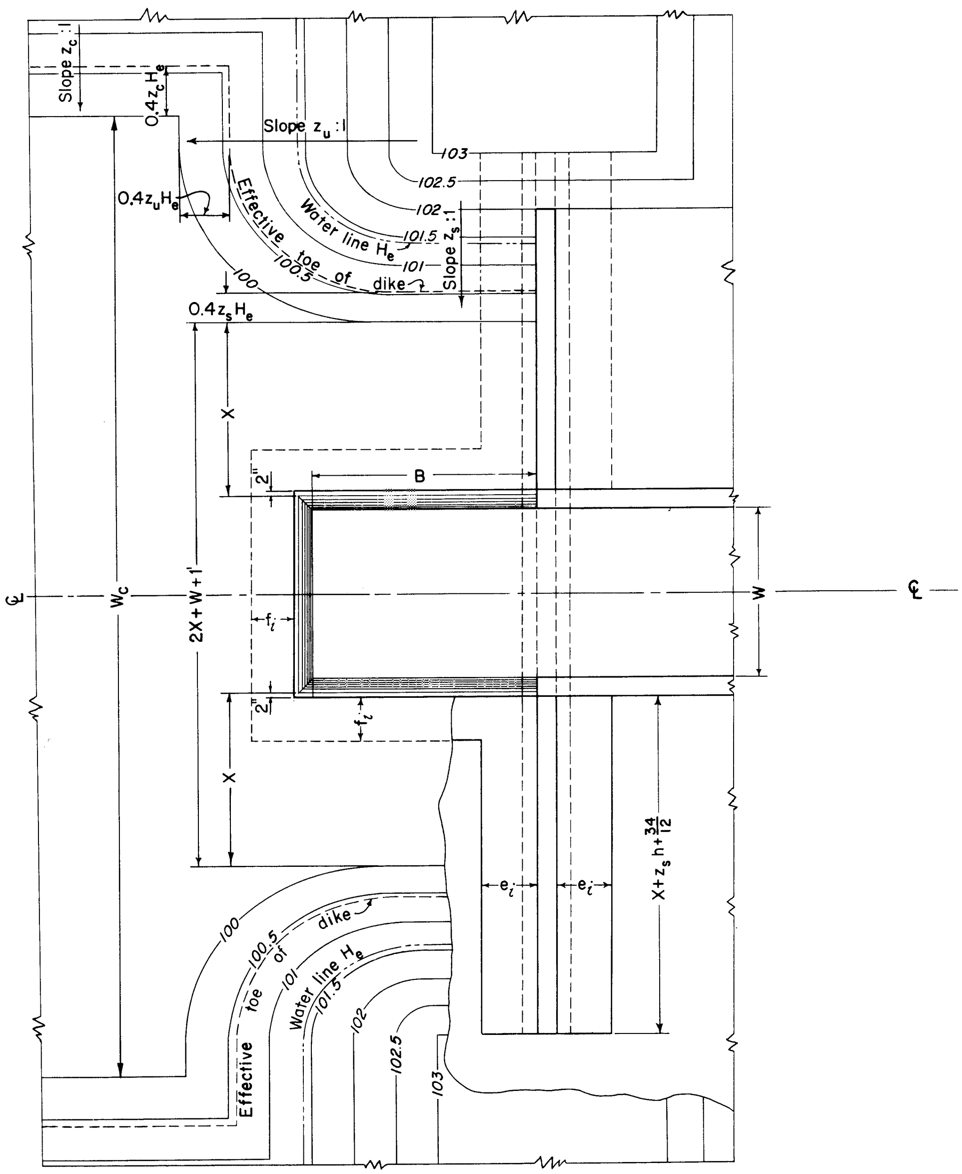
Capacities of this structure with dike effect are given by sheets 11, 12, and 13.

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

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

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

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

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

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

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

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

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 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.

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

The value of $\tau_{i-1,i}$ is read from sheets 11, 12, and 13 at T_{i-1} and $\frac{\bar{\eta}_i}{W + 1}$. 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

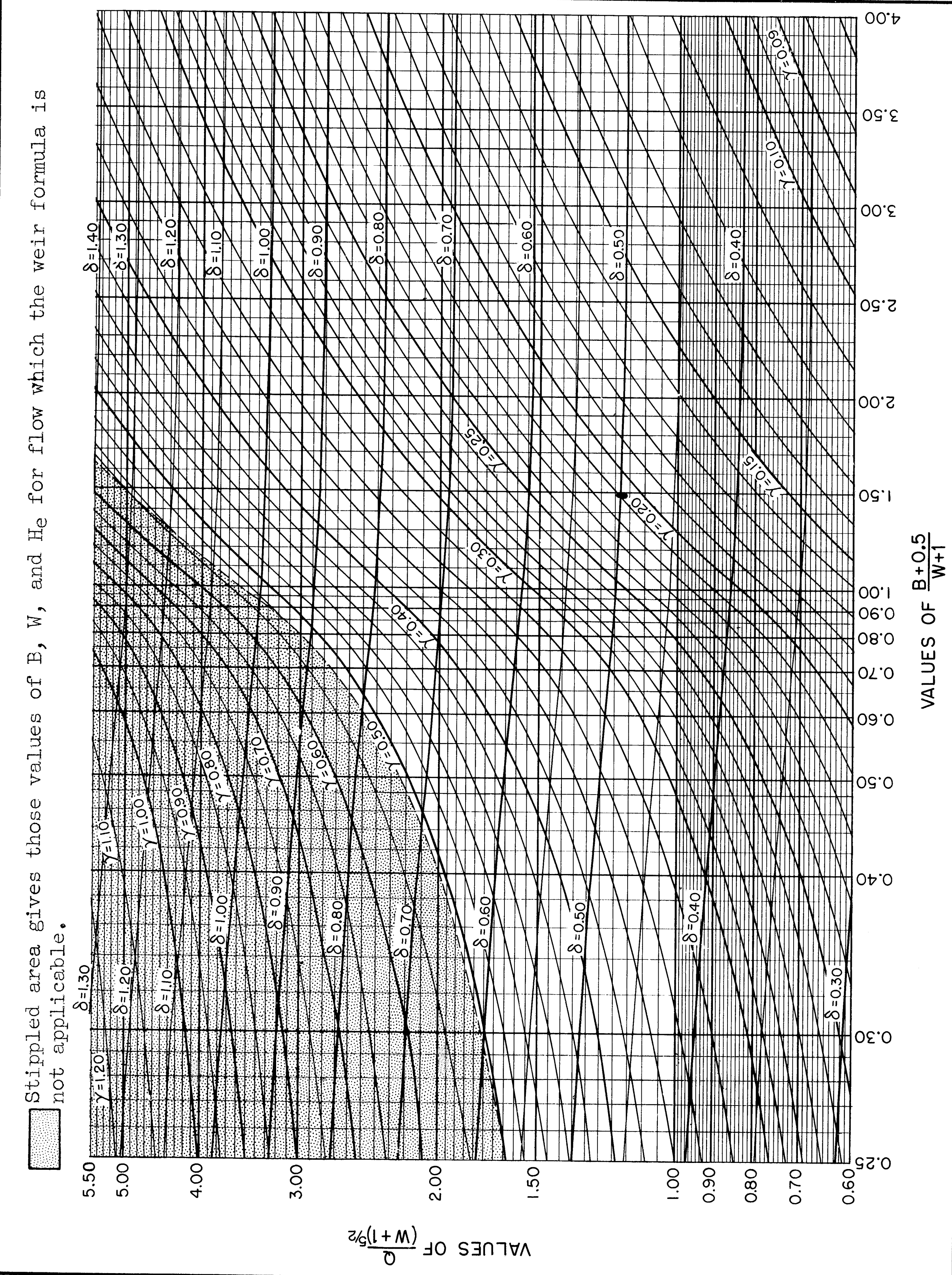
$$T_n + 3.09 = \frac{Q_\lambda}{(W + 1)\ H_e^{3/2}}$$

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.

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

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

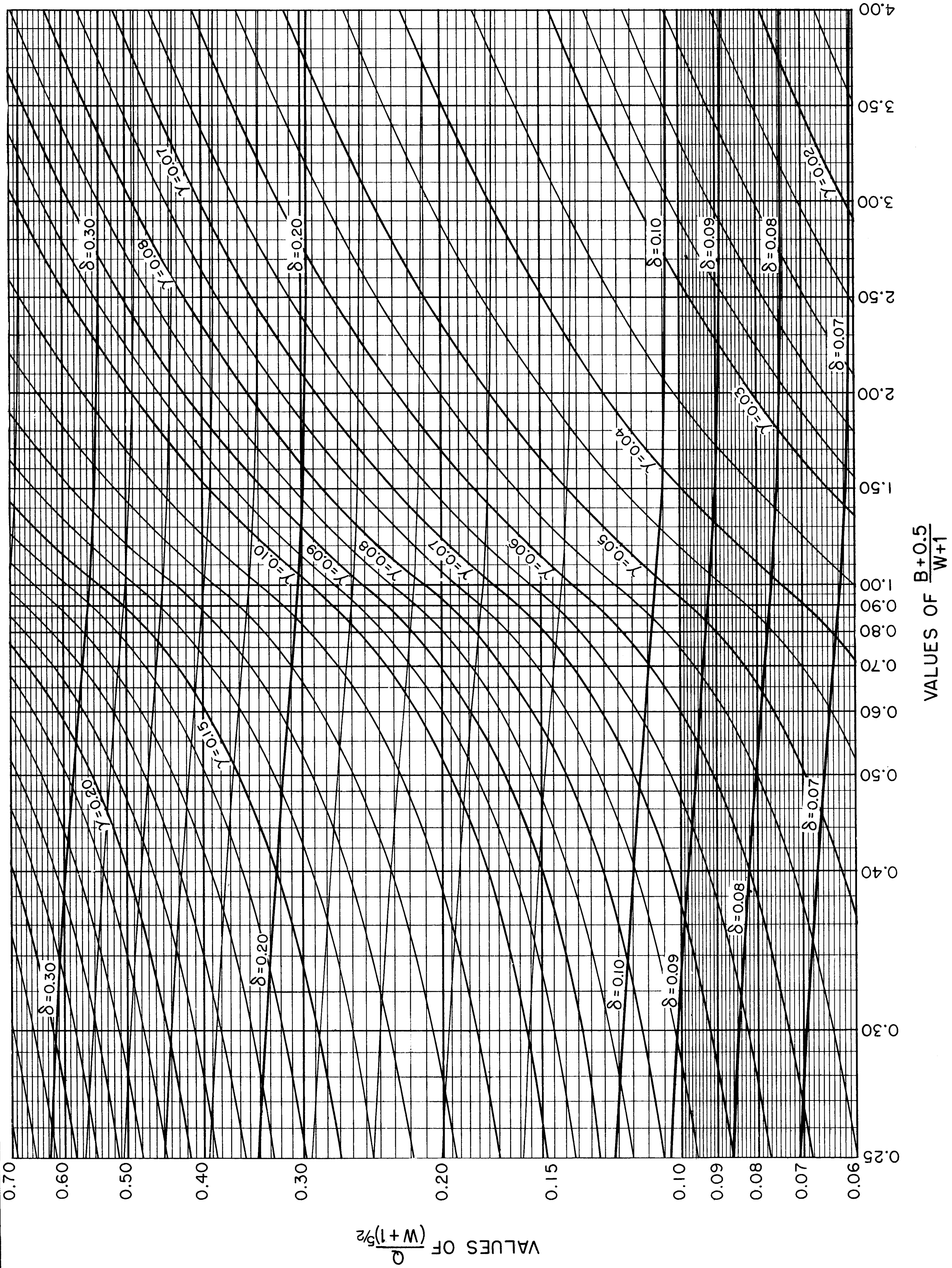


REFERENCE		STANDARD DWG. NO.
This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	ES-91 SHEET 5 OF 24 DATE 4-5-55

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.

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

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



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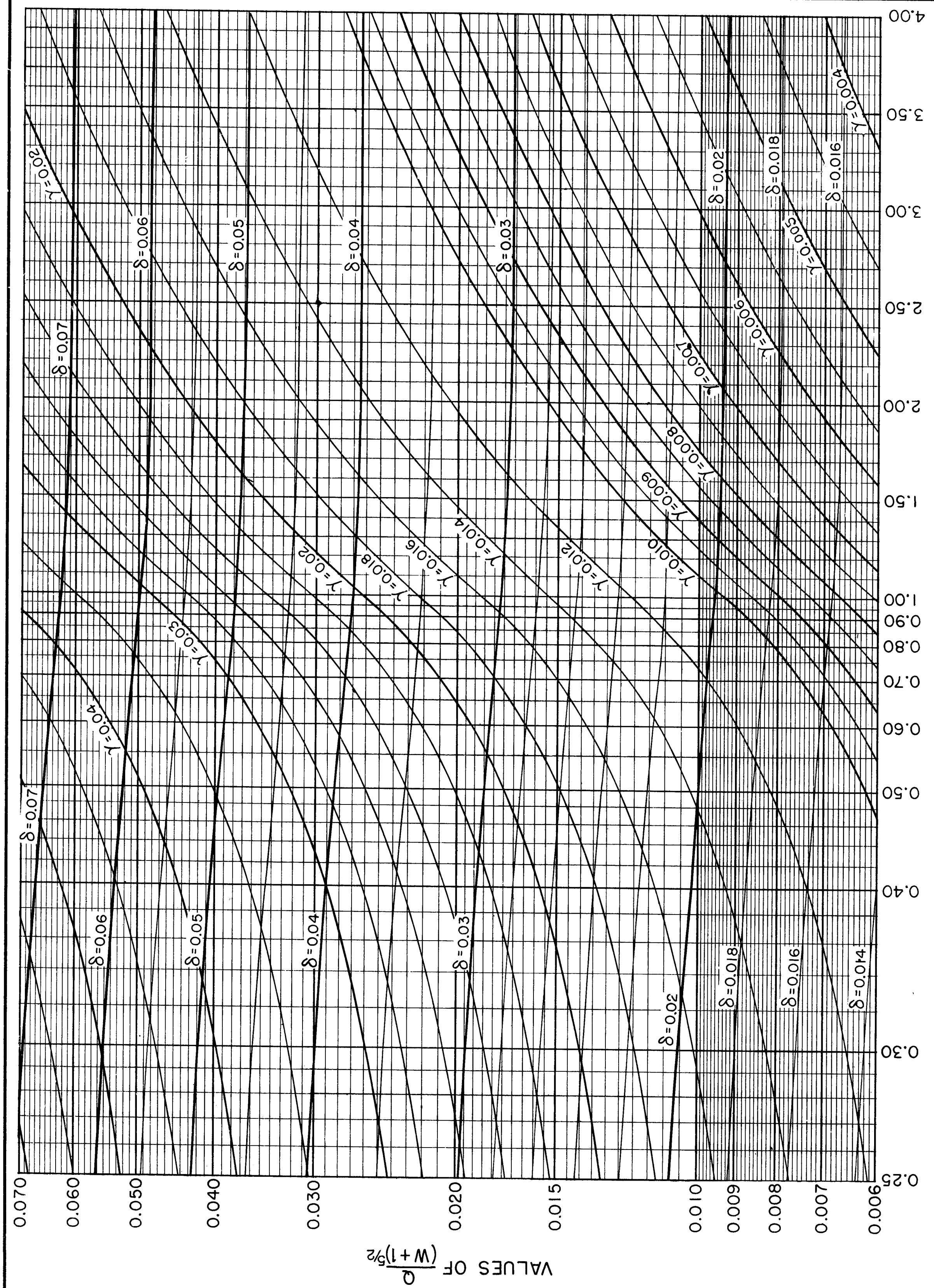
CHUTE SPILLWAYS: The discharge-head relationship for a ROUNDED-RECTANGULAR WEIR box inlet with free-flow conditions at the crest and no dike or narrow channel effects.

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



REFERENCE

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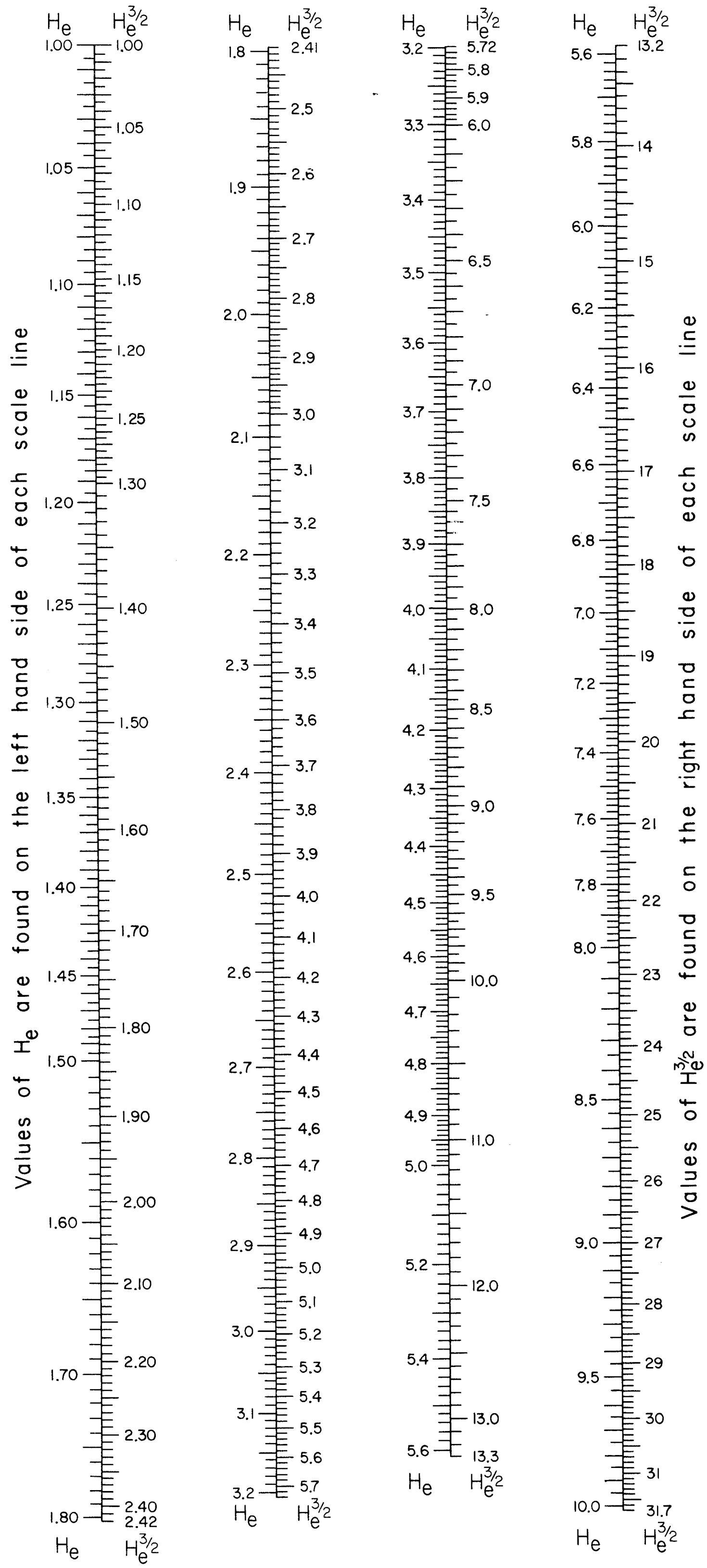
STANDARD DWG. NO. ES-91

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

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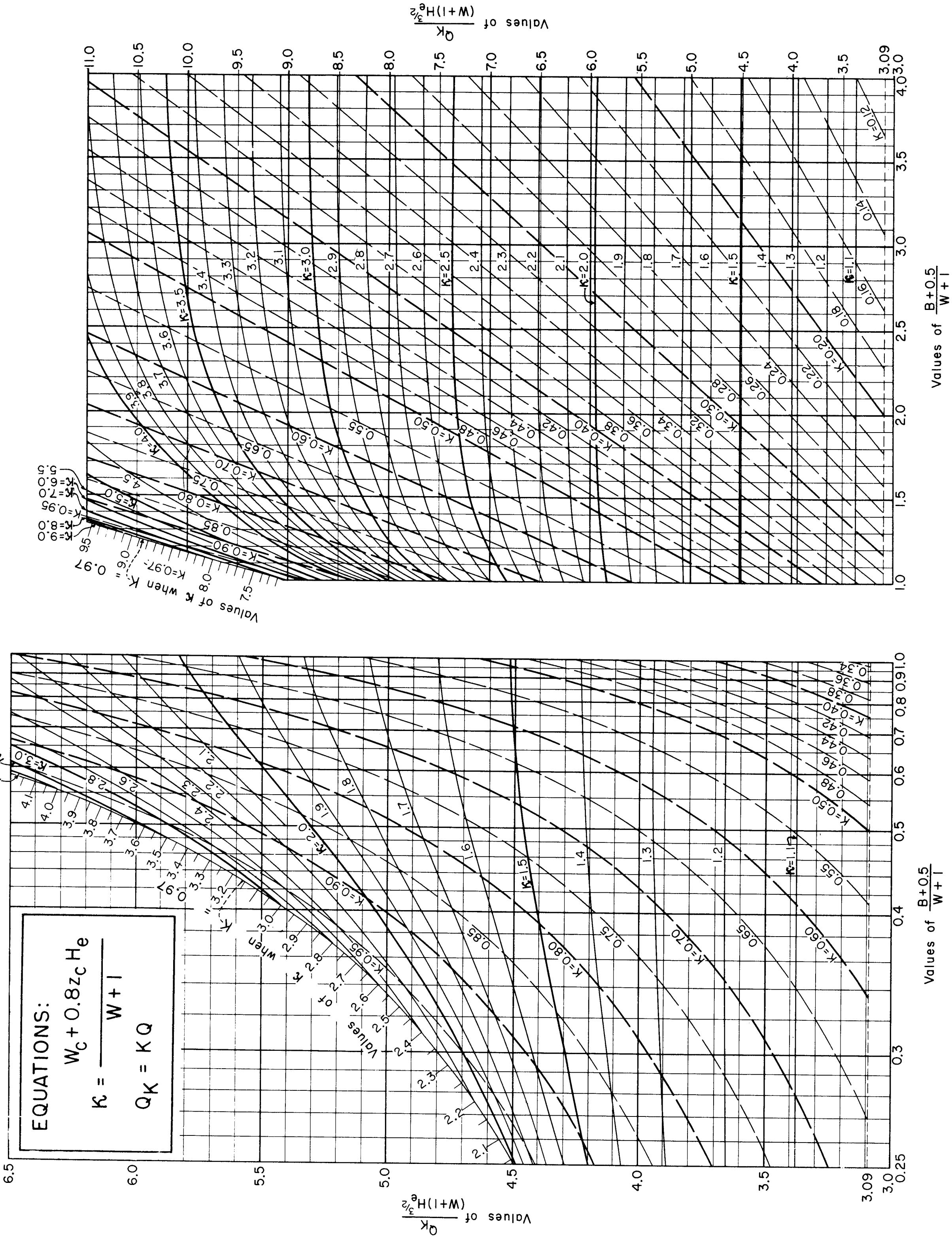
SHEET 8 OF 24
DATE 6-10-55

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:

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

$$Q_K = KQ$$

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

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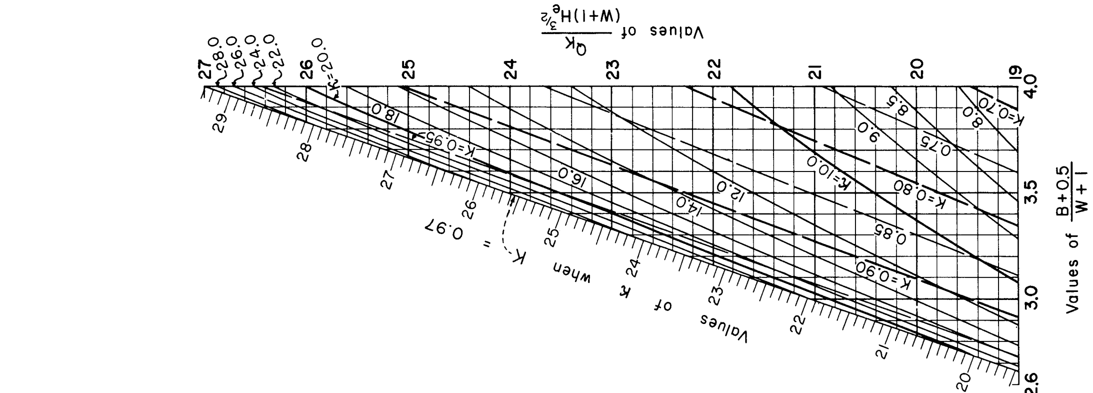
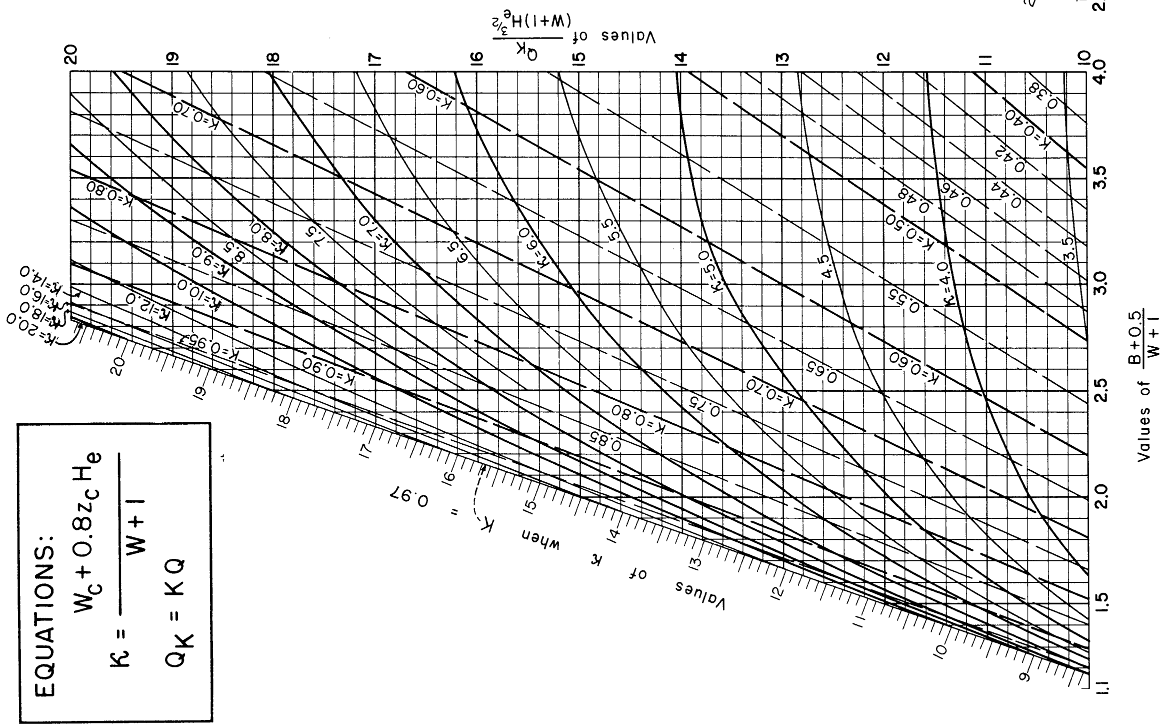
DATE 5-20-55

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

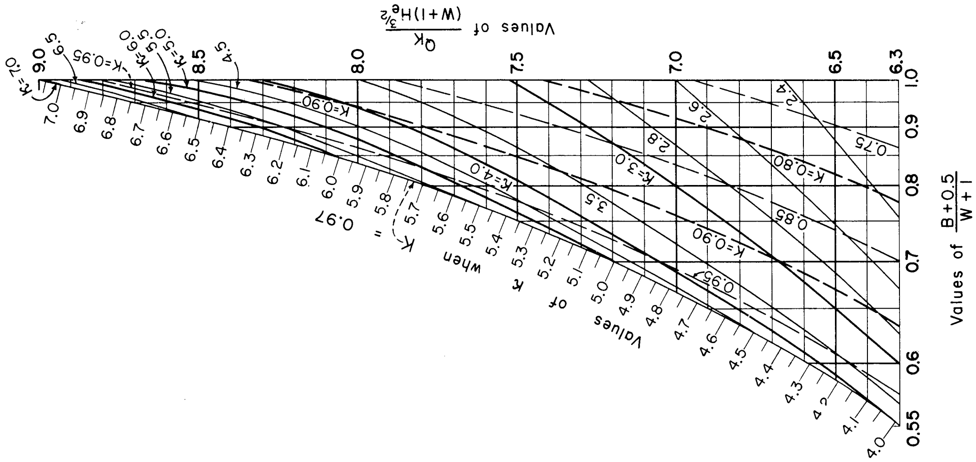




EQUATIONS:

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

$$Q_K = KQ$$



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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.

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

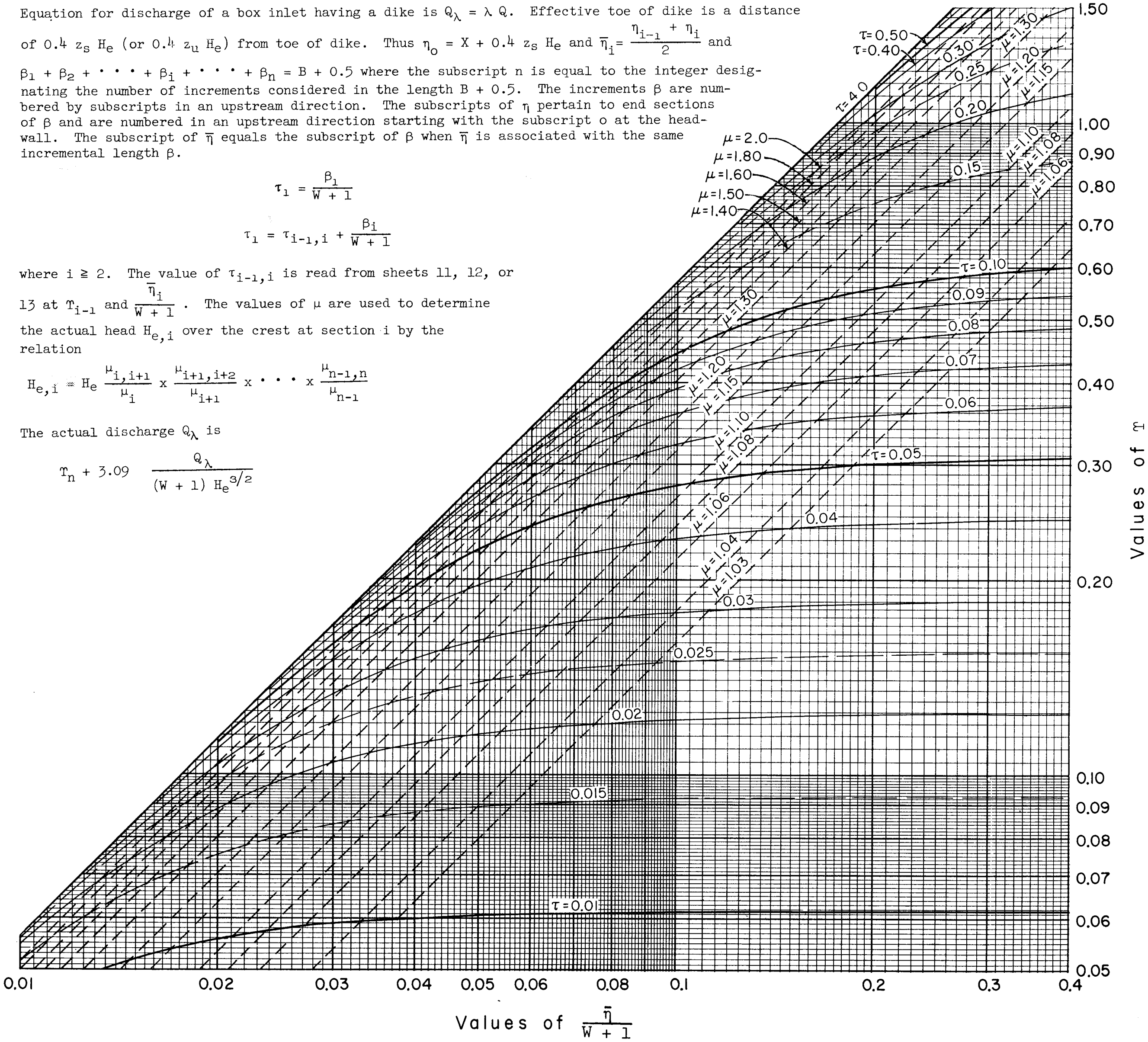
$$\tau_i = \tau_{i-1,i} + \frac{\beta_i}{W + 1}$$

where i ≥ 2. The value of $\tau_{i-1,i}$ is read from sheets 11, 12, or 13 at 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

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

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.

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SHEET 11 OF 24
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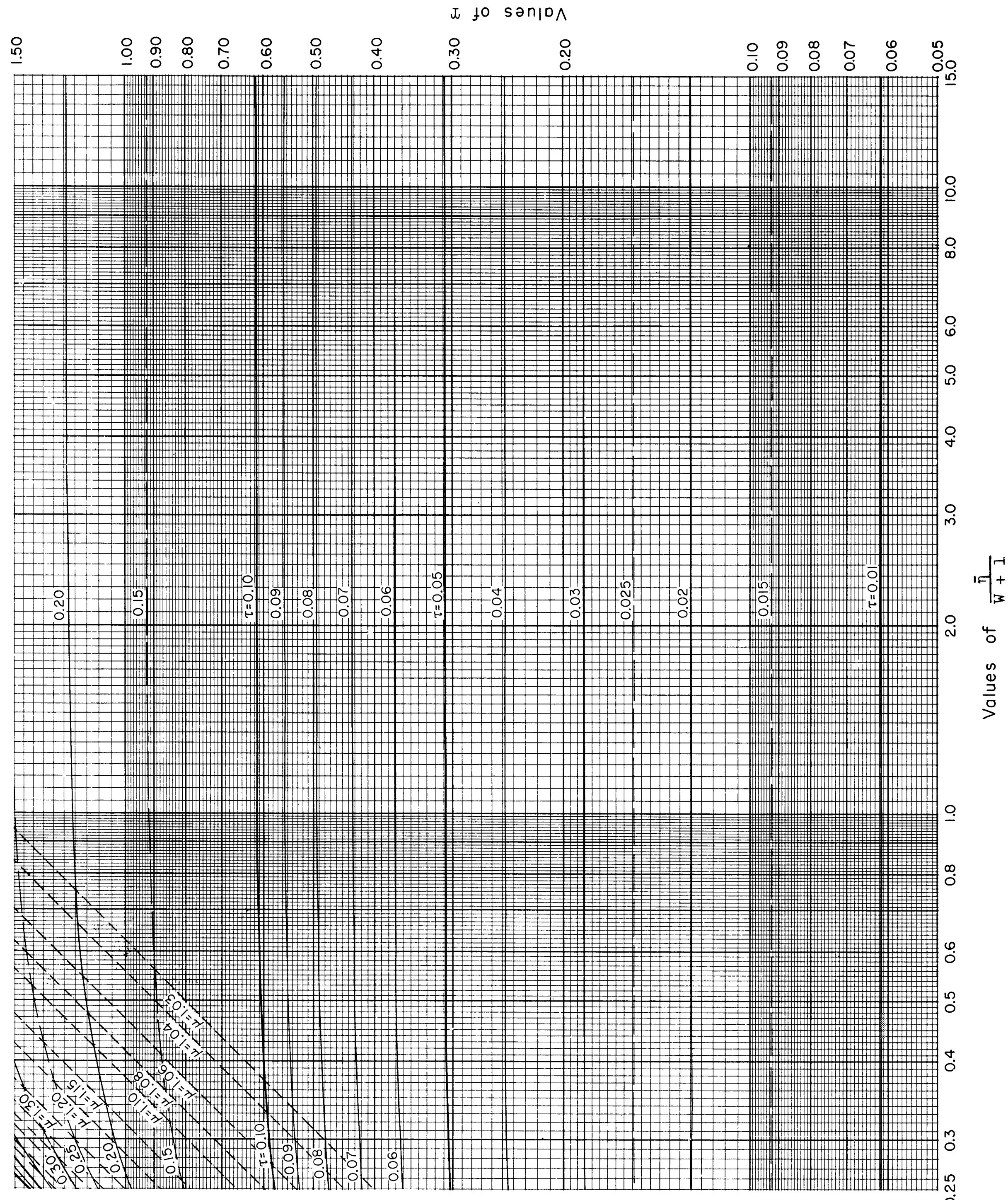
CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Effect of dike on discharge.



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

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

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

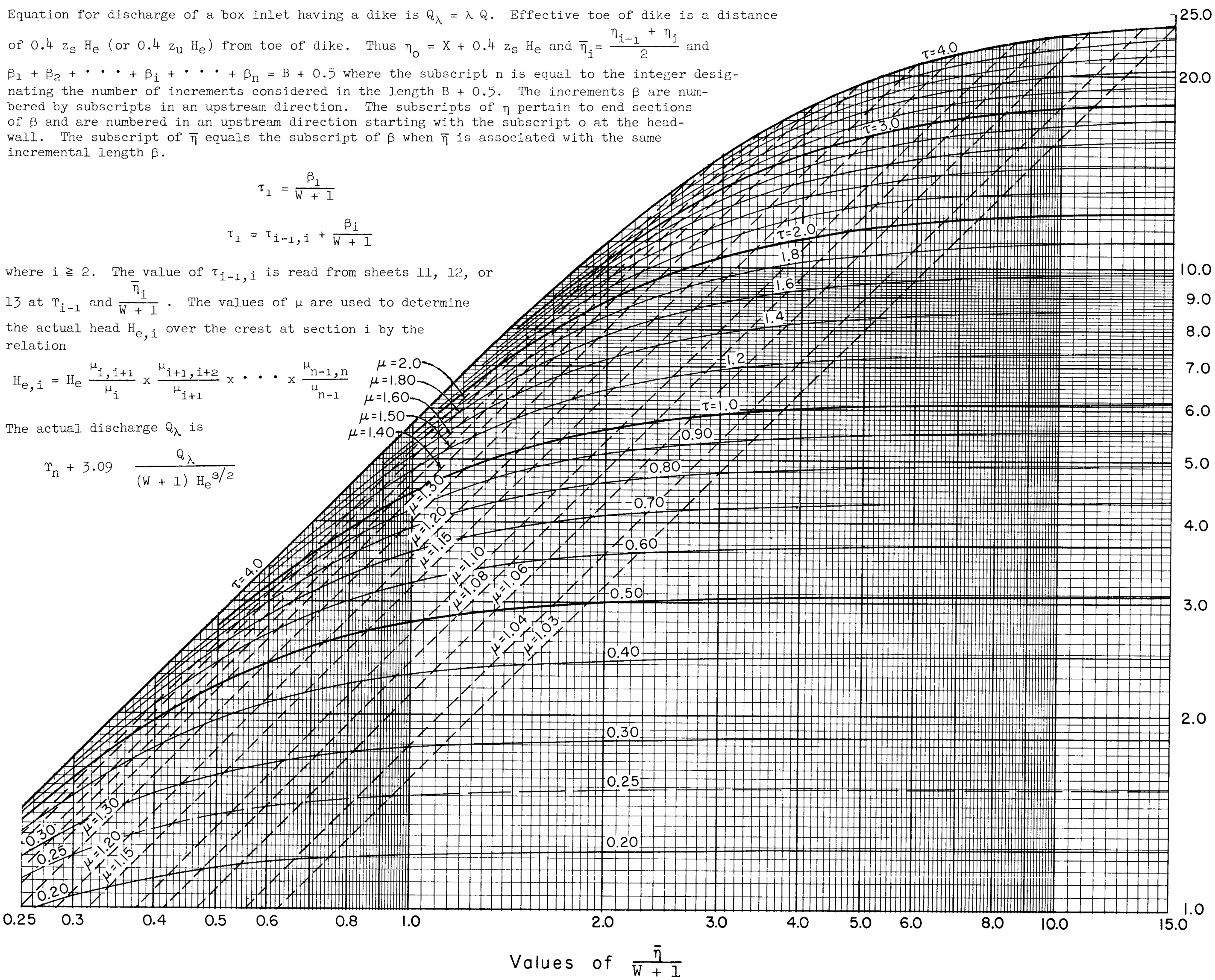
$$\tau_1 = \tau_{i-1,i} + \frac{\beta_i}{W + 1}$$

where $i \geq 2$. The value of $\tau_{i-1,i}$ is read from sheets 11, 12, or 13 at τ_{i-1} and $\frac{\overline{\eta}_i}{W + 1}$. 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

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



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STANDARD DWG. NO.
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SHEET 13 OF 24
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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.

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

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}

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

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 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

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

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}.

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

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

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

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

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

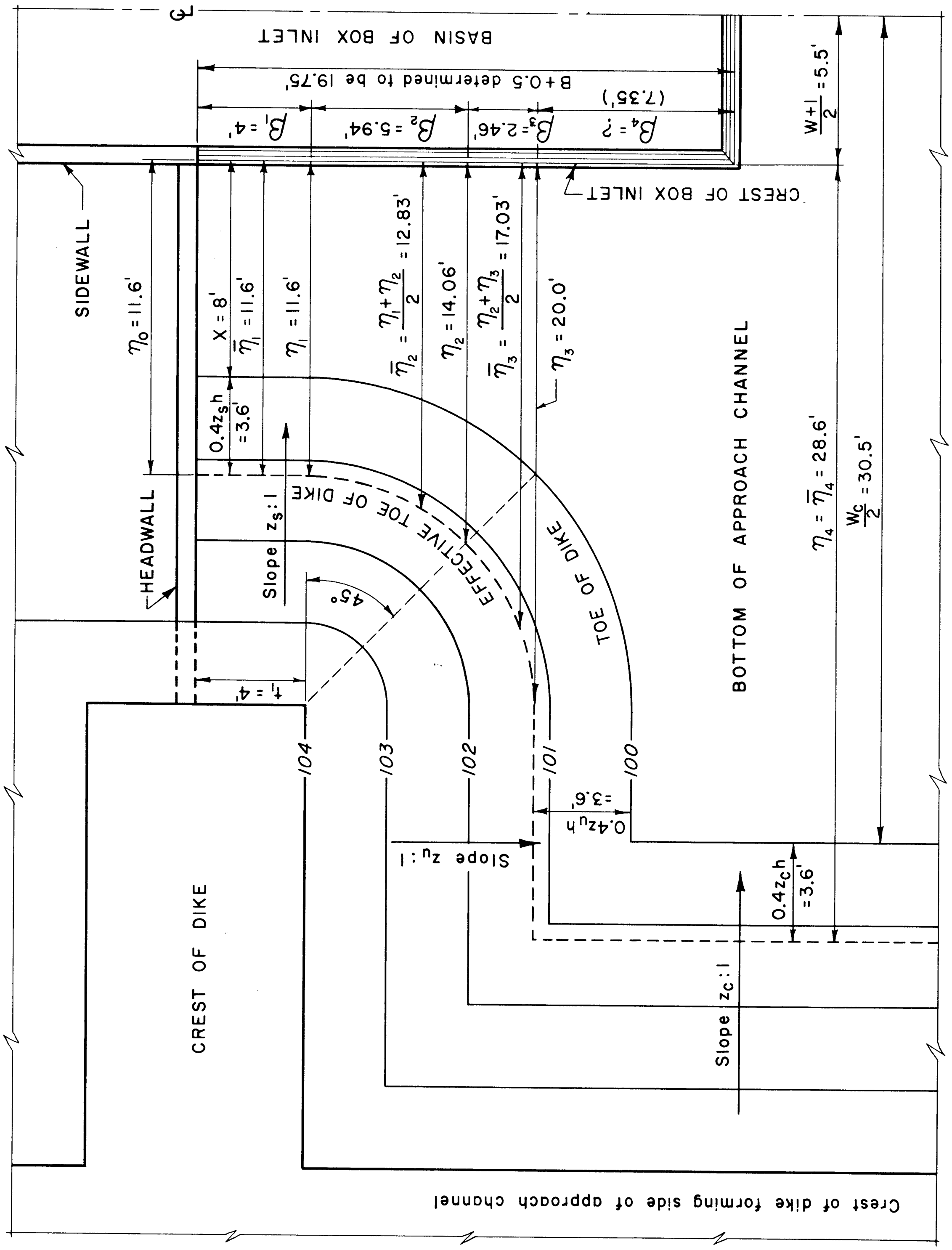
3. The dimension B of the box inlet required to convey a discharge of Q_{fr} = 660 cfs with free-flow conditions at the crest and the given approach conditions is determined in the following manner. The value of B is greater than 14.35 ft for these conditions.

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

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 20 OF 24 DATE 6-14-55

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

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 $\mathcal{T}_2 = 4.33$ 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 $\mathcal{T}_3 = 5.37$.

$$\mathcal{T}_n > \mathcal{T}_3$$

b. Read the intersection of $\mathcal{T}_3 = 5.37$ 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 $\mathcal{T}_n = 8.43$ and obtain from sheet 13

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

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

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

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

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

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

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

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

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

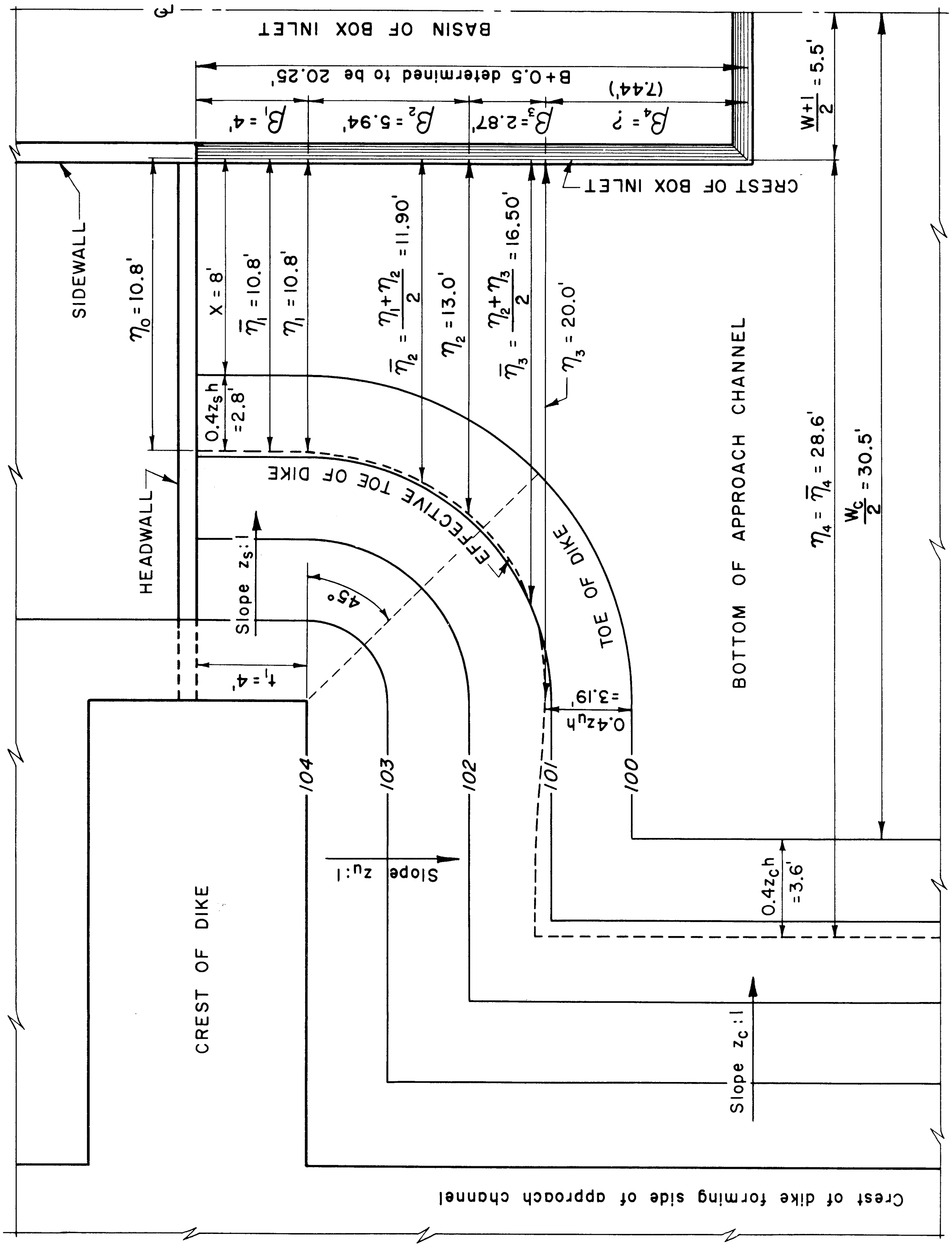
6. The required depth of box inlet D_r to prevent submergence of the crest may be determined at the point of intersection of lines $\frac{(Q_\lambda)_{mh}}{(W + 1)^{5/2}} = \frac{660}{(10 + 1)^{5/2}} = 1.645$ and $\frac{B + 0.5}{W + 1} = \frac{20.25}{11} = 1.84$. From sheet 5, read

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

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

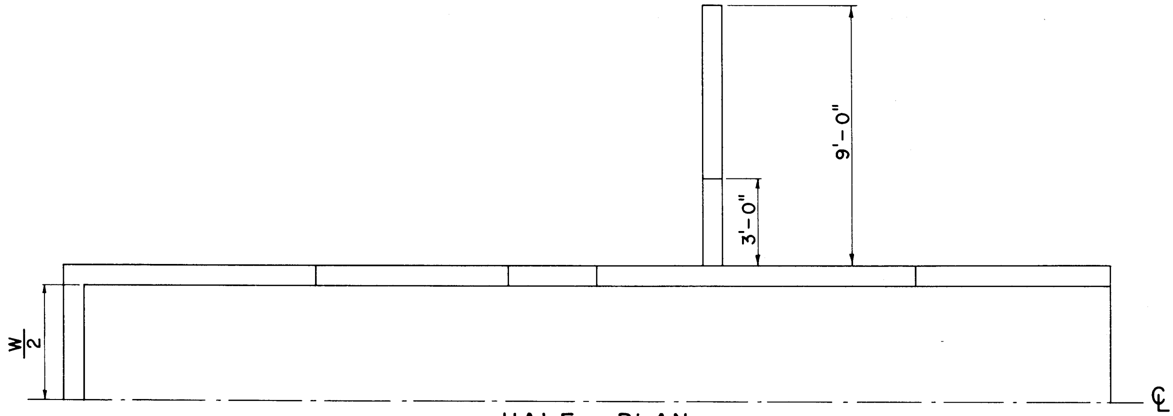
$$\text{Use } D = 7.5 \text{ ft}$$

CHUTE SPILLWAYS: ROUNDED-RECTANGULAR WEIR BOX INLETS; Examples

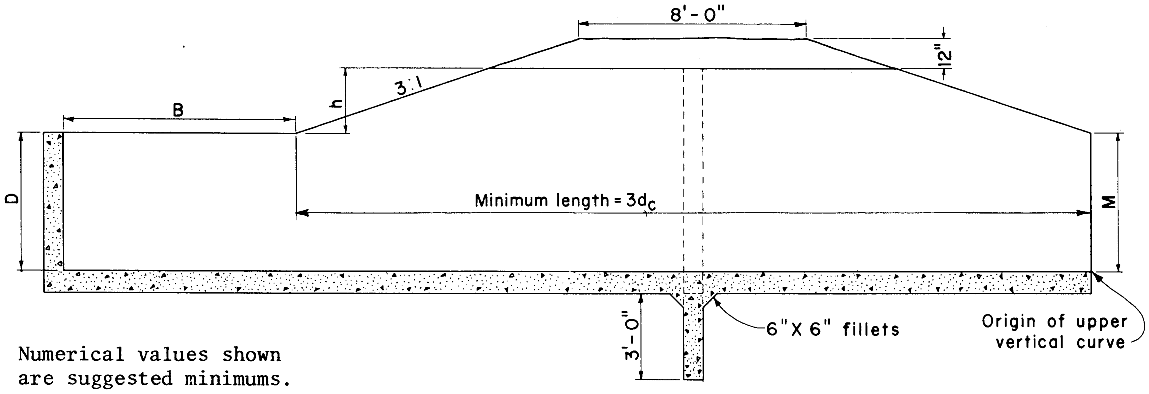


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-91 SHEET 24 OF 24 DATE 6-14-55

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



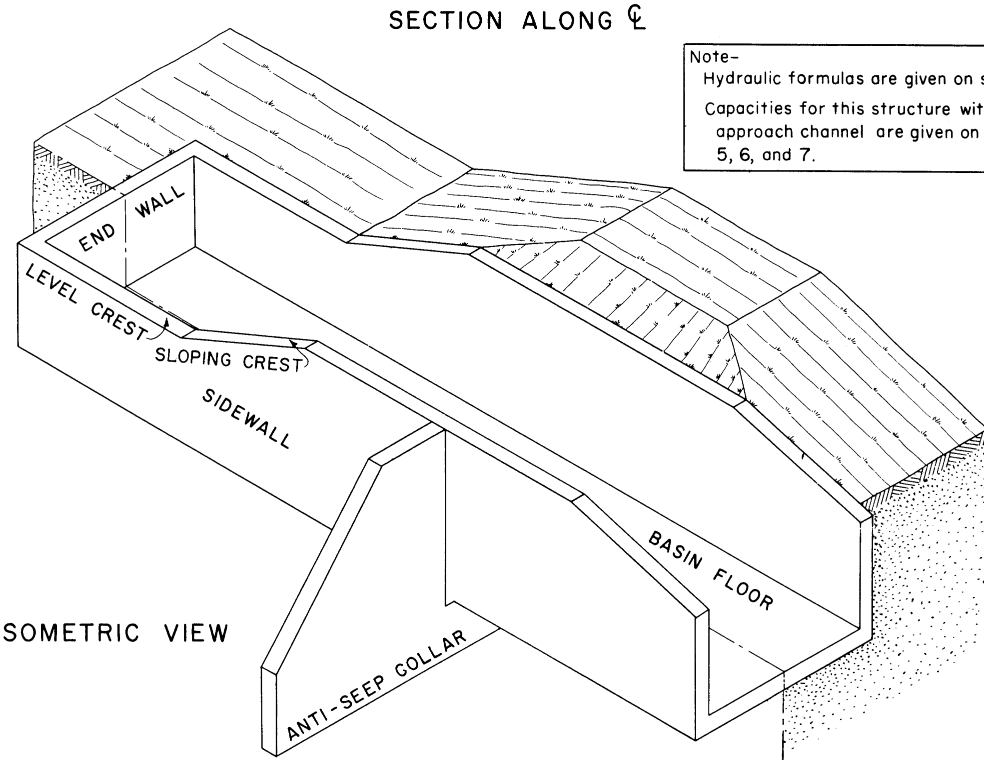
HALF – PLAN



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.

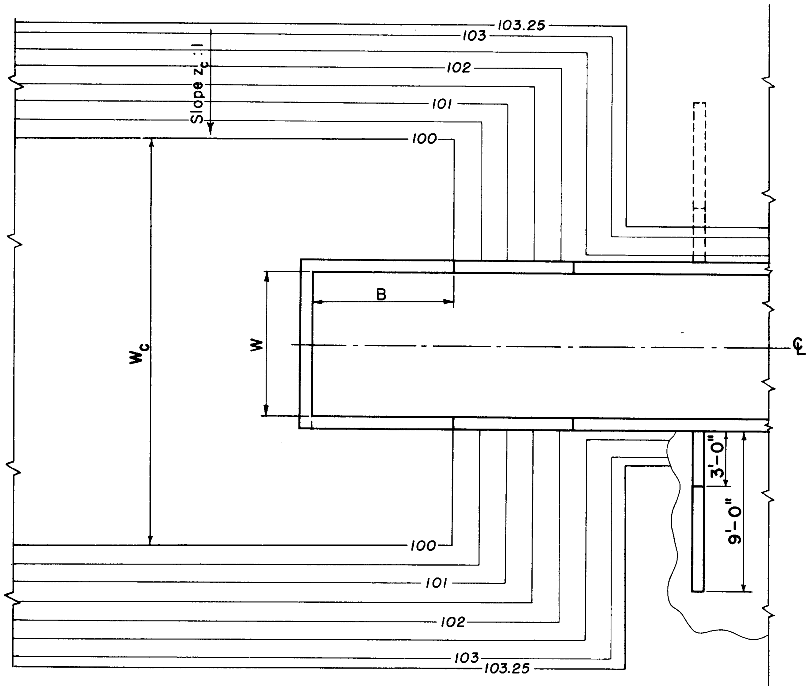


ISOMETRIC VIEW

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

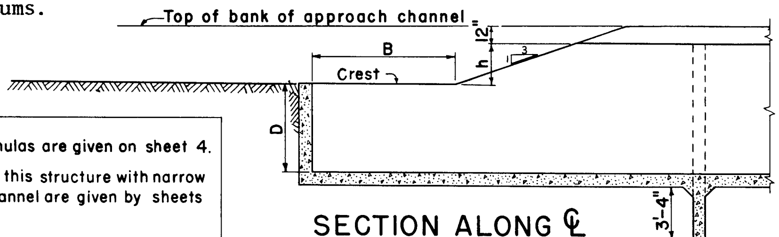
Revised 10/77

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



PLAN

Numerical values shown are suggested minimums.

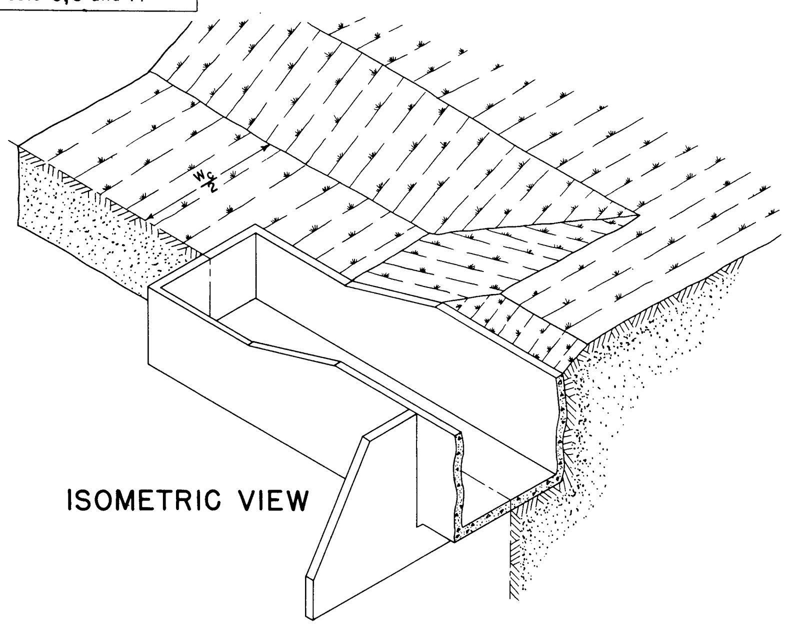


SECTION ALONG ℄

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

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

γ = Ratio $\frac{H_e}{W}$

δ = Ratio $\frac{D_r}{W}$

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 92 SHEET 3 OF 16 DATE 6-4-55

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

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

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

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

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

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

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

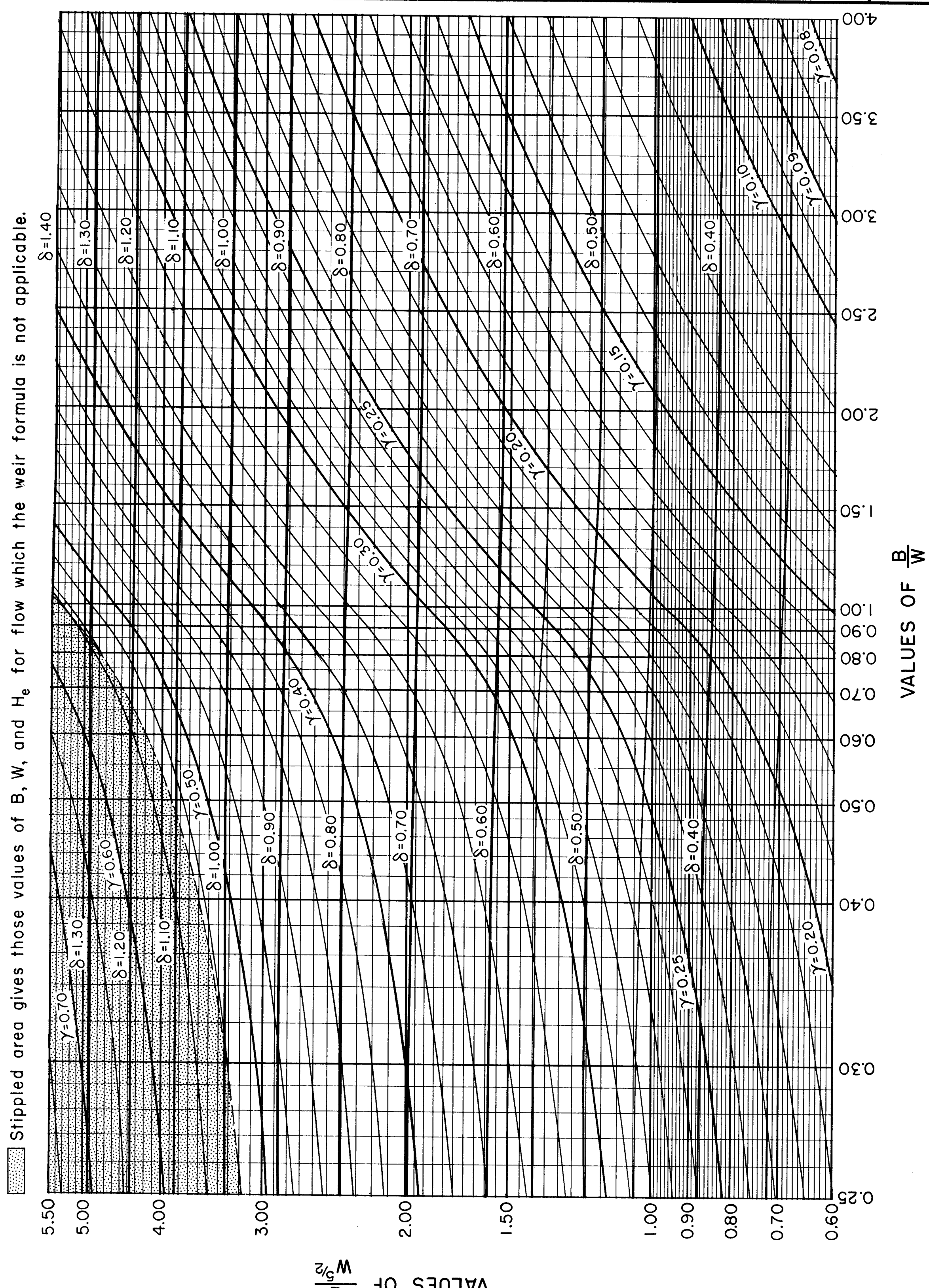
$$\kappa = \frac{W_c + 0.8\ z_c\ H_e}{W}$$

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 92 SHEET 4 OF 16 DATE 6-4-55

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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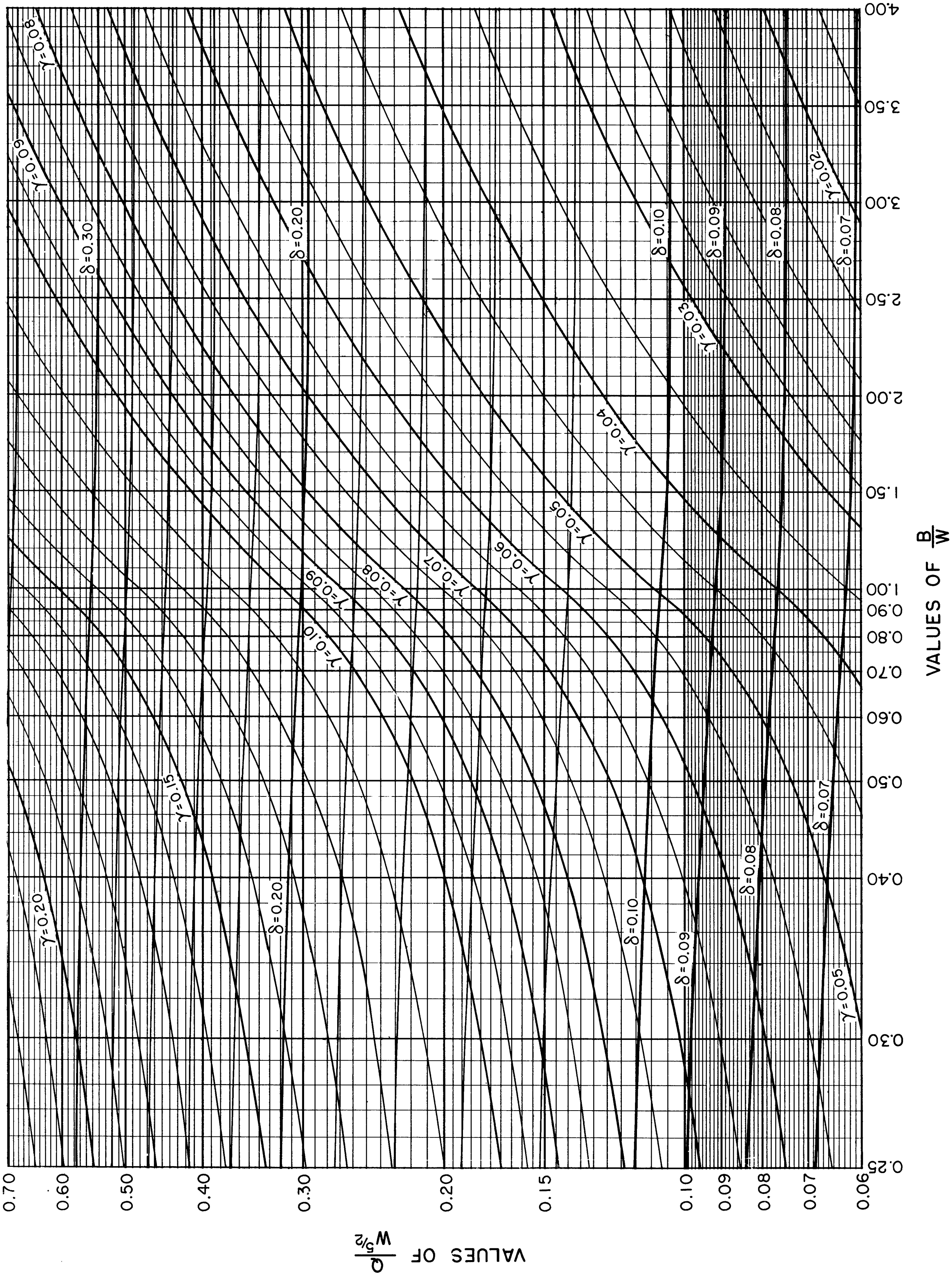
DATE 5-27-55

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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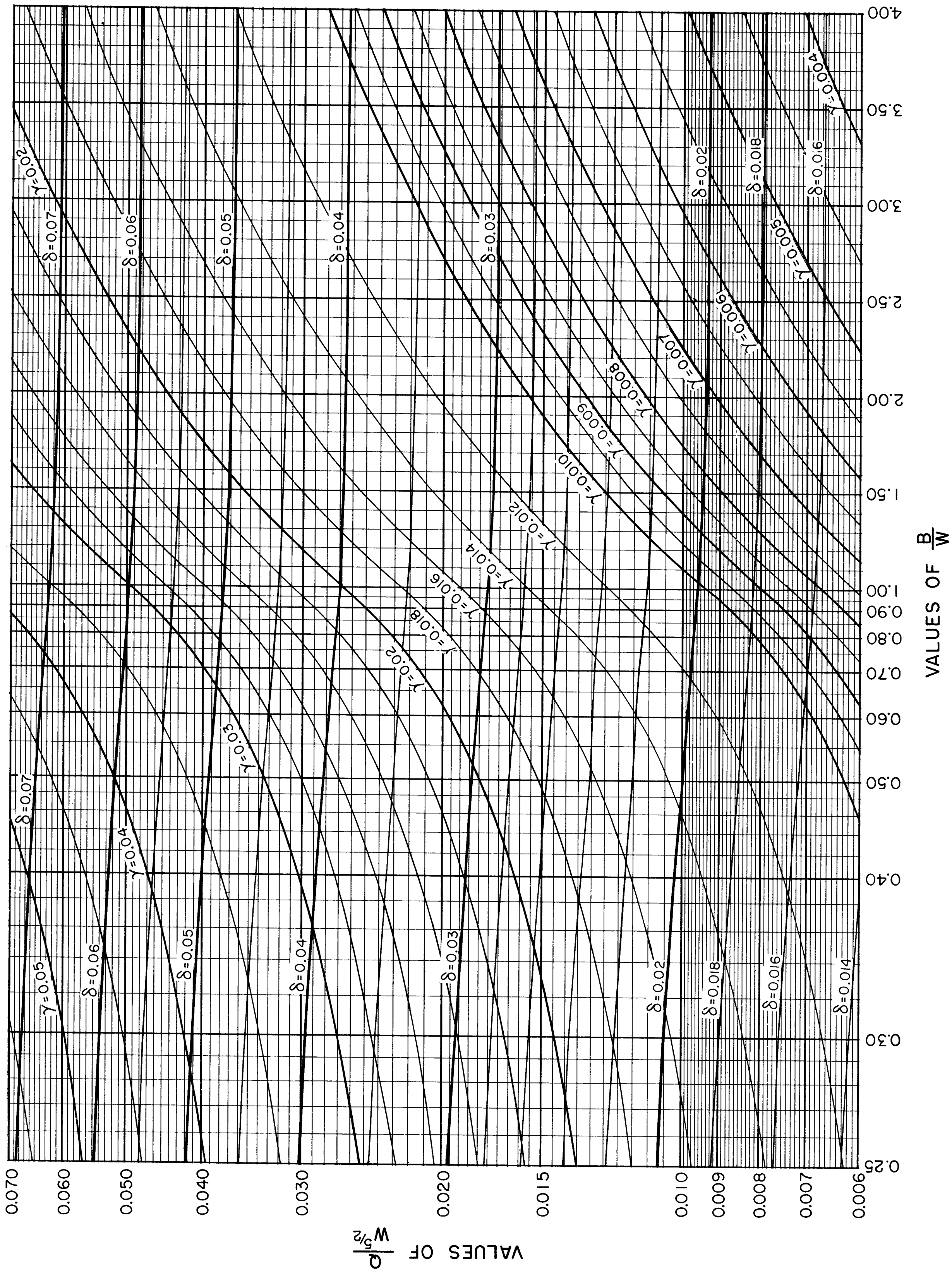
SHEET 6 OF 16
DATE 5-27-55

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, $z_o = 3:1$

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

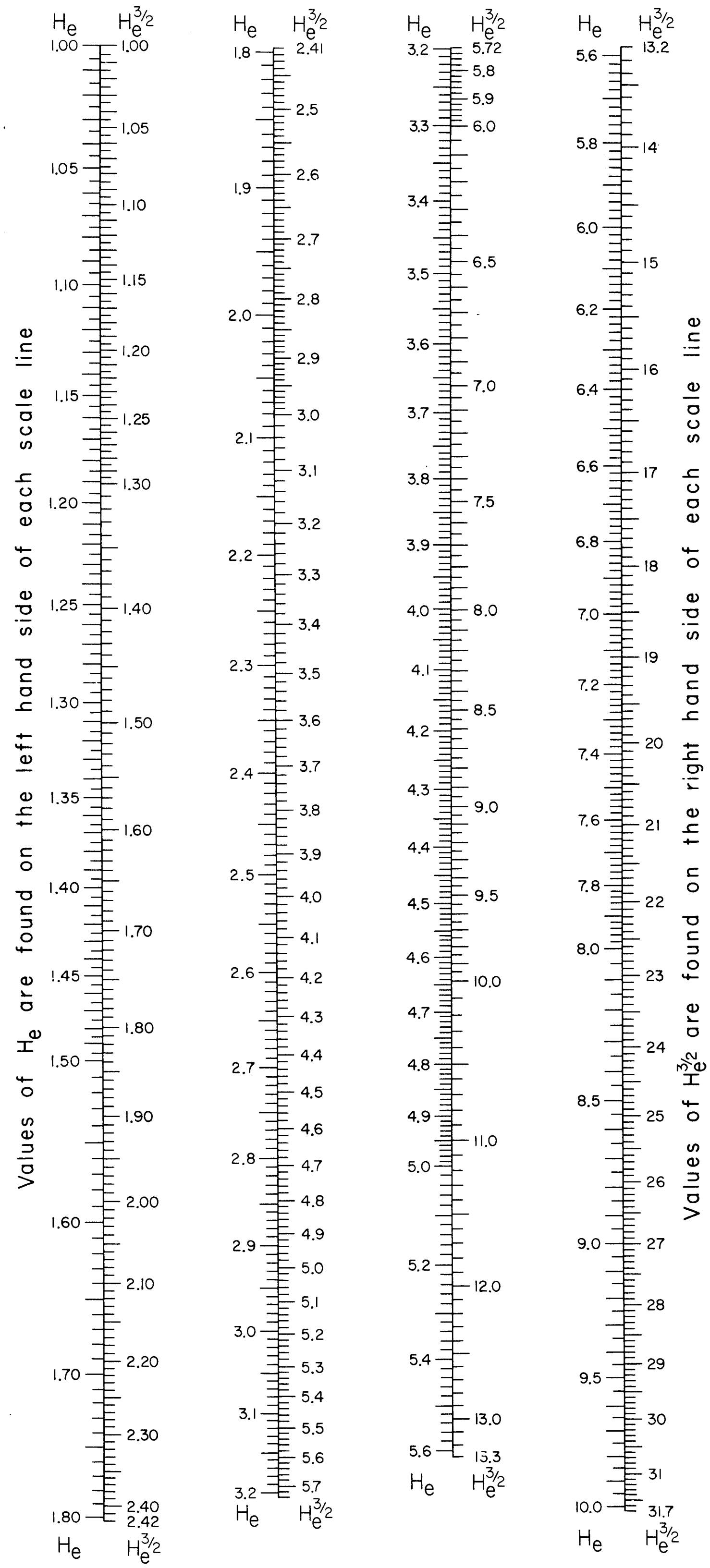
$\gamma = \frac{H_e}{W}$



REFERENCE This chart was developed by Paul D. Doubt of the Design Section.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-92 SHEET 7 OF 16 DATE 5-27-55

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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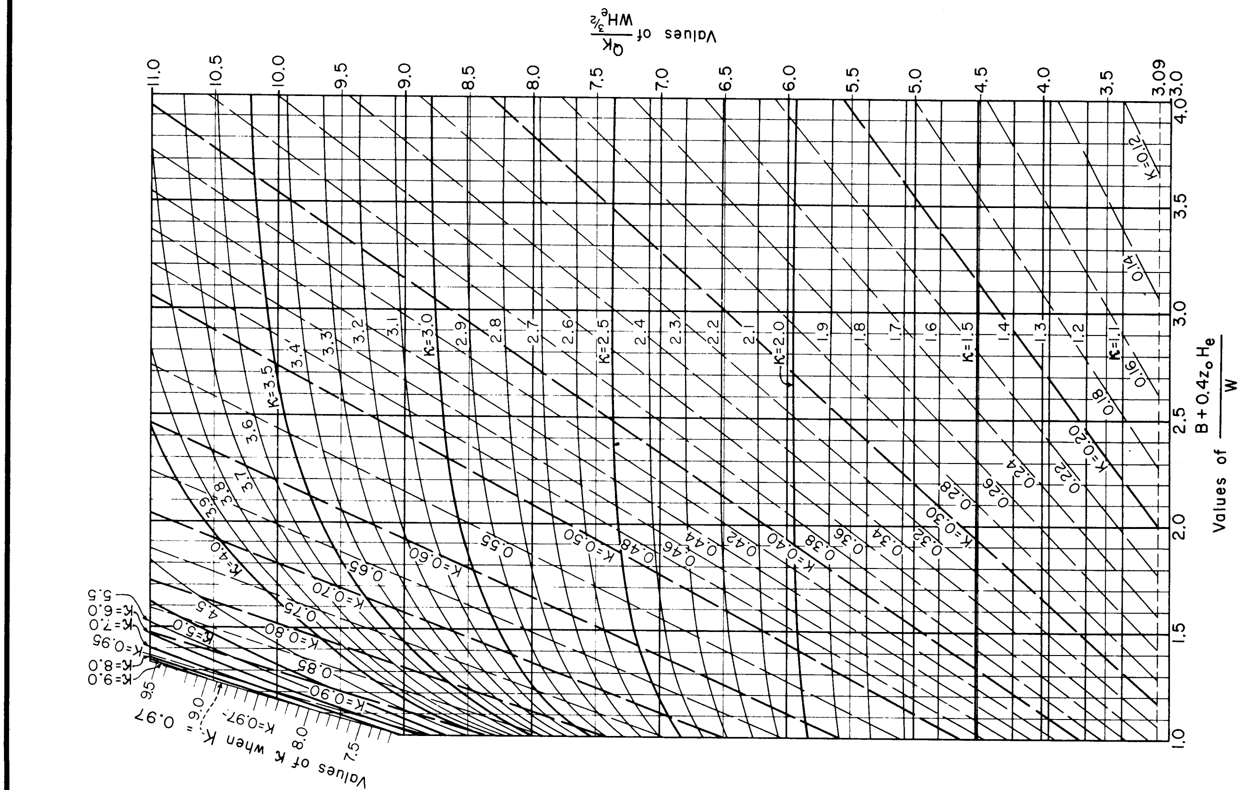
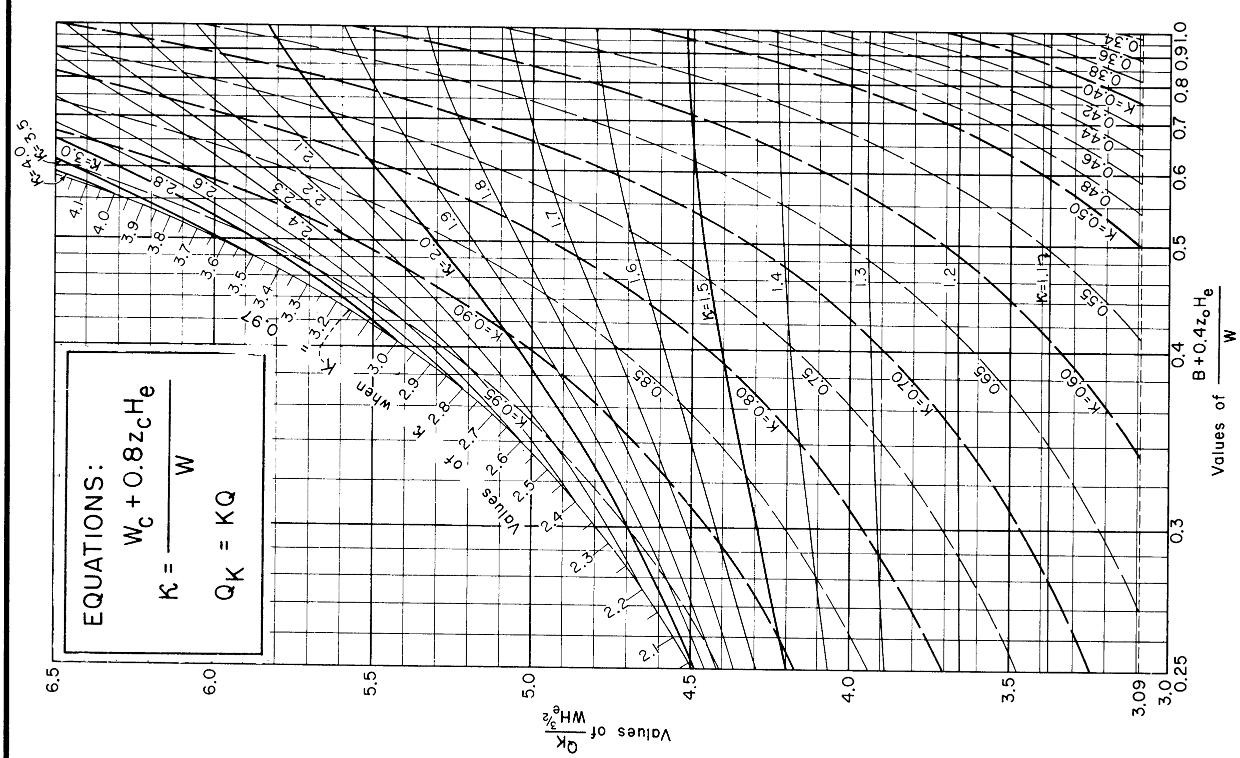
STANDARD DWG. NO.
ES-92
SHEET 8 OF 16
DATE 6-10-55

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.

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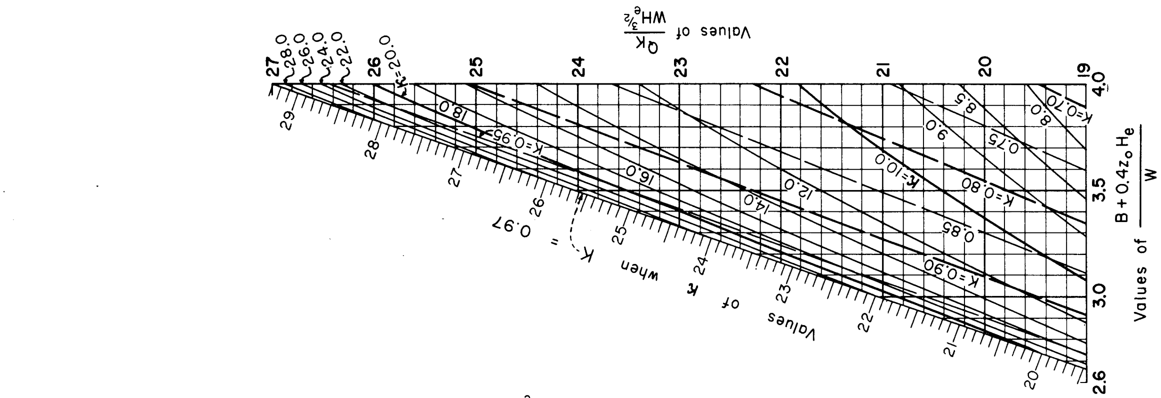
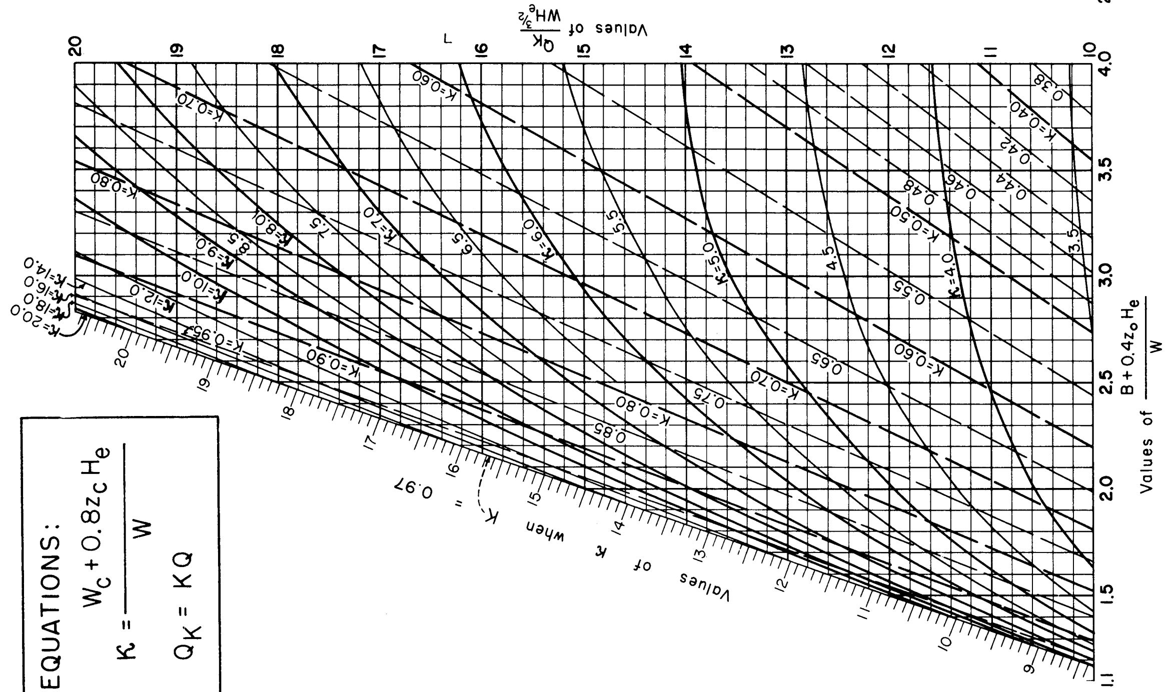
STANDARD DWG. NO.
ES- 92
SHEET 9 OF 16
DATE 5-20-55

CHUTE SPILLWAYS: FLAT-TRAPEZOIDAL WEIR BOX INLETS;

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

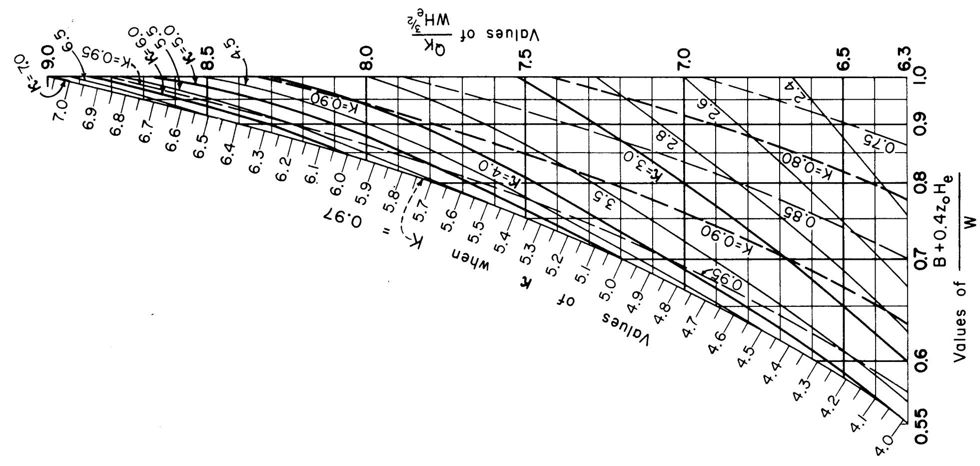




EQUATIONS:

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

$$Q_K = KQ$$



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

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STANDARD DWG. NO. ES-92
SHEET 10 OF 16
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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

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

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

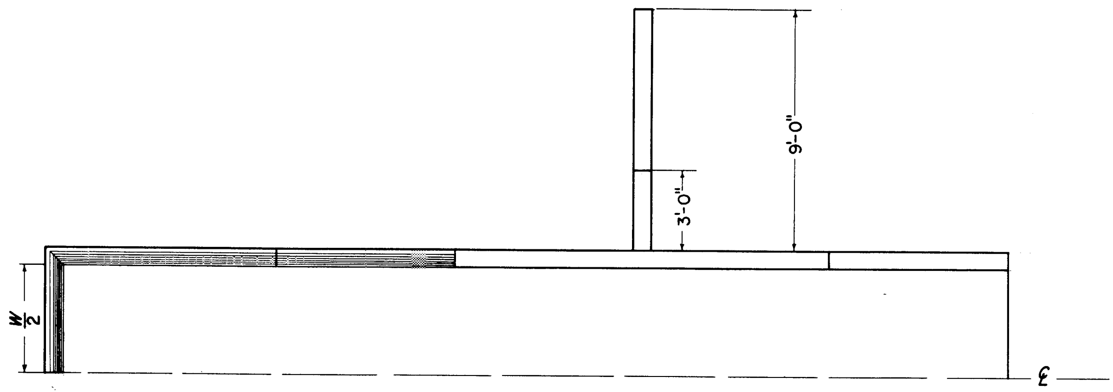
$$(Q_K)_{mh} = K\ (Q_{mh}) = 0.745\ (349) = 260\ \text{cfs}$$

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.

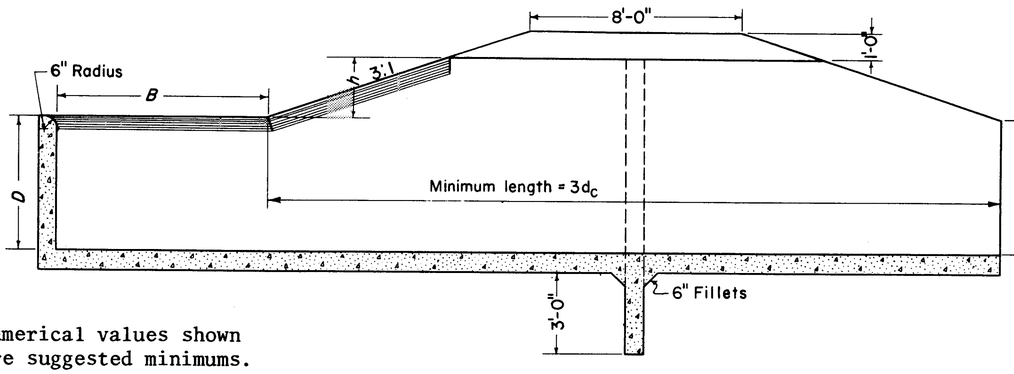
8. Solving for the capacity without freeboard of the box inlet $(Q_K)_{mi}$ considering the effect of the narrow channel and free-flow conditions. The value of $(Q_K)_{mi}$ is equal to the smaller of the values $(Q_K)_{mh}$ and Q_{mM}.

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

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



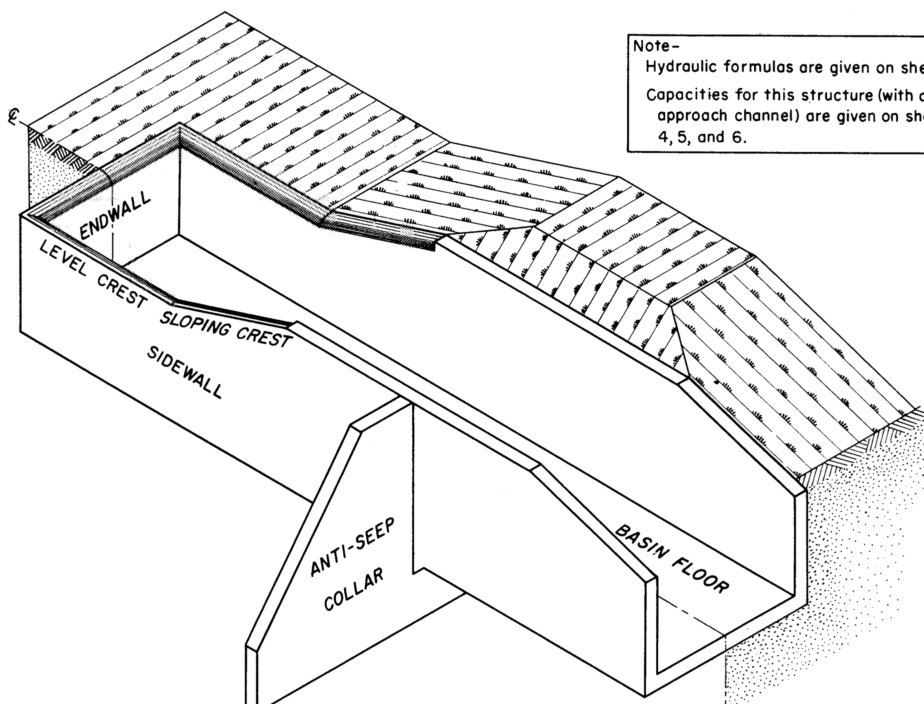
HALF PLAN



Numerical values shown are suggested minimums.

SECTION ALONG CENTER-LINE

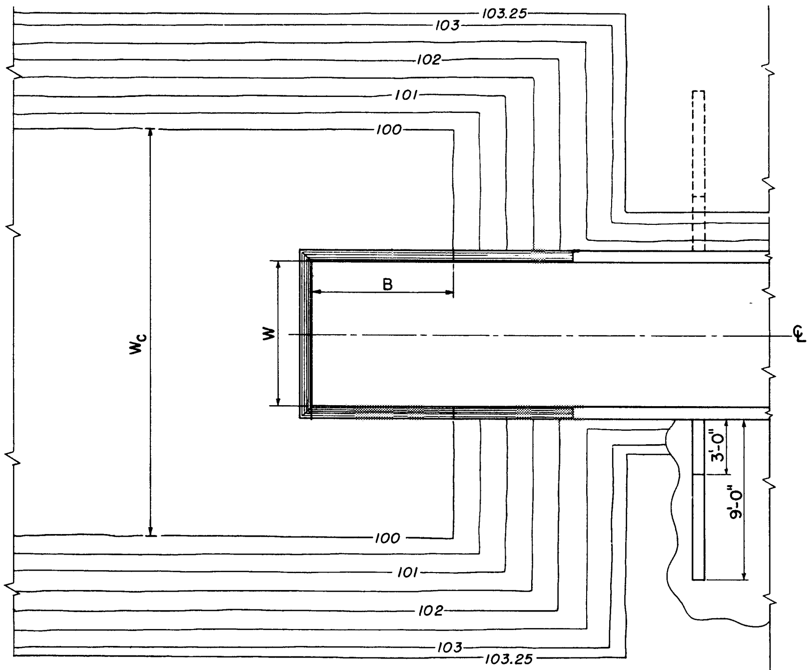
Note-
Hydraulic formulas are given on sheet 4.
Capacities for this structure (with a wide approach channel) are given on sheets 4, 5, and 6.



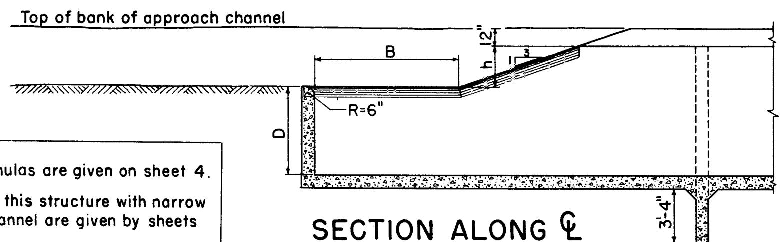
ISOMETRIC VIEW

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

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



PLAN



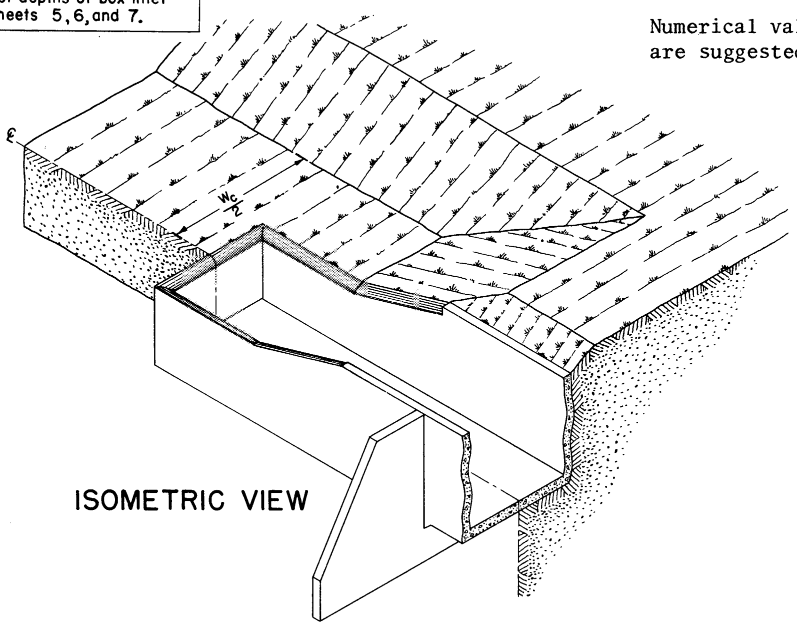
SECTION ALONG ℄

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 = $2B + W + 0.4 z_o H_e + 2$

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

$$Q_K = K\ Q$$

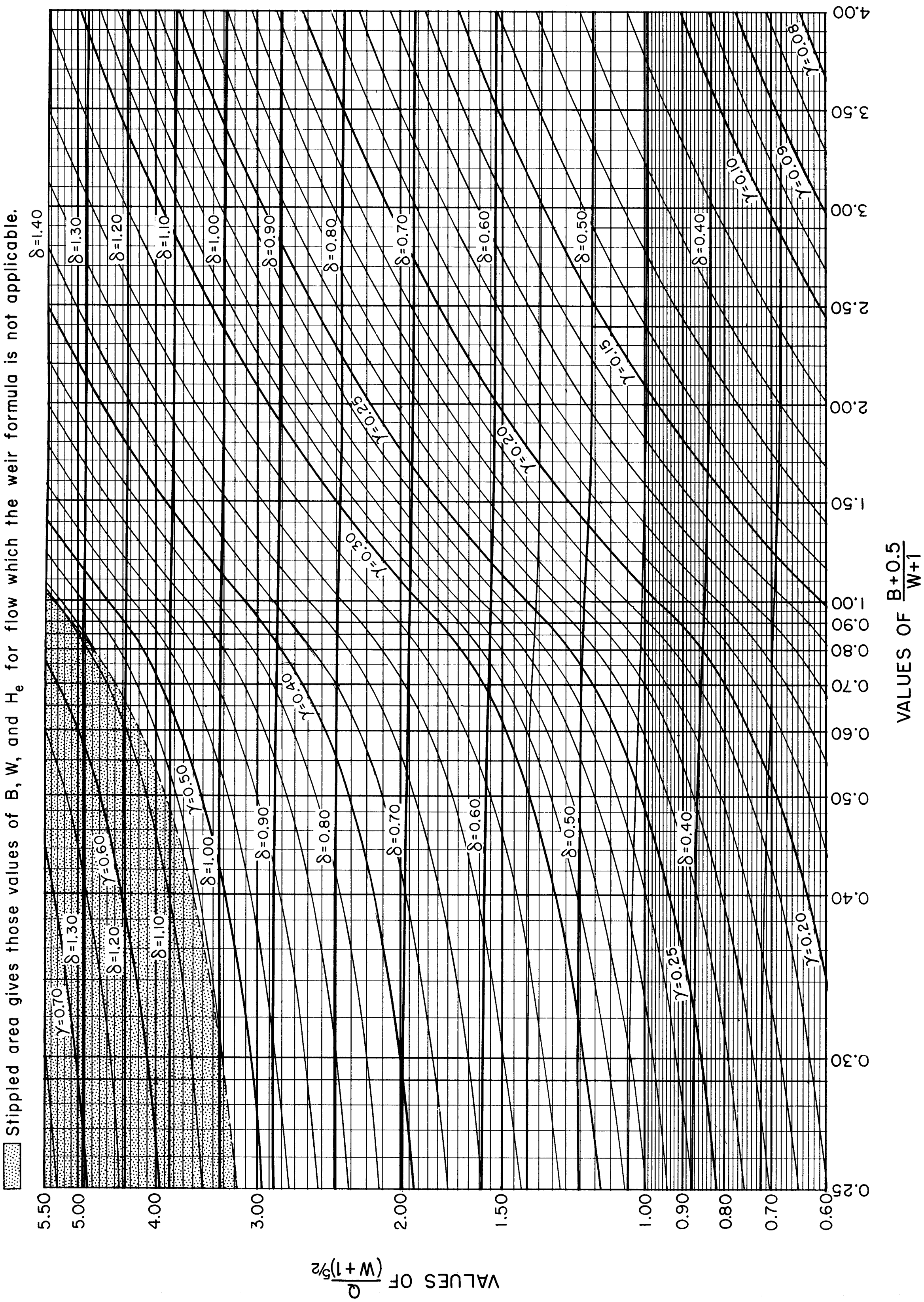
where the value of K is obtained from sheets 9 and 10. The value of Q_K may be obtained from sheets 9 and 10 without determining the value of K. The value of κ is

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

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, $z_o = 3:1$

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



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

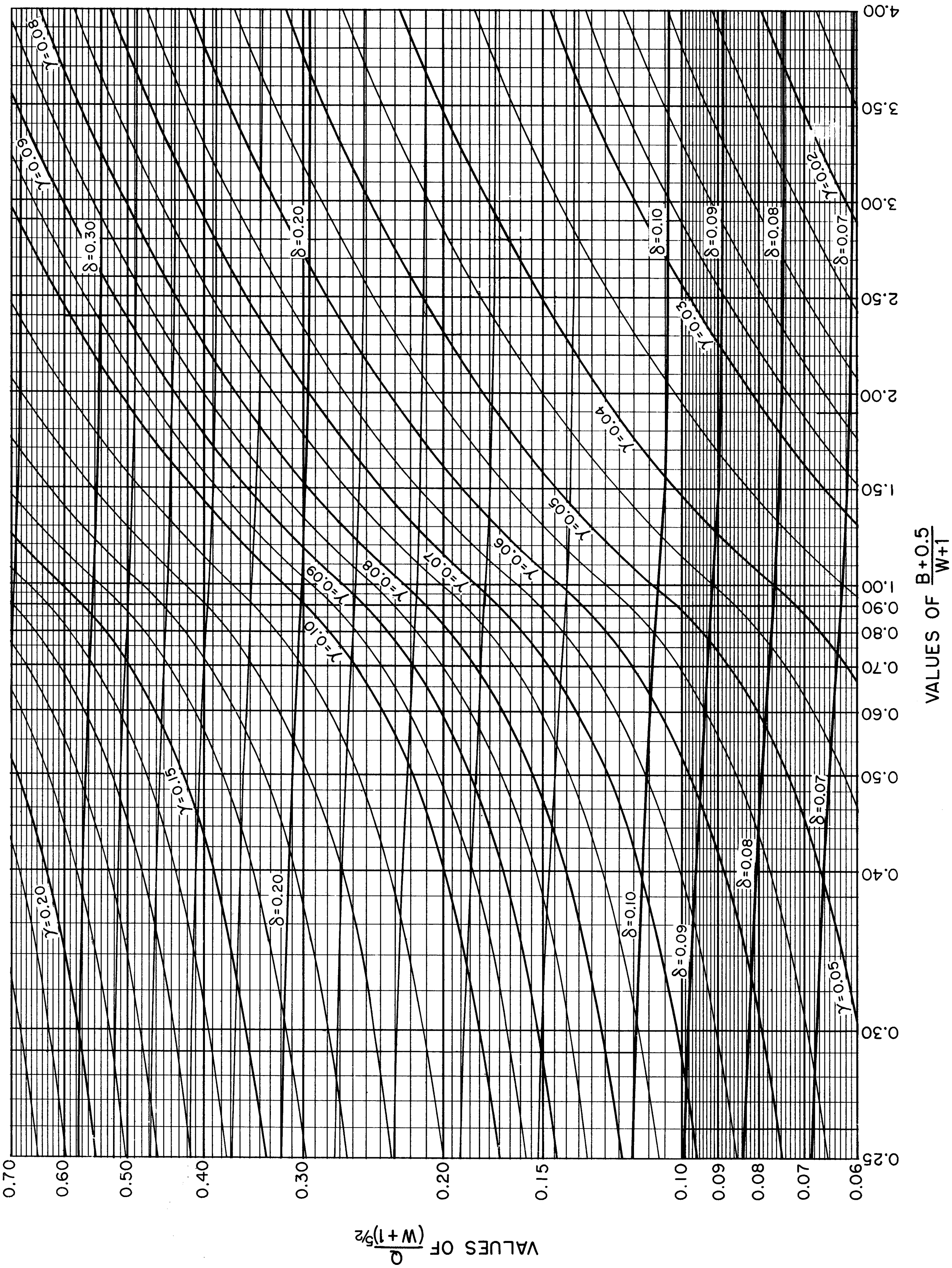
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

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

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

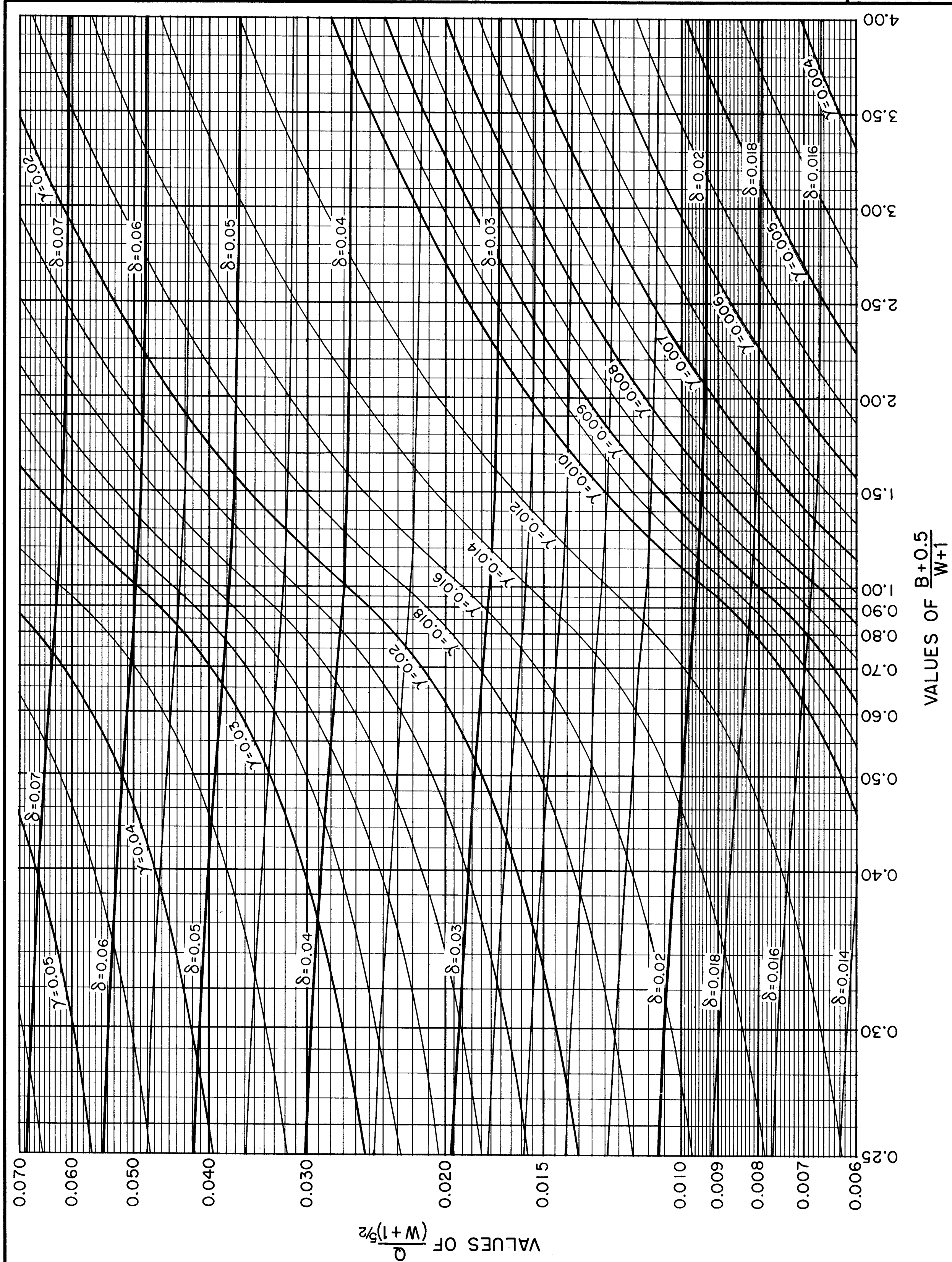
STANDARD DWG. NO. ES-93

SHEET 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, $z_o = 3:1$

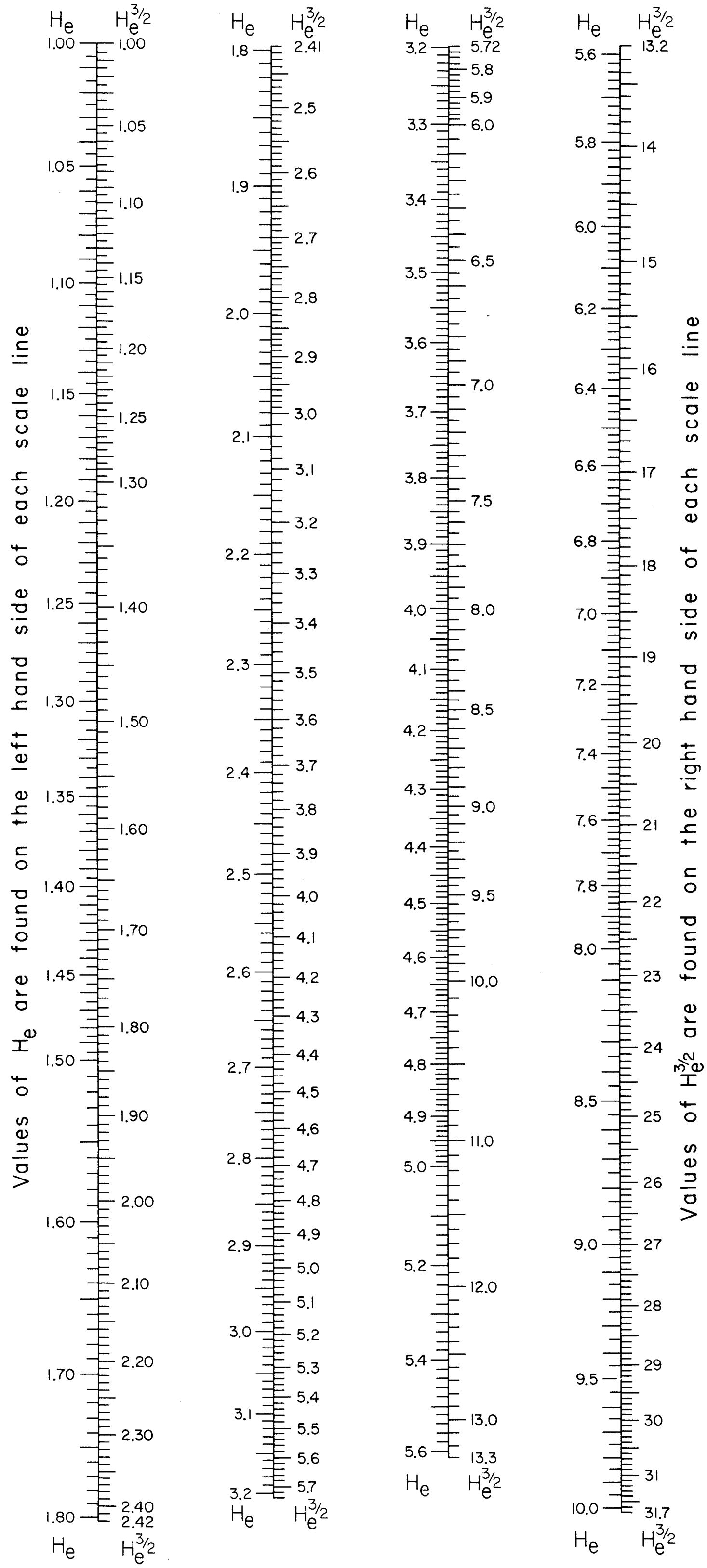
$$\delta = \frac{W^{2/3}}{(W+1)^{5/3}} D_r \qquad \gamma = \frac{H_e}{W+1}$$



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 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



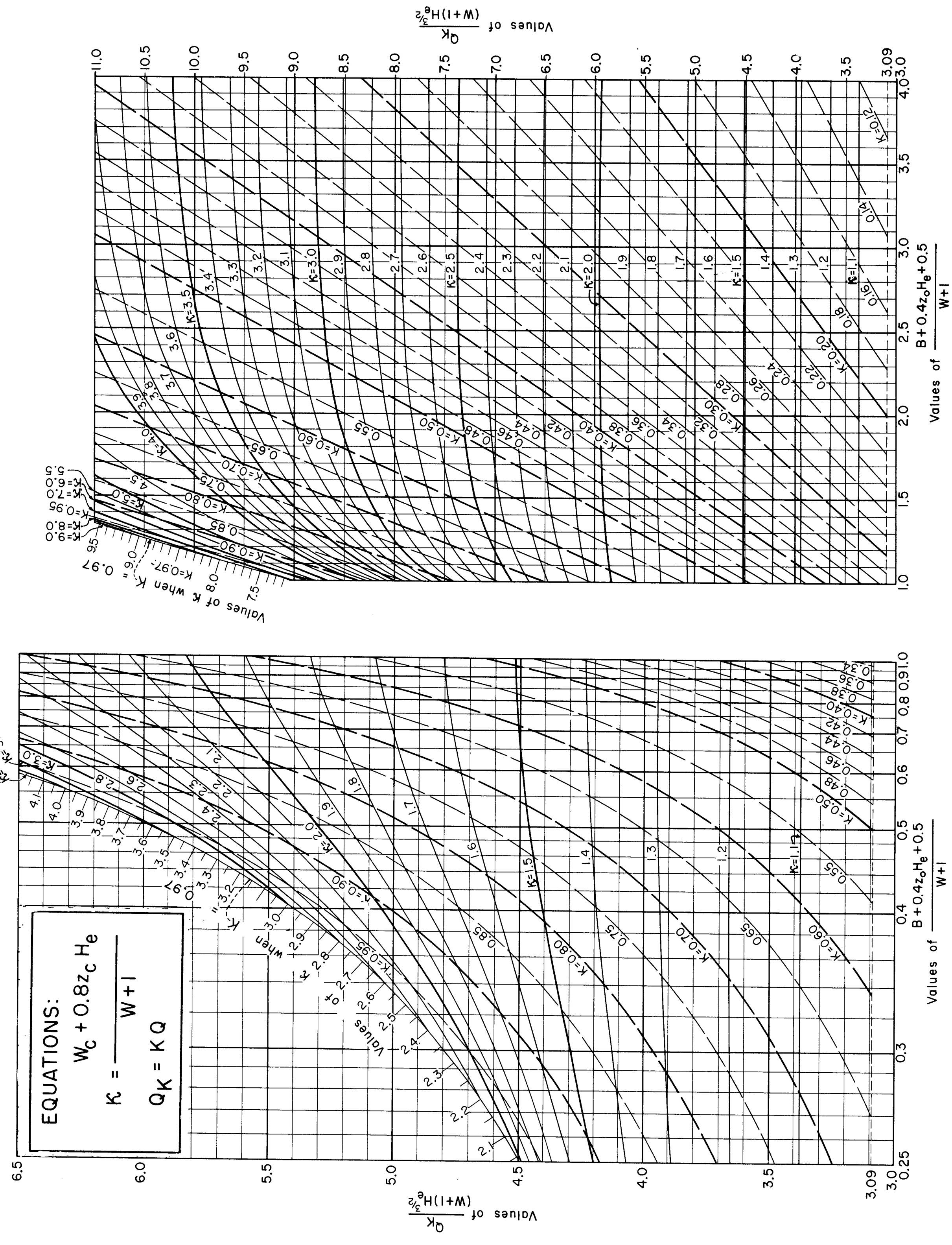
REFERENCE

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.



EQUATIONS:

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

$$Q_K = KQ$$

REFERENCE

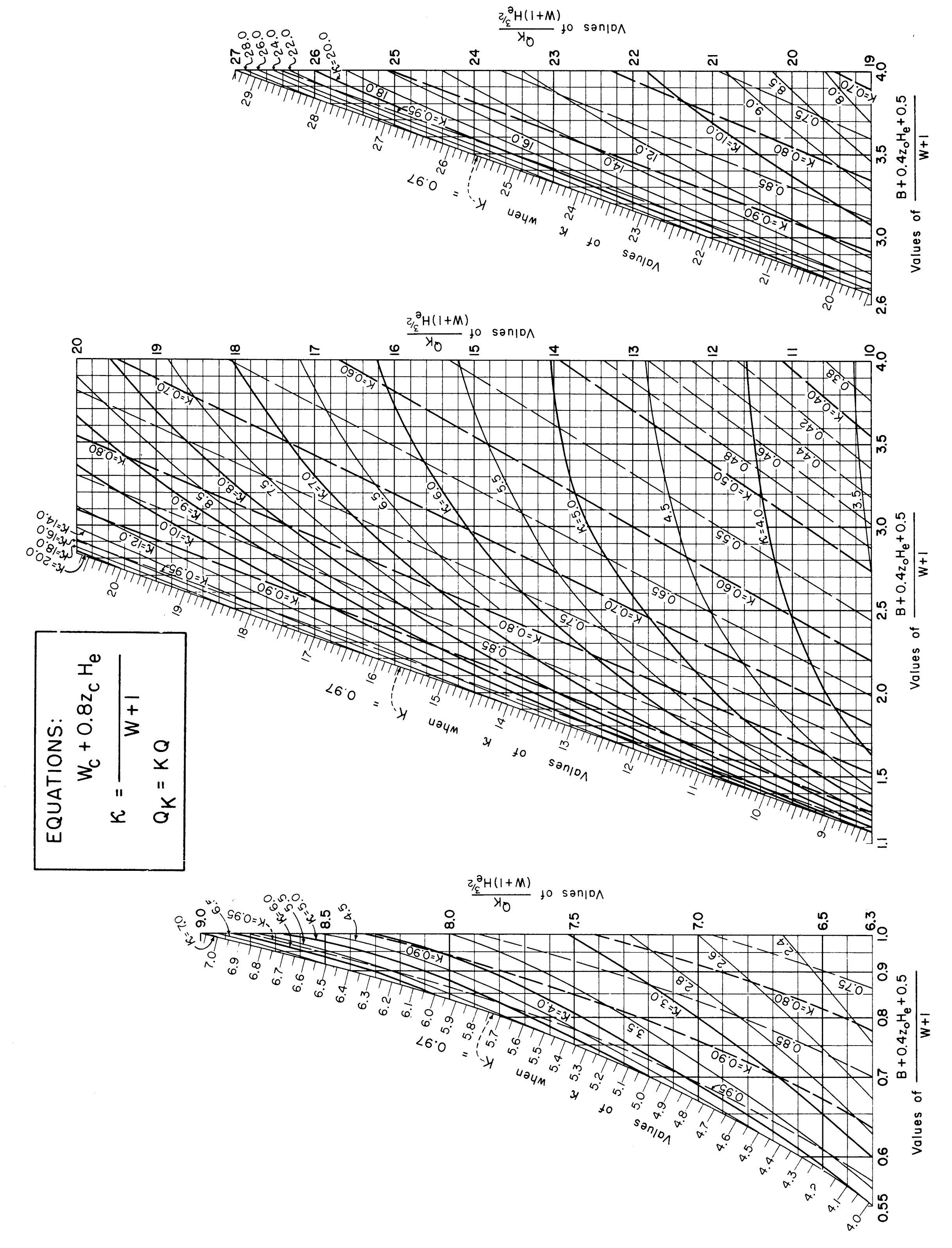
This chart was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES- 93
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.



EQUATIONS:

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

$$Q_K = KQ$$

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-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 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

$$\delta = \frac{W^{2/3}}{(W + 1)^{5/3}} D_r = 0.418 \quad \text{and} \quad D_r = \frac{\delta\ (W + 1)^{5/3}}{W^{2/3}} = \frac{0.418\ (9 + 1)^{5/3}}{9^{2/3}} = 4.48 \text{ ft}$$

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}.

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

Side-Channel Inlet. (See ES-85, page 2.114, for nomenclature.) Side-channel inlets are used only in those sites which require that the spillway be placed adjacent to or in a steep bank. The hydraulic theory of the side-channel inlet was first given by Julian Hinds.[1]

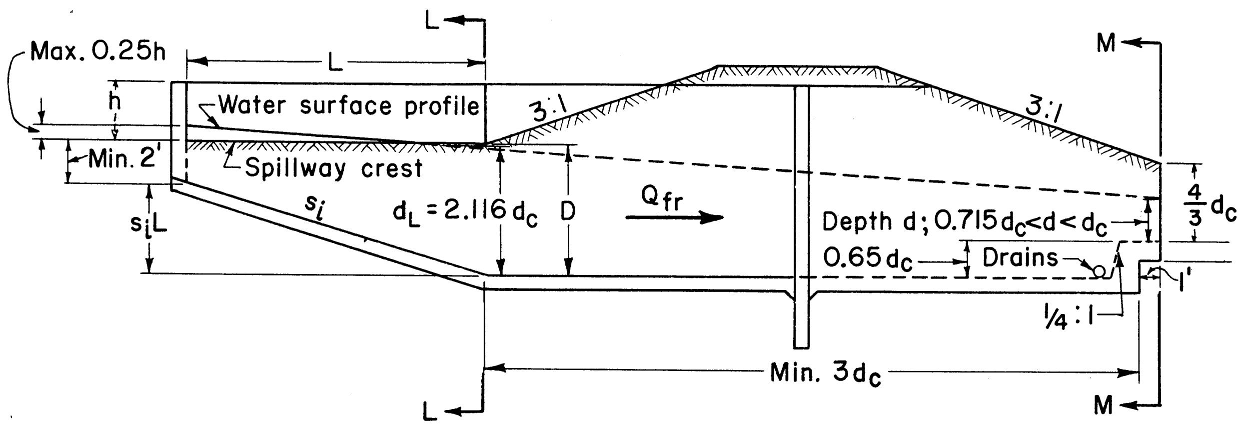


FIGURE 6

Arbitrarily designating the shape of the side-channel inlet to be rectangular removes the shape factor, which is generally decided by economic considerations. When the structure has small dimensions, the cost of a trapezoidal inlet is undoubtedly more than the simpler rectangular inlet, even though the rectangular inlet requires more concrete. Only a side-channel inlet having a rectangular shape is considered here.

The flow over the crest of a side-channel spillway is in a direction perpendicular to the axis of the inlet. (See Fig. 6.) The flow through the sections immediately below section L is very turbulent. The flow at section M will have acceptable velocity and discharge distribution if:[2]

a. A cross weir having a height of 0.65 d_c is placed at section M.
b. The prismatic channel has a level floor and a length of 3 d_c from section L to the cross weir.

The quantity d_c is that critical depth corresponding to the required capacity Q_{fr} at section M.

The depth of flow in the prismatic channel at section L can be determined by assuming the head losses due to friction and turbulence between section L and M. This depth is

$$d_L = 2.116\ d_c$$

[1]Side Channel Spillways, Trans. ASCE, Vol. 89, p. 881, 1926.

[2]From a composite study of existing model studies of side-channel spillways. Example; See Diversion, Outlet, and Spillway Structures; Boulder Canyon Project; Final Reports; Part IV; U. S. Bureau of Reclamation.

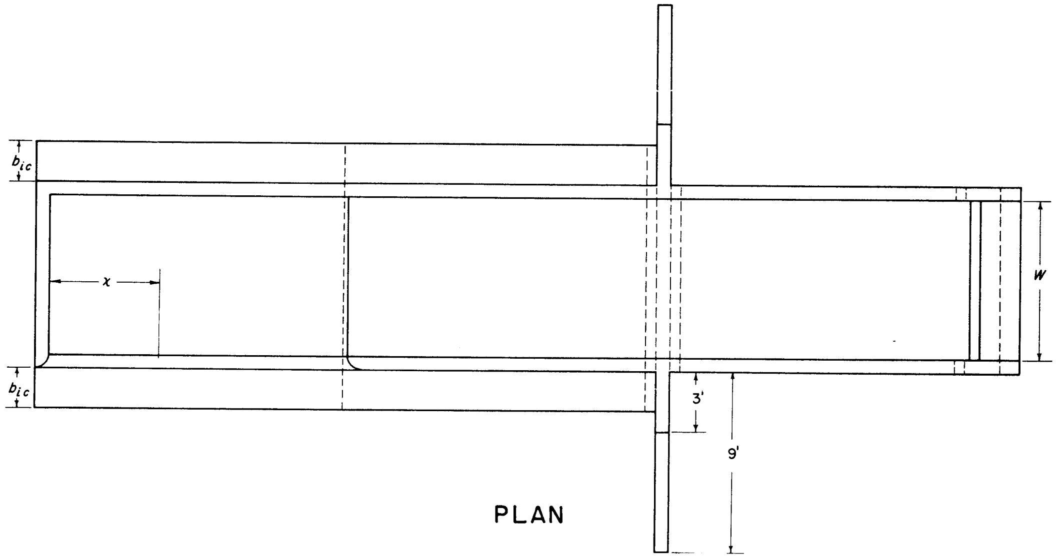
<u>Capacity</u>. The capacity without freeboard of a side-channel inlet is given by the weir formula:

$$Q_{mi} = 3.1\ L\ h^{3/2}$$

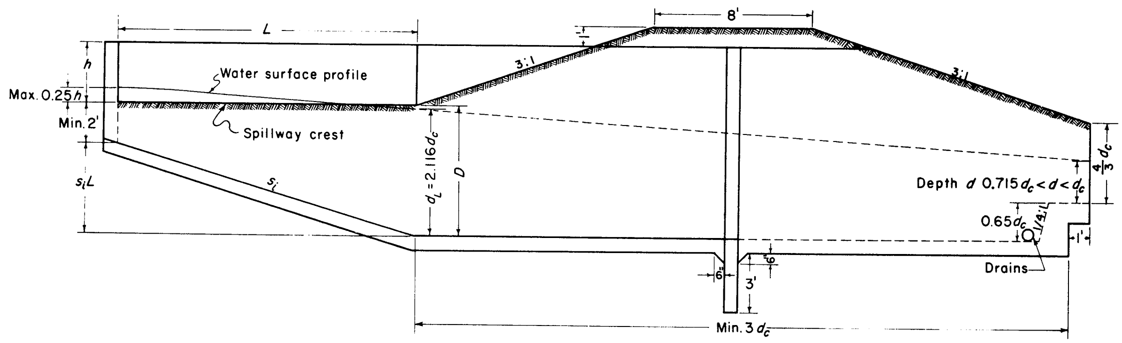
where Q_{mi} = capacity without freeboard in cfs
L = length of spillway crest in ft
h = height of sidewalls above the spillway crest in ft

The coefficient 3.1 is believed to be conservative and its use is based on the assumption that the crest at the endwall is not submerged by more than 0.25 h. The water-surface profile upstream from section L is given by ES-85, page 2.114. This profile is required to determine that depth of the inlet D to prevent a submergence of greater than 0.25 h at the endwall.

CHUTE SPILLWAYS: SIDE-CHANNEL INLETS; Layout

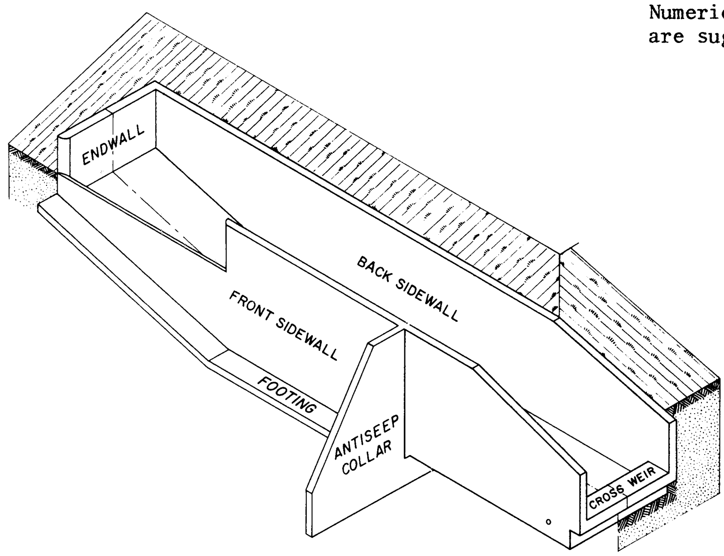


PLAN



SIDE ELEVATION

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-85 SHEET 1 OF 3 DATE MAY 1954

Revised 10/77

CHUTE SPILLWAYS : SIDE-CHANNEL INLETS ; Definitions, Formulas, Charts

DEFINITION OF SYMBOLS

- h = Height of sidewalls over crest in ft
- M = Height of sidewalls above cross weir at origin of upper vertical curve in ft
- W = Width of chute in ft
- L = Length of inlet crest in ft
- D = Height of inlet crest above floor of basin in ft
- d = Depth of flow in ft
- d_c = Critical depth corresponding to capacity without freeboard of inlet in inlet basin Q_{mi} in ft
- d_L = Depth of flow at section L of discharge Q_{mi} in ft
- x = Distance from endwall measured along inlet crest in ft
- e = Elevation of water surface in basin measured above level portion of basin floor in ft
- s_i = Slope of basin floor from x = 0 to x = L in ft/ft
- b_{ii} = Width of footing in ft
- Q_r = Design discharge in cfs
- Q_{fr} = Capacity without freeboard in cfs
- Q_{si} = Capacity of vertical curve section with the recommended freeboard in cfs

FORMULAS

$$Q = 3.1\ LH^{3/2}$$

$$\frac{d\left(\frac{d}{d_L}\right)}{d\left(\frac{x}{L}\right)} = \frac{K^3 - 2m\,\frac{x}{L}\,\frac{d}{d_L}}{\left(\frac{d}{d_L}\right)^3 - m\left(\frac{x}{L}\right)^2}\ ; \quad \text{where } m = \frac{d_c^{\,3}}{d_L^{\,3}} \quad \text{and} \quad K = \frac{Ls_i}{d_L}$$

CHARTS

CHART I.

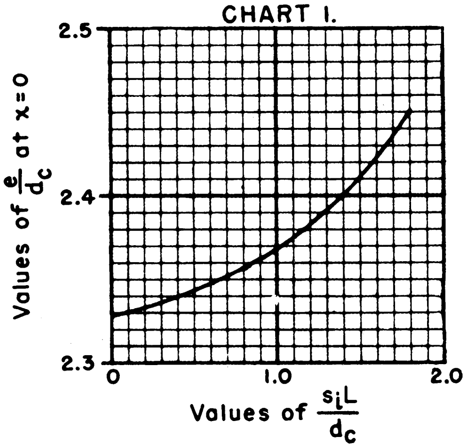
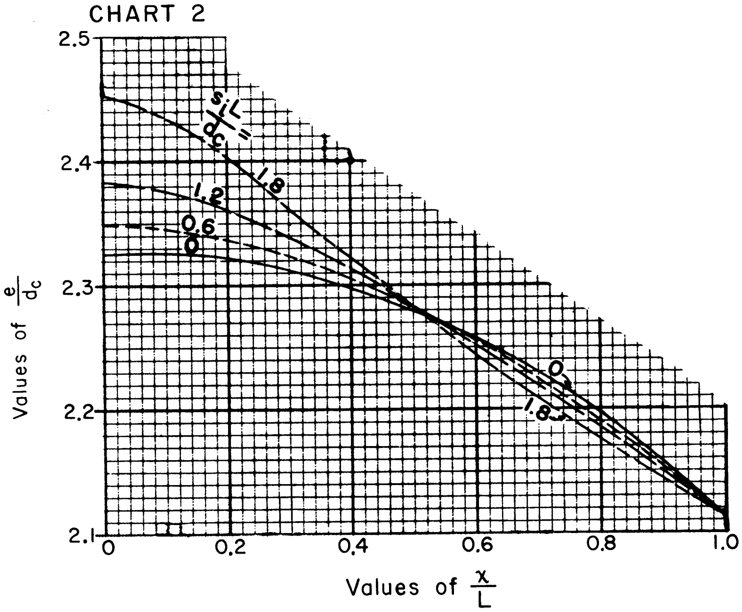


CHART 2



REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-85 SHEET 2 OF 3 DATE MAY 1954

CHUTE SPILLWAYS : SIDE-CHANNEL INLETS ; Example

Given: A chute 8 ft wide having a total drop from crest of side-channel inlet to floor of outlet of Z = 30 ft and a design discharge of Q_r = 180 cfs. The height of sidewalls h above the crest is 3 ft. No waves are anticipated.

Determine: 1. Required capacity of inlet without freeboard Q_{fr}.
2. Dimensions of side-channel inlet with the recommended freeboard using hydraulic criteria.
3. Approximate water-surface profile in the basin.

Solution: 1. $Q_{fr} = (1.20 + 0.003\ Z)Q_r$

$$= [(1.20 + (0.003)(30)] \ 180 = 232.2 \text{ cfs}$$

2. The value of critical depth d_c for the discharge 232.2 cfs is, from ES-24,

$$q_{fr} = \frac{232.2}{8} = 29.03\ ;\ d_c = 2.975 \text{ ft}$$

(a) The required length L of inlet crest having the recommended freeboard is

$$Q_{fr} = 3.1\ Lh^{3/2}$$

$$L = \frac{232.2}{3.1(3)^{3/2}} = 14.4\ ;\quad \text{take } L = 15 \text{ ft}$$

(b) Value of $M = \frac{4}{3} d_c$

$$M = \frac{4}{3} d_c = \frac{4}{3} \times 2.975 = 3.97 \text{ ft}\ ;\quad \text{take } M = 4 \text{ ft}$$

(c) Height of cross weir = 0.65 d_c

$$0.65\ d_c = 0.65(2.975) = 1.93 \text{ ft}$$

take height of cross weir = 2.00 ft

(d) The value of D is dependent, in part, on the value of s_i. Assume s_iL/d_c = 1.5, then the lower elevation of the water surface at x = 0; see chart 1 is 2.41 d_c or

$$e = 2.41 \times 2.975 = 7.17 \text{ ft}\ ;\quad \text{take } e = 7.25 \text{ ft}$$

$$s_iL = 1.5 \times 2.975 = 4.46 \text{ ft}\ ;\quad \text{take } s_iL = 4.50 \text{ ft}$$

Since the maximum submergence at x = 0 is h/4 = 0.75 ft, this will make

$$D = e - \frac{h}{4} = 7.25 - 0.75 = 6.50 \text{ ft}$$

and

$$D - s_iL = 6.50 - 4.50 = 2.0 \text{ ft min.}$$

3. From chart 2 and interpolating for the line s_iL/d_c = 1.5 between the the given lines s_iL/d_c = 1.2 and 1.8, the approximate water surface profile is readily defined.

VERTICAL CURVE SECTION

Function of Vertical Curve Section. (See ES-88, page 2.125, for nomenclature.) The explicit function of the vertical curve section is to convey and guide all discharges of water less than the design discharge with a recommended freeboard from a channel of one bottom slope to a channel having a different bottom slope in a manner which

a. provides positive bed pressures
b. will not cause any appreciable waves in the steeply-sloped channel.

Flow in a channel having a bottom slope which increases in the downstream direction will exert a pressure on the channel bottom (or bed) less than the depth of flow above the bed. When the rate of change in the bottom slope is sufficiently great, negative pressure will exist on the bed. Negative bed pressures indicate the flow springs free of the channel bottom. It also indicates an upward force is applied against the channel bottom. Both of these effects are undesirable. Flow springing free of the channel bottom can cause unacceptable flow conditions downstream by impinging back onto the channel bottom. Further, flow springing free of the channel bed may cause overtopping of the channel sidewalls. The force created by the negative pressure can be so large that structural failure occurs from uplift of channel or of the channel bottom.

The vertical curve sections considered will be rectangular with straight, parallel sidewalls to insure favorable velocity and discharge distributions.

The top edges of the sidewalls are designed to be flush with the embankment slope. (See Fig. 7b, page 2.119.) In most instances, this requires that a vertical curve be constructed at each end of the vertical curve section. Vertical curve sections having their top edge on a slope of 3 to 1 and capable of conveying a discharge without freeboard q_{mv} equal to or less than 20.196 cfs/ft do not require a lower vertical curve. Requiring the top edge of the sidewall to be flush with the embankment as shown by Fig. 7b usually will require the inlet to be of shorter length and the vertical curve section longer than for a structure with a vertical curve as shown by Fig. 7a.

Vertical Curve Used to Change a Channel Bottom of Zero Slope to a Slope s_v (Upper Vertical Curve). The momentum theorem gives the horizontal velocity v_M of flow over a broad crested weir as

$$v_M = \frac{3}{2} v_c \qquad 5.1$$

where v_c = critical velocity of the discharge in the weir section in ft/sec

The actual horizontal velocity of flow over a broad-crested weir is lower than the velocity v_M given by Eq. 5.1. A vertical curve for a particle of water in the surface of the lower nappe and having a velocity of v_M can be deduced from the theory of free-falling bodies.

Equation 5.2 gives the equation of the upper vertical curve in the vertical curve section when the origin is at the TC of the curve. (See ES-88, page 2.134.) Coordinates for the vertical curve as defined by Eq. 5.2 are given in Table A. This vertical curve is satisfactory for all discharges having a critical depth of 8 ft or less and is used to convey flow from zero slope to a slope of s_v.

$$y = \frac{x^2}{36} \qquad 5.2$$

where y = vertical distance from the origin to any point on the upper vertical curve in ft

x = horizontal distance from the origin to any point on the upper vertical curve in ft

A set of values of x and y are given in Table A, ES-88, page 2.134. The values are applicable for any slope s_o as the discharge is less than that corresponding to $d_c = 8$ ft; i.e., $q < 128.5$ cfs/ft.

The coordinates of the points x_1 and y_1 at which the upper vertical curve has a slope of s_v are

$$x_1 = 18\ s_v$$
$$y_1 = 9\ s_v^2 \qquad 5.3$$

where s_v = slope of the bed of the vertical curve section ft/ft. (See next paragraph for method of determining this value.)

y_1 = vertical distance from the origin to the end of upper vertical curve in ft

x_1 = horizontal distance from the origin to the end of upper vertical curve in ft

The coordinates x_1 and y_1 give the dimensions from the origin to the downstream end of the upstream vertical curve. These values are tabulated in Table 3b, ES-88, page 2.126, when $s_o = 1/3$.

<u>Slope s_v of bottom of vertical curve section connecting the upper and lower vertical curves</u> is given by the solution of the quadratic equation

$$16\ s_o\ s_v^2 + \left[M + z - N \sec(\tan^{-1} s_o) - 50\ s_o^2\right] s_v + s_o\,(25\ s_o^2 - z) = 0$$

When s_v is imaginary, no vertical curve is required and the bottom slope becomes equal to s_o. Values of s_v may be read from Table 3b, ES-88, page 2.126, when $s_o = 1/3$.

Values of x_2 and y_2 (see ES-88, page 2.125, for definition) are given by the equations

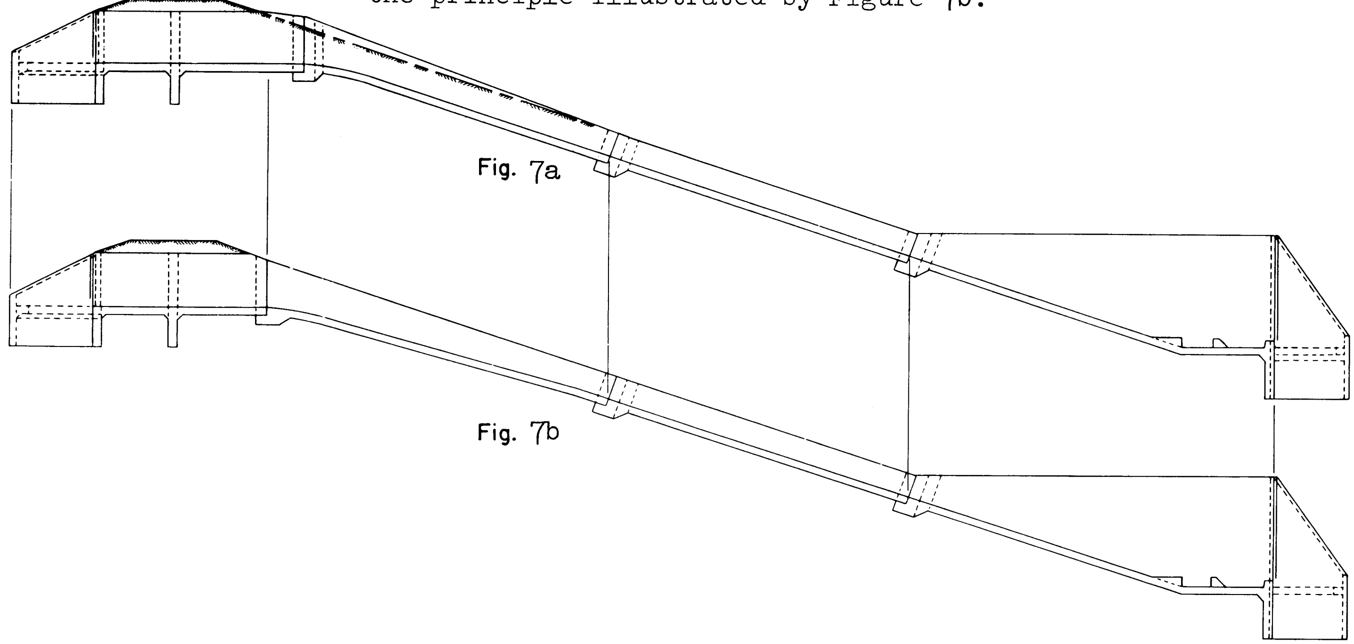
$$x_2 = \frac{1}{s_o}\left[M + z - N \sec(\tan^{-1} s_o)\right] - 50\ s_o + 32\ s_v$$

$$y_2 = z + 16\ s_v^2 - 25\ s_o^2$$

Values of x_2 and y_2 for channel bottoms having 3 to 1 slope may be read from Table 3b, ES-88, page 2.126.

NOTE--

Figure 7b shows chute spillway having its top edge of sidewalls of channel and vertical curve straight and flush with the embankment. Figure 7a shows a chute spillway with a bottom slope s_o of the channel and lower portion of the vertical curve section parallel to the embankment slope. Observe how the top edge of the vertical curve section in Figure 7a projects above the embankment and has a vertical curve section shorter than that of Figure 7b but an inlet longer than that shown in Figure 7b. In some instances Figure 7b has a vertical curve at the downstream end of the vertical curve section. Figure 7a does not require such a vertical curve. Drawing ES-88 is based on the principle illustrated by Figure 7b.



Comparison of a chute position in an embankment obtained by (a) fixing the bottom slope of the channel and vertical curve section to be parallel to the embankment slope and (b) fixing the top edge of the sidewalls parallel (and flush) with the embankment.

FIGURE 7

Vertical Curve Used to Change a Channel Bottom of Slope s_v to Slope of s_o (Lower Vertical Curve). The lower vertical curve is also deduced from the theory of free falling bodies. Equation 5.4 gives the coordinates of the lower vertical curve in vertical curve sections when the origin is at the TC of the curve. This vertical curve is satisfactory for changing bottom slopes from s_v to any other greater slope for all discharges having a velocity less than 40 ft/sec. It is also satisfactory for all discharges which have critical depths less than 8 ft provided the lower end of this vertical curve is a distance z of 8 ft or less below the floor of the inlet.

$$y = 0.01\ x^2 + s_v\ x \qquad 5.4$$

where y = vertical distance from the origin to any point on the lower vertical curve in ft

x = horizontal distance from the origin to any point on the lower vertical curve in ft

s_v = slope of the floor of the vertical curve section at the origin of the lower vertical curve in ft/ft

Values of the coordinates x and y of the lower vertical curve may be obtained from pages 2.135, 2.136, and 2.137 of ES-88. Values of x_3 and y_3 for any channel slope are

$$x_3 = 50\ (s_o - s_v)$$

$$y_3 = 25\ (s_o^2 - s_v^2)$$

Values of x_3 and y_3 for chutes having 3 to 1 slope may be read from Table 3b, ES-88, page 2.126.

Replacement of Vertical Curves by Straight Chords. Drawing ES-88, page 2.124, shows the replacement of vertical curves by straight chords. Values of x_1, x_2, x_3, y_1, y_2, y_3, and s_v may be determined by the preceding paragraphs. Vertical curves will provide better flow conditions than straight chords.

The associated values of z, M, N, R, x_1, x_2, x_3, y_1, y_2, y_3, s_v, and q_{mv} for vertical curve sections having the top of their sidewalls on a slope of 3 to 1 are given in Tables 3a and 3b, ES-88, pages 2.125 and 2.126. These values are for vertical curve sections used to convey water from a horizontal bottom channel to a channel having a 3 to 1 slope. The general formulas to determine the value of x_1, x_2, x_3, y_1, y_2, y_3, and s_v for any value of M, N, s_o, and z are given by ES-88, page 2.134. These formulas will give satisfactory vertical curves provided the restrictions noted in the preceding paragraphs are satisfied.

Freeboard at any section in the vertical curve section is the difference in the normal height of the sidewall above the floor and the perpendicular depth of flow of the design discharge Q_r. It is measured in feet and is a safety factor to prevent overtopping of the sidewall as a result of several factors. These factors include wave action, incorrect evaluation of air entrainment (see page 2.139) and depth of flow, or a larger discharge than anticipated.

The information available to the design engineer to determine the depth of flow for a given discharge in a steep channel is meager. The presence of small waves even with good velocity and discharge distribution is likely. Because of these facts, a slightly greater factor of safety to prevent overtopping will be recommended for vertical curve sections and steep channels than was recommended for inlets.

The recommended freeboard at any section in the vertical curve section is given in terms of an increased discharge Q_{fr} and a recommended height of sidewall 4/3 times the depth of flow for the discharge Q_{fr} derived by not considering air entrainment. The recommended sidewall height at section M is $4\ d_c/3$ where d_c is the critical depth corresponding to the discharge Q_{fr}. This recommendation gives a more positive assurance that the chute spillway will be capable of conveying the discharge Q_{fr} without splashing over the sidewall in the steep channel section.

Capacity. In view of the possibility of small waves, the capacity without freeboard q_{mv} for any section in the vertical curve section is defined as that discharge which has a depth of flow of 3/4 of the sidewall height. The depth of flow is to be evaluated without air entrainment.

The depth of flow at section M is assumed to be the critical depth of the discharge. Therefore, the capacity without freeboard q_{mM} at section M is the critical discharge corresponding to the depth 3 M/4. The capacity without freeboard q_{mM} at the origin of the upper vertical curve is given by Table 1, ES-88, page 2.125. The required capacity without freeboard for this section is Q_{fr}.

The effect of a change of width and a change of slope on discharge in steep channels is considered. Given two channels of different widths but having the same depth of flow d_1 at the same vertical drop y_1 below the control section and of the same slope, the wider channel will have a slightly greater discharge q than the narrower channel. This can be verified by ES-78, page 2.143, for channels having the same slope but different widths. Given two channels of different slopes but of the same width and the same depth of flow d_1 at the same vertical drop y_1 below the control section, the steeper channel will have a slightly greater discharge q than the flatter channel. This can be ascertained by consulting ES-78, page 2.143, for channels having the same width but different slopes. The error in taking the discharge q of any channel having a depth d_1 for a drop less than 10 ft, a width less than 30 ft, and a slope steeper than 10 to 1 as being equal to the discharge of a 4-ft channel laid on a 3 to 1 slope and having the same depth of flow and drop is minor.

The capacity without freeboard q_{mN} for section N at the downstream end of the vertical curve section having a vertical drop z is the same as the discharge q of a 4-foot-wide channel on a 3 to 1 slope when its depth of flow without air entrainment is 3 N/4 at a vertical drop z below its control section. The values of q_{mN} are tabulated in Table 2, ES-88, page 2.125.

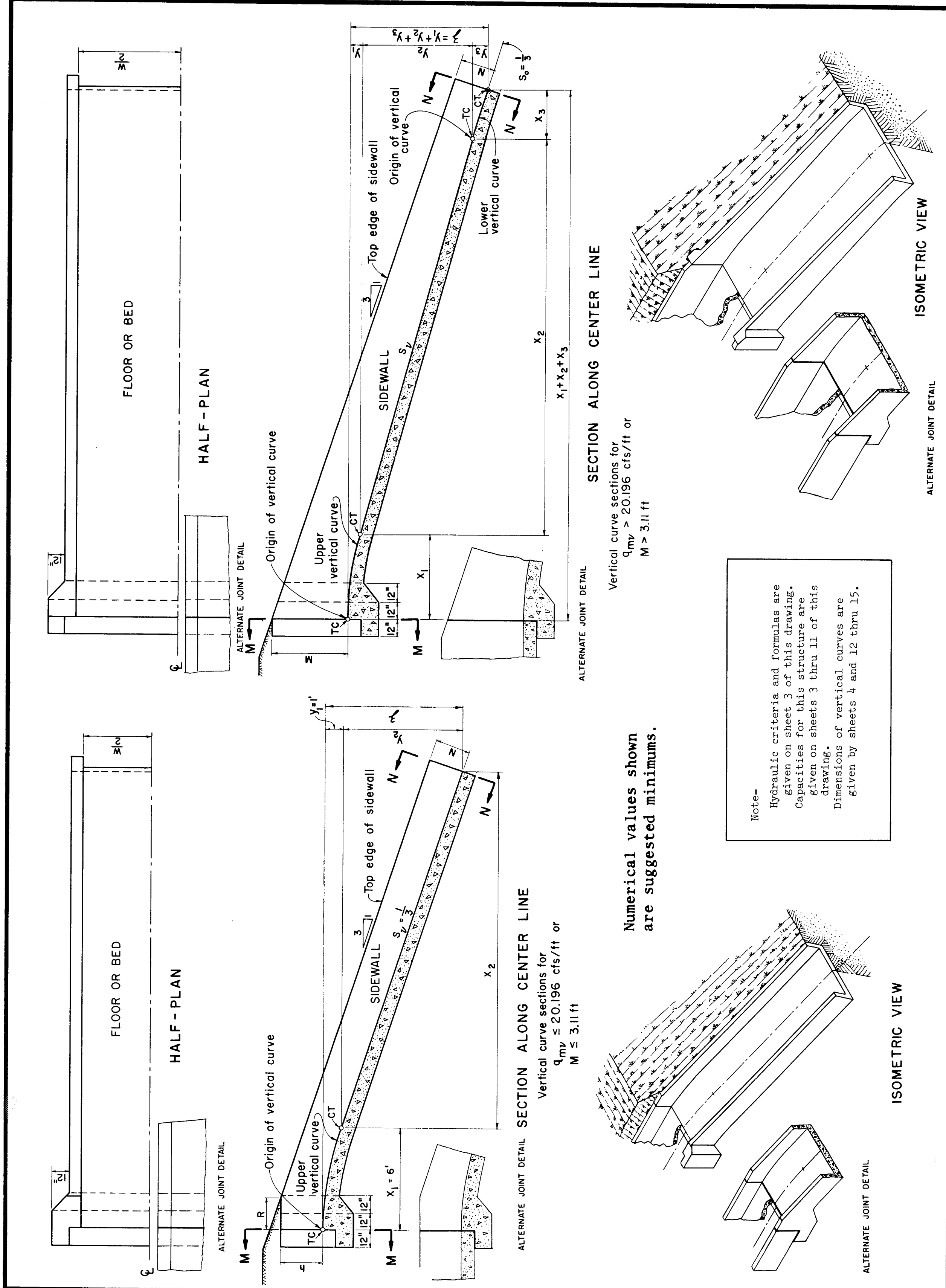
The capacity without freeboard q_{mv} of a vertical curve section is the lower value of q_{mM} and q_{mN} determined at the section M and N. Capacities for vertical curve sections having various values of M, N, and z may be determined from Tables 3a and 3b, pages 2.125 and 2.126. The capacity without freeboard Q_{mv} for various widths W and drops z is given by ES-88, pages 2.127, 2.128, 2.129, 2.130, 2.131, 2.132, and 2.133.

Value of z. The value of z is chosen as large as maximum joint spacing or value of the vertical drop from the floor of the inlet to SAF outlet (i.e., F + z) will permit. (See section on "Channels" for formula giving the value of F.) By choosing z in this manner, the minimum value of side height N is obtained.

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

The general layout drawing

$S_0 = \frac{1}{3}$



Numerical values shown are suggested minimums.

Note-
Hydraulic criteria and formulas are given on sheet 3 of this drawing.
Capacities for this structure are given on sheets 3 thru 11 of this drawing.
Dimensions of vertical curves are given by sheets 4 and 12 thru 15.

REFERENCE:

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

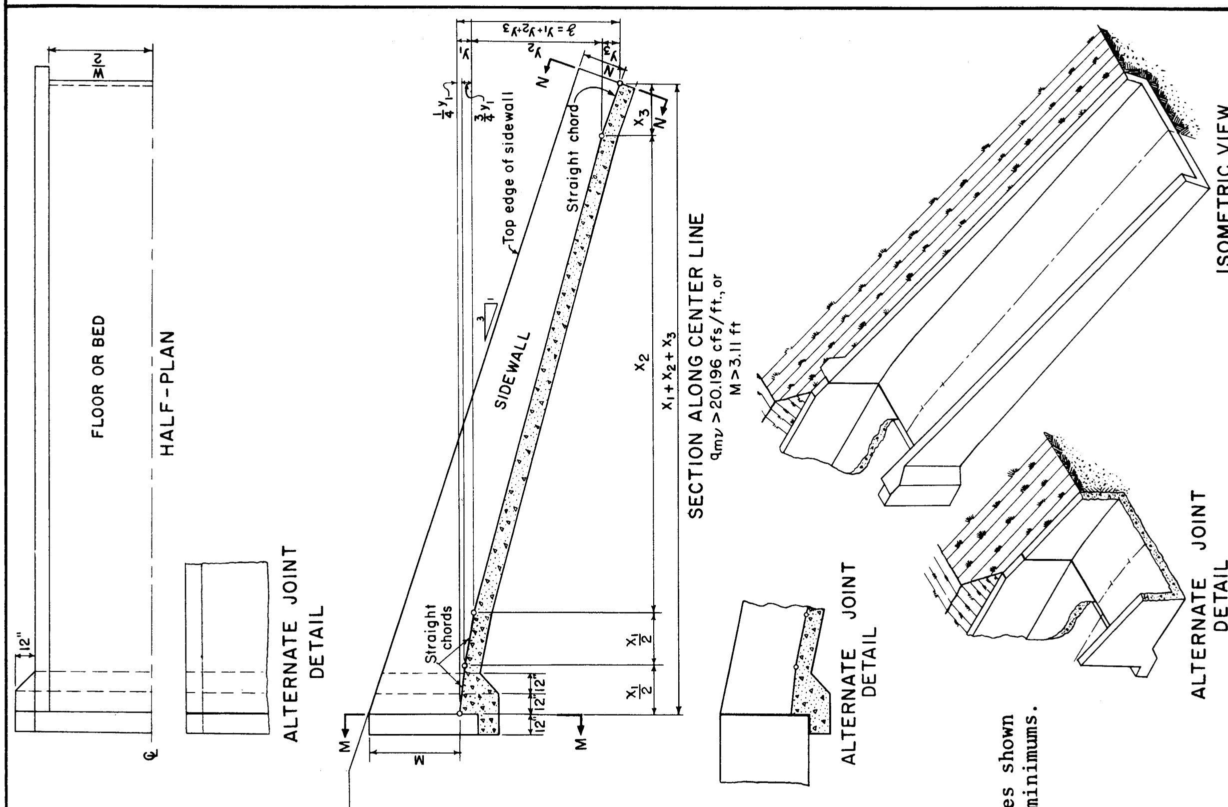
STANDARD DWG. NO. ES-88
SHEET 1 OF 16
DATE 11-18-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS WITH STRAIGHT CHORDS;

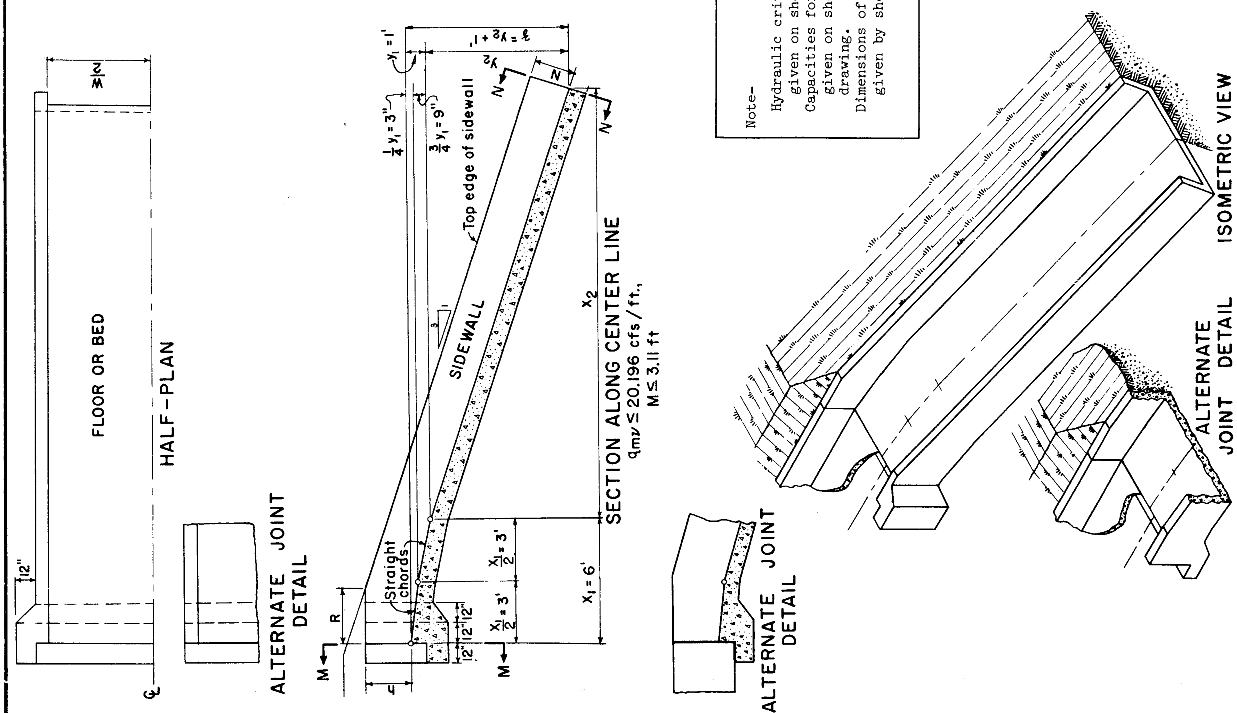
The general layout drawing

$S_O = \frac{1}{3}$



Note-
Hydraulic criteria and formulas are given on sheet 3 of this drawing.
Capacities for this structure are given on sheets 3 thru 11 of this drawing.
Dimensions of vertical curves are given by sheets 4 and 12 thru 15.

Numerical values shown are suggested minimums.



REFERENCE:	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION- DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 2 OF 16 DATE: 11-17-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS; $s_o = \frac{1}{3}$

Definition of symbols, Formulas, Dimensions, and Capacities

Table 1
Capacities at Section M

M	q_{mM}
2.00	10.42
2.25	12.43
2.50	14.56
2.75	16.80
3.00	19.14
3.11	20.20
3.25	21.58
3.50	24.12
3.75	26.74
4.00	29.47
4.25	32.27
4.50	35.16
4.75	38.13
5.00	41.18
5.25	44.31
5.50	47.51
5.75	50.78
6.00	54.14
6.25	57.56
6.50	61.08
6.75	64.59
7.00	68.22

Table 2
Capacities at Section N for Various Values of $\mathfrak{z}$ and N
Table gives q_{mN}

N	Values of $\mathfrak{z}$					
	8	7	6	5	4	3
2.00	41.00	39.00	36.85	34.55	32.00	29.00
2.25	46.80	44.70	42.30	39.55	36.65	33.33
2.50	52.65	50.25	47.55	44.72	41.50	37.75
2.75	58.65	55.85	52.90	49.75	46.25	42.20
3.00	64.80	61.90	58.55	54.90	51.10	46.80
3.25	71.15	67.80	64.25	60.40	56.15	51.30
3.50		73.90	70.10	65.85	61.35	56.05
3.75				71.70	66.65	61.15
4.00					72.00	66.15
4.25						71.30

Table 3a
Dimensions and Capacities of Vertical Curve Sections[1]

M	N	R	q_{mv}
2.00	2.00	3.33	10.42
2.25	2.00	2.58	12.43
2.50	2.00	1.83	14.56
2.75	2.00	1.08	16.80
3.00	2.00	0.33	19.14

[1] See sheet 4, table 3b, for vertical curve sections with larger dimensions

FORMULAS

$Q_{fr} = (1.20 + 0.003\ Z)\ Q_r$

$q_{mM}^2 = \frac{27}{64} gM^3$

q_{mN} = discharge having a depth of 3/4 N; when W = 4 and y = $\mathfrak{z}$ as shown by water surface profile without air entrainment for 3 to 1 slope.

DEFINITION OF SYMBOLS

M = height of sidewall at origin of upper vertical curve in ft
N = normal height of sidewall of channel to slope s_o in ft
W = width of vertical curve section in ft
Z = vertical drop from crest of inlet to floor of outlet in ft
R = length of level portion of top of sidewall in ft
$\mathfrak{z}$ = vertical drop of vertical curve section in ft
s_v = slope of floor of vertical curve section in ft/ft
s_o = slope of floor of channel in ft/ft
θ = $\tan^{-1} s_o$
d_M = actual depth of flow at origin of vertical curve in ft
d_N = depth of flow without air entrainment at beginning of channel in ft
d = depth of flow without air entrainment in ft
d_c = critical depth of flow in ft
x_1, y_1 = coordinates of upper vertical curve having a slope of s_v in ft
x_2, y_2 = horizontal and vertical lengths of that portion of the floor of the vertical curve section having a slope of s_v in ft
x_3, y_3 = coordinates of lower vertical curve having a slope of of s_o in ft
x, y = coordinates for vertical curves in ft
Q_r = design discharge in cfs
Q_{fr} = required capacity without freeboard in cfs
Q_{sv} = capacity of vertical curve section with the recommended freeboard in cfs
q_{fr} = required discharge without freeboard per foot width of chute in cfs/ft
q_{sv} = capacity of vertical curve section with the recommended freeboard in cfs/ft
q_{mv} = capacity of vertical curve section without freeboard in cfs/ft

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Dimensions and Capacities of Vertical Curve Sections for Chutes having 3 to 1 slope

Table 3b

Dimensions and Capacities of Vertical Curve Sections[1]

z = 8 ft.

M	N	x_1	y_1	x_2	y_2	x_3	y_3	s_v	q_{mv}
3.11	2.00	6.0000	1.0000	21.000	7.0000	0	0	0.3333	20.19
3.25	2.00	5.8802	0.9606	21.213	6.9299	0.3320	0.1095	0.3267	21.58
3.50	2.00	5.6777	0.8955	21.603	6.8145	0.8950	0.2900	0.3154	24.12
3.75	2.00	5.4860	0.8360	22.012	6.7085	1.4275	0.4555	0.3048	26.74
4.00	2.00	5.3037	0.7814	22.438	6.6113	1.9340	0.6073	0.2947	29.47
4.25	2.00	5.1311	0.7313	22.881	6.5224	2.4135	0.7463	0.2851	32.27
4.50	2.00	4.9673	0.6854	23.339	6.4407	2.8685	0.8739	0.2760	35.16
4.75	2.00	4.8118	0.6431	23.813	6.3656	3.3007	0.9913	0.2673	38.13
5.00	2.00	4.6640	0.6043	24.300	6.2964	3.7110	1.0993	0.2591	41.00
5.00	2.25	4.8197	0.6454	23.787	6.3694	3.2780	0.9852	0.2678	41.18
5.25	2.25	4.6717	0.6063	24.274	6.3000	3.6895	1.0937	0.2595	44.31
5.50	2.25	4.5310	0.5703	24.773	6.2360	4.0805	1.1937	0.2517	46.80
5.50	2.50	4.6796	0.6083	24.247	6.3036	3.6675	1.0881	0.2600	47.51
5.75	2.50	4.5385	0.5722	24.746	6.2394	4.0595	1.1884	0.2521	50.78
6.00	2.50	4.4042	0.5386	25.257	6.1799	4.4345	1.2815	0.2447	52.65
6.00	2.75	4.5459	0.5741	24.719	6.2427	4.0390	1.1832	0.2526	54.14
6.25	2.75	4.4114	0.5406	25.230	6.1832	4.4125	1.2762	0.2451	57.56
6.50	2.75	4.2835	0.5097	25.752	6.1283	4.7680	1.3620	0.2380	58.65
6.50	3.00	4.4188	0.5424	25.202	6.1865	4.3920	1.2711	0.2455	61.08
6.75	3.00	4.2903	0.5113	25.724	6.1313	4.7490	1.3574	0.2384	64.59
7.00	3.00	4.1683	0.4827	26.256	6.0802	5.0880	1.4371	0.2316	64.80
7.00	3.25	4.2971	0.5130	25.696	6.1341	4.7300	1.3529	0.2387	68.22

z = 6 ft.

M	N	x_1	y_1	x_2	y_2	x_3	y_3	s_v	q_{mv}
3.11	2.00	6.0000	1.0000	15.000	5.0000	0	0	0.3333	20.19
3.25	2.00	5.8331	0.9451	15.129	4.9024	0.4639	0.1525	0.3241	21.58
3.50	2.00	5.5532	0.8566	15.381	4.7450	1.2412	0.3984	0.3085	24.12
3.75	2.00	5.2909	0.7776	15.665	4.6046	1.9697	0.6178	0.2939	26.74
4.00	2.00	5.0459	0.7073	15.979	4.4796	2.6502	0.8131	0.2803	29.47
4.25	2.00	4.8172	0.6446	16.323	4.3681	3.2857	0.9873	0.2676	32.27
4.50	2.00	4.6030	0.5885	16.692	4.2685	3.8807	1.1430	0.2557	35.16
4.75	2.00	4.4032	0.5385	17.087	4.1796	4.4357	1.2819	0.2446	36.85
4.75	2.25	4.6145	0.5915	16.672	4.2737	3.8487	1.1348	0.2564	38.13
5.00	2.25	4.4127	0.5409	17.063	4.1838	4.4092	1.2753	0.2452	41.18
5.25	2.25	4.2260	0.4961	17.481	4.1042	4.9277	1.3997	0.2348	42.30
5.25	2.50	4.4240	0.5436	17.043	4.1888	4.3777	1.2676	0.2458	44.31
5.50	2.50	4.2358	0.4984	17.458	4.1082	4.9007	1.3934	0.2353	47.51
5.75	2.75	4.2458	0.5007	17.435	4.1124	4.8732	1.3869	0.2359	50.78
6.00	2.75	4.0689	0.4599	17.871	4.0398	5.3640	1.5003	0.2261	52.90
6.00	3.00	4.2556	0.5031	17.412	4.1165	4.8457	1.3804	0.2364	54.14
6.25	3.00	4.0783	0.4620	17.847	4.0436	5.3380	1.4944	0.2266	57.56
6.50	3.00	3.9125	0.4253	18.302	3.9781	5.7985	1.5966	0.2174	58.55
6.50	3.25	4.0874	0.4641	17.823	4.0473	5.3125	1.4886	0.2271	61.08
6.75	3.25	3.9213	0.4272	18.277	3.9815	5.7740	1.5913	0.2179	64.25
6.75	3.50	4.0968	0.4663	17.799	4.0510	5.2865	1.4827	0.2276	64.59
7.00	3.50	3.9299	0.4291	18.252	3.9849	5.7500	1.5860	0.2183	68.22

z = 4 ft.

M	N	x_1	y_1	x_2	y_2	x_3	y_3	s_v	q_{mv}
3.11	2.00	6.0000	1.0000	9.000	3.0000	0	0	0.3333	20.19
3.25	2.00	5.7218	0.9094	8.931	2.8390	0.7727	0.2516	0.3179	21.58
3.50	2.00	5.2592	0.7683	8.859	2.5881	2.0577	0.6436	0.2922	24.12
3.75	2.00	4.8316	0.6484	8.848	2.3750	3.2457	0.9766	0.2684	26.74
4.00	2.00	4.4397	0.5476	8.902	2.1956	4.3342	1.2568	0.2467	29.47
4.25	2.00	4.0831	0.4631	9.018	2.0456	5.3245	1.4913	0.2268	32.00
4.25	2.25	4.4600	0.5526	8.897	2.2045	4.2777	1.2429	0.2478	32.27
4.50	2.25	4.1015	0.4673	9.010	2.0529	5.2735	1.4798	0.2279	35.16
4.75	2.25	3.7764	0.3962	9.182	1.9265	6.1765	1.6773	0.2098	36.65
4.75	2.50	4.1200	0.4715	9.002	2.0605	5.2220	1.4680	0.2289	38.13
5.00	2.50	3.7933	0.3997	9.171	1.9328	6.1295	1.6675	0.2107	41.18
5.25	2.50	3.4988	0.3400	9.398	1.8268	6.9475	1.8332	0.1944	41.50
5.25	2.75	3.8102	0.4033	9.161	1.9392	6.0825	1.6575	0.2117	44.31
5.50	2.75	3.5140	0.3430	9.384	1.8320	6.9055	1.8250	0.1952	46.25
5.50	3.00	3.8272	0.4069	9.150	1.9455	6.0355	1.6476	0.2126	47.51
5.75	3.00	3.5293	0.3460	9.371	1.8374	6.8630	1.8166	0.1961	50.78
6.00	3.00	3.2614	0.2955	9.645	1.7475	7.6070	1.9570	0.1812	51.10
6.00	3.25	3.5446	0.3490	9.357	1.8427	6.8205	1.8083	0.1969	54.14
6.25	3.25	3.2751	0.2980	9.628	1.7519	7.5690	1.9501	0.1820	56.15
6.25	3.50	3.5599	0.3521	9.344	1.8480	6.7780	1.7999	0.1978	57.56
6.50	3.50	3.2890	0.3004	9.612	1.7563	7.5305	1.9433	0.1827	61.08
6.75	3.50	3.0460	0.2578	9.930	1.6804	8.2055	2.0618	0.1692	61.35
6.75	3.75	3.3028	0.3031	9.597	1.7609	7.4920	1.9360	0.1835	64.59
7.00	3.75	3.0584	0.2599	9.912	1.6841	8.1710	2.0560	0.1699	66.65
7.00	4.00	3.3169	0.3056	9.581	1.7656	7.4530	1.9288	0.1843	68.22

z = 7 ft.

M	N	x_1	y_1	x_2	y_2	x_3	y_3	s_v	q_{mv}
3.11	2.00	6.0000	1.0000	18.000	6.0000	0	0	0.3333	20.19
3.25	2.00	5.8606	0.9541	18.178	5.9184	0.3870	0.1275	0.3256	21.58
3.50	2.00	5.6257	0.8791	18.510	5.7851	1.0397	0.3358	0.3125	24.12
3.75	2.00	5.4043	0.8113	18.866	5.6645	1.6547	0.5242	0.3002	26.74
4.00	2.00	5.1957	0.7499	19.246	5.5553	2.2340	0.6948	0.2887	29.47
4.25	2.00	4.9993	0.6942	19.647	5.4564	2.7797	0.8494	0.2777	32.27
4.50	2.00	4.8139	0.6437	20.067	5.3666	3.2947	0.9897	0.2674	35.16
4.75	2.00	4.6391	0.5978	20.506	5.2850	3.7802	1.1172	0.2577	38.13
5.00	2.00	4.4743	0.5561	20.963	5.2108	4.2382	1.2331	0.2486	39.00
5.00	2.25	4.6498	0.6005	20.485	5.2898	3.7505	1.1096	0.2583	41.18
5.25	2.25	4.4831	0.5582	20.938	5.2147	4.2137	1.2271	0.2491	44.31
5.50	2.25	4.3268	0.5201	21.411	5.1467	4.6477	1.3332	0.2404	44.70
5.50	2.50	4.4917	0.5605	20.913	5.2185	4.1897	1.2210	0.2495	47.51
5.75	2.50	4.3353	0.5221	21.385	5.1503	4.6242	1.3276	0.2409	50.25
5.75	2.75	4.5004	0.5626	20.888	5.2224	4.1657	1.2150	0.2500	50.78
6.00	2.75	4.3434	0.5240	21.359	5.1538	4.6016	1.3222	0.2413	54.14
6.25	2.75	4.1951	0.4889	21.845	5.0913	5.0135	1.4198	0.2331	55.85
6.25	3.00	4.3517	0.5261	21.333	5.1574	4.5787	1.3165	0.2418	57.56
6.50	3.00	4.2030	0.4906	21.818	5.0946	4.9917	1.4148	0.2335	61.08
6.75	3.00	4.0626	0.4585	22.319	5.0372	5.3815	1.5043	0.2257	61.90
6.75	3.25	4.2107	0.4925	21.792	5.0978	4.9702	1.4097	0.2337	64.59
7.00	3.25	4.0700	0.4602	22.292	5.0402	5.3610	1.4996	0.2261	67.80

z = 5 ft.

M	N	x_1	y_1	x_2	y_2	x_3	y_3	s_v	q_{mv}
3.11	2.00	6.0000	1.0000	12.000	4.0000	0	0	0.3333	20.19
3.25	2.00	5.7915	0.9317	12.055	3.8786	0.5792	0.1897	0.3218	21.58
3.50	2.00	5.4439	0.8233	12.187	3.6857	1.5447	0.4910	0.3024	24.12
3.75	2.00	5.1210	0.7285	12.363	3.5172	2.4417	0.7543	0.2845	26.74
4.00	2.00	4.8222	0.6460	12.582	3.3706	3.2717	0.9834	0.2679	29.47
4.25	2.00	4.5459	0.5740	12.840	3.2427	4.0392	1.1833	0.2526	32.27
4.50	2.00	4.2907	0.5114	13.137	3.1313	4.7482	1.3573	0.2384	34.55
4.50	2.25	4.5601	0.5776	12.825	3.2492	3.9997	1.1732	0.2533	35.16
4.75	2.25	4.3038	0.5147	13.119	3.1371	4.7117	1.3482	0.2391	38.13
5.00	2.25	4.0676	0.4596	13.450	3.0393	5.3675	1.5011	0.2260	39.55
5.00	2.50	4.3171	0.5177	13.103	3.1426	4.6747	1.3397	0.2398	41.18
5.25	2.50	4.0797	0.4624	13.431	3.0441	5.3340	1.4935	0.2267	44.31
5.50	2.50	3.8610	0.4141	13.792	2.9584	5.9415	1.6275	0.2145	44.72
5.50	2.75	4.0921	0.4652	13.412	3.0491	5.2995	1.4857	0.2273	47.51
5.75	2.75	3.8723	0.4166	13.771	2.9628	5.9100	1.6206	0.2151	49.75
5.75	3.00	4.1047	0.4680	13.394	3.0542	5.2645	1.4778	0.2280	50.78
6.00	3.00	3.8840	0.4191	13.751	2.9672	5.8775	1.6137	0.2158	54.14
6.25	3.00	3.6805	0.3763	14.139	2.8912	6.4430	1.7325	0.2045	54.90
6.25	3.25	3.8954	0.4215	13.731	2.9716	5.8460	1.6069	0.2164	57.56
6.50	3.25	3.6911	0.3785	14.118	2.8950	6.4135	1.7265	0.2051	60.40
6.50	3.50	3.9069	0.4240	13.711	2.9760	5.8140	1.6000	0.2171	61.08
6.75	3.50	3.7017	0.3806	14.096	2.8989	6.3840	1.7205	0.2057	64.59
7.00	3.50	3.5123	0.3427	14.510	2.8315	6.9100	1.8258	0.1951	65.85
7.00	3.75	3.0911	0.2654	12.970	2.6941	8.0800	2.0405	0.1717	58.22

z = 3 ft.

M	N	x_1	y_1	x_2	y_2	x_3	y_3	s_v	q_{mv}
3.11	2.00	6.0000	1.0000	6.000	2.0000	0	0	0.3333	20.19
3.25	2.00	5.5782	0.8644	5.676	1.7588	1.1717	0.3768	0.3099	21.58
3.50	2.00	4.8546	0.6547	5.139	1.3860	3.1817	0.9593	0.2697	24.12
3.75	2.00	4.1645	0.4817	4.662	1.0787	5.0985	1.4396	0.2314	26.74
4.00	2.00	3.5188	0.3439	4.264	0.8337	6.8920	1.8224	0.1955	29.00
4.00	2.25	4.2007	0.4902	4.686	1.0936	4.9982	1.4162	0.2334	29.47
4.25	2.25	3.5525	0.3506	4.284	0.8454	6.7985	1.8040	0.1974	32.27
4.50	2.25	2.9615	0.2437	3.983	0.6554	8.4400	2.1009	0.1645	33.33
4.50	2.50	3.5860	0.3572	4.303	0.8573	6.7055	1.7855	0.1992	35.16
4.75	2.50	2.9918	0.2486	3.996	0.6643	8.3560	2.0871	0.1662	37.75
4.75	2.75	3.6202	0.3641	4.323	0.8694	6.6105	1.7665	0.2011	38.13
5.00	2.75	3.0220	0.2537	4.010	0.6732	8.2720	2.0731	0.1679	41.18
5.25	2.75	2.0407	0.1157	3.015	0.4279	10.998	2.4564	0.1134	42.20
5.25	3.00	3.0532	0.2590	4.024	0.6826	8.1855	2.0584	0.1696	44.31
5.50	3.00	2.5205	0.1765	3.827	0.5360	9.6650	2.2875	0.1400	46.80
5.50	3.25	3.0838	0.2642	4.038	0.6918	8.1005	2.0440	0.1713	47.51
5.75	3.25	2.5472	0.1803	3.834	0.5426	9.5910	2.2771	0.1415	50.78
6.00	3.25	2.0902	0.1214	3.772	0.4379	10.861	2.4407	0.1161	51.30
6.00	3.50	2.5744	0.1841	3.842	0.5495	9.5155	2.2664	0.1430	54.14
6.25	3.50	2.1127	0.1240	3.771	0.4426	10.798	2.4334	0.1174	56.05
6.25	3.75	2.6017	0.1880	3.850	0.5565	9.4395	2.2555	0.1445	57.56
6.50	3.75	2.1355	0.1267	3.771	0.4474	10.735	2.4259	0.1186	61.08
6.75	4.00	2.1586	0.1294	3.772	0.4523	10.671	2.4183	0.1199	64.59
7.00	4.00	1.7712	0.0871	3.833	0.3772	11.747	2.5357	0.0984	66.15
7.00	4.25	2.1818	0.1322	3.772	0.4573	10.606	2.4105	0.1212	68.22

[1] See sheet 3, table 3a, for vertical curve sections with smaller dimensions

When M ≤ 3.11 ft, the value of $x_2 = 3(z - 1)$ and $y_2 = z - 1$; $x_1 = 6$, $y_1 = 1.0$ are to be used.

REFERENCE

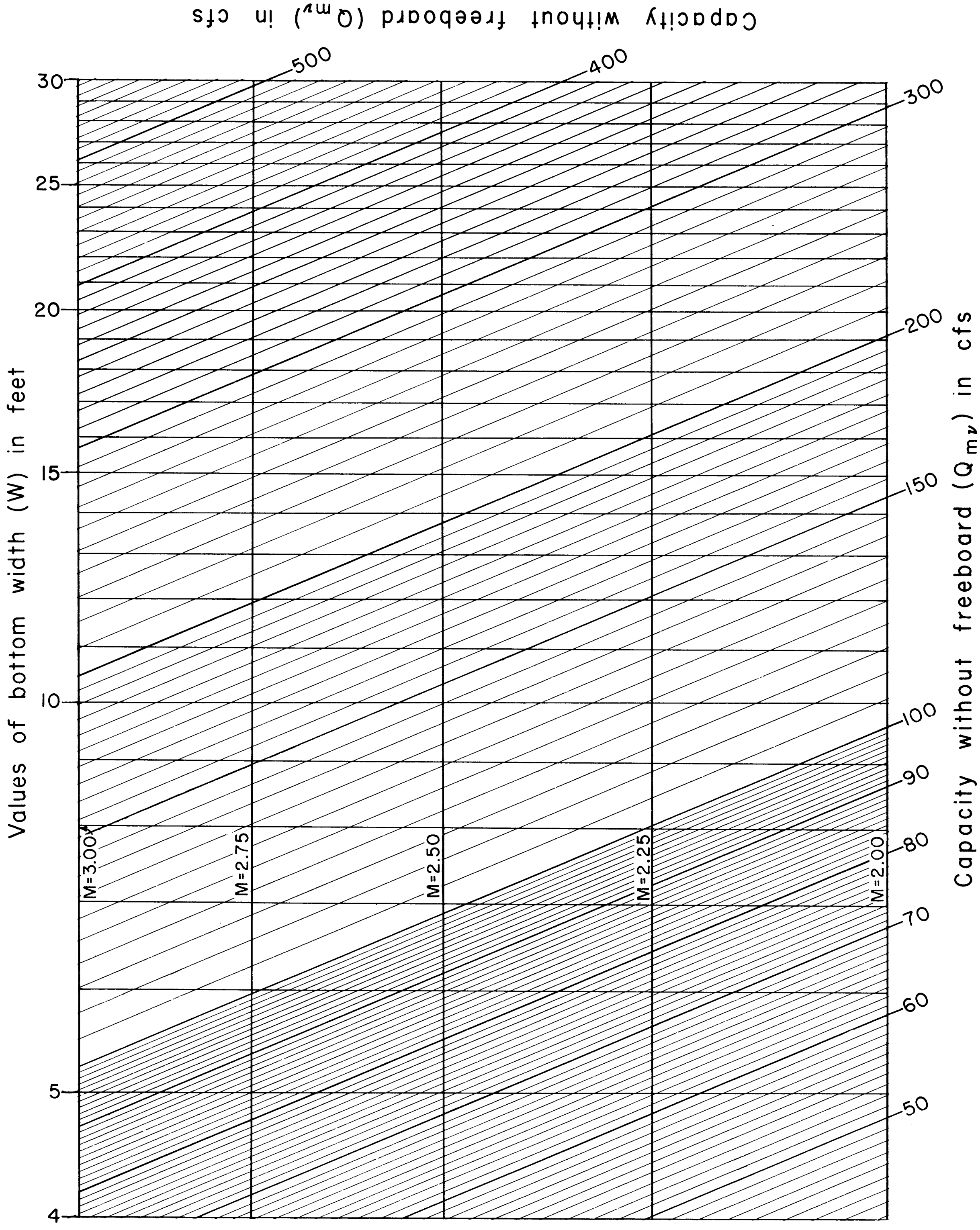
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.
ES-88
SHEET 4 OF 16
DATE February 1954

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, $Q_{m\nu}$.



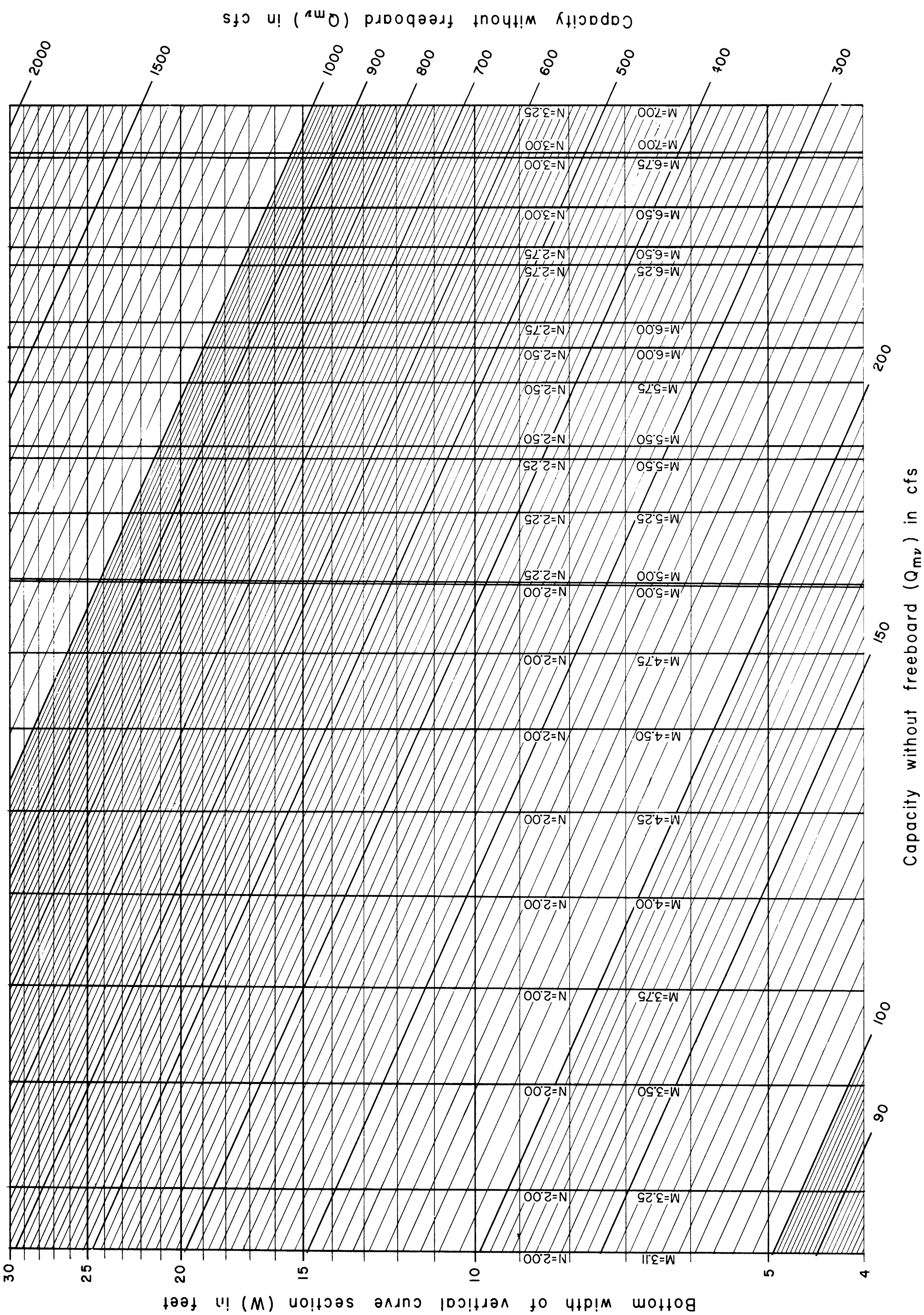
REFERENCE:	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 5 OF 16 DATE

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

z = 8 feet



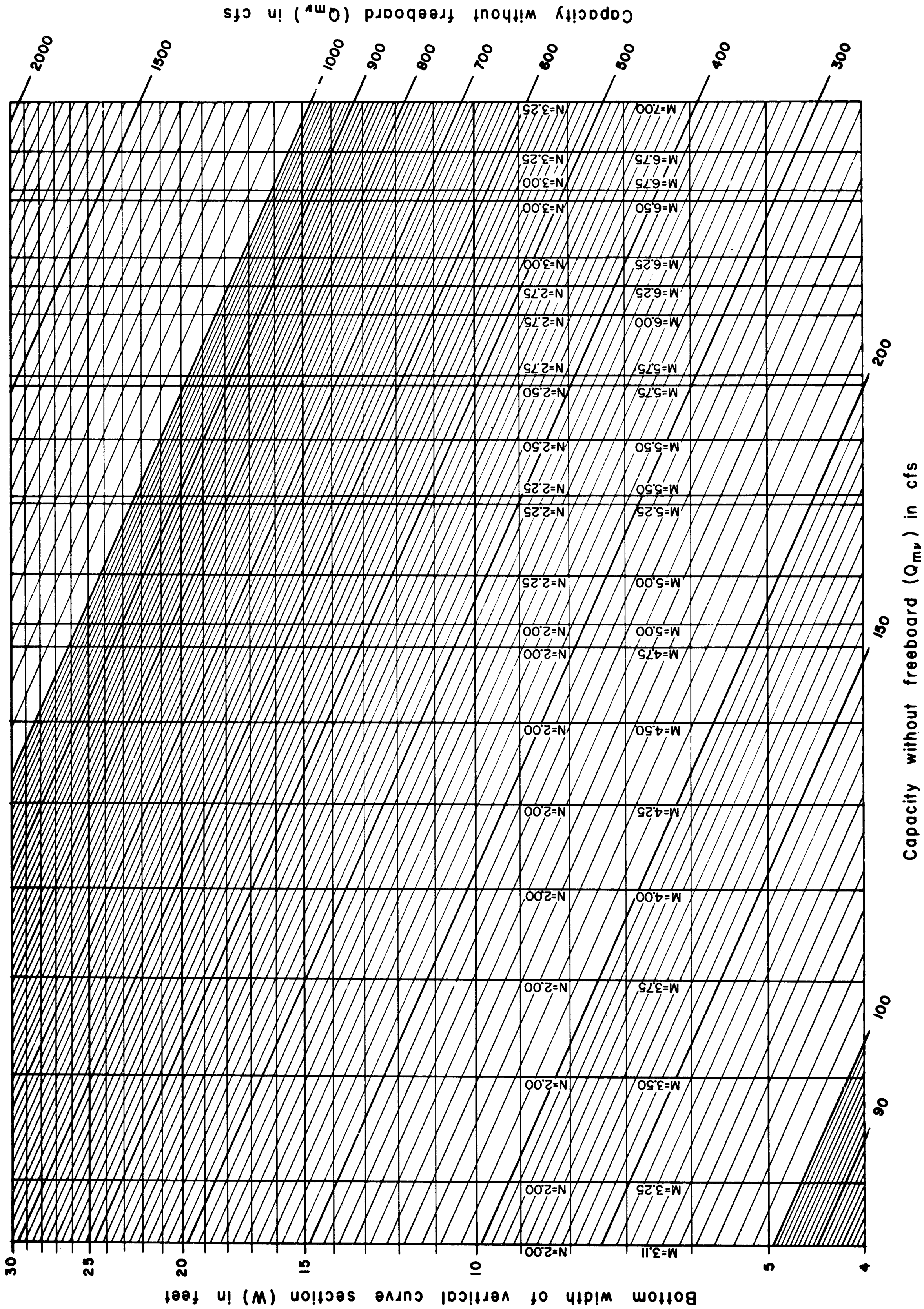
REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 6 OF 16 DATE 3-29-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

z = 7 feet

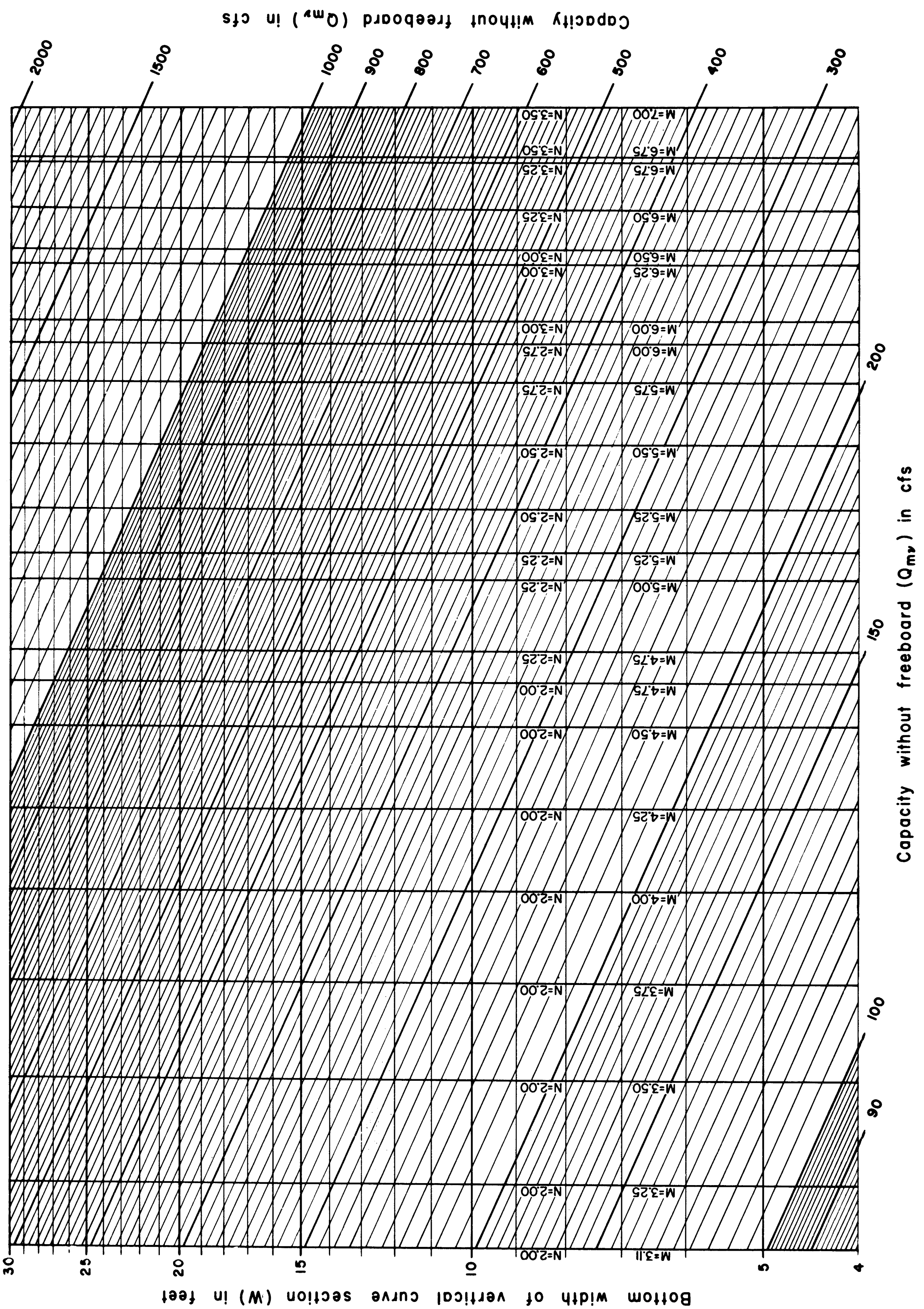


REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 7 OF 16 DATE 3-29-54

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

z = 6 feet



REFERENCE

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

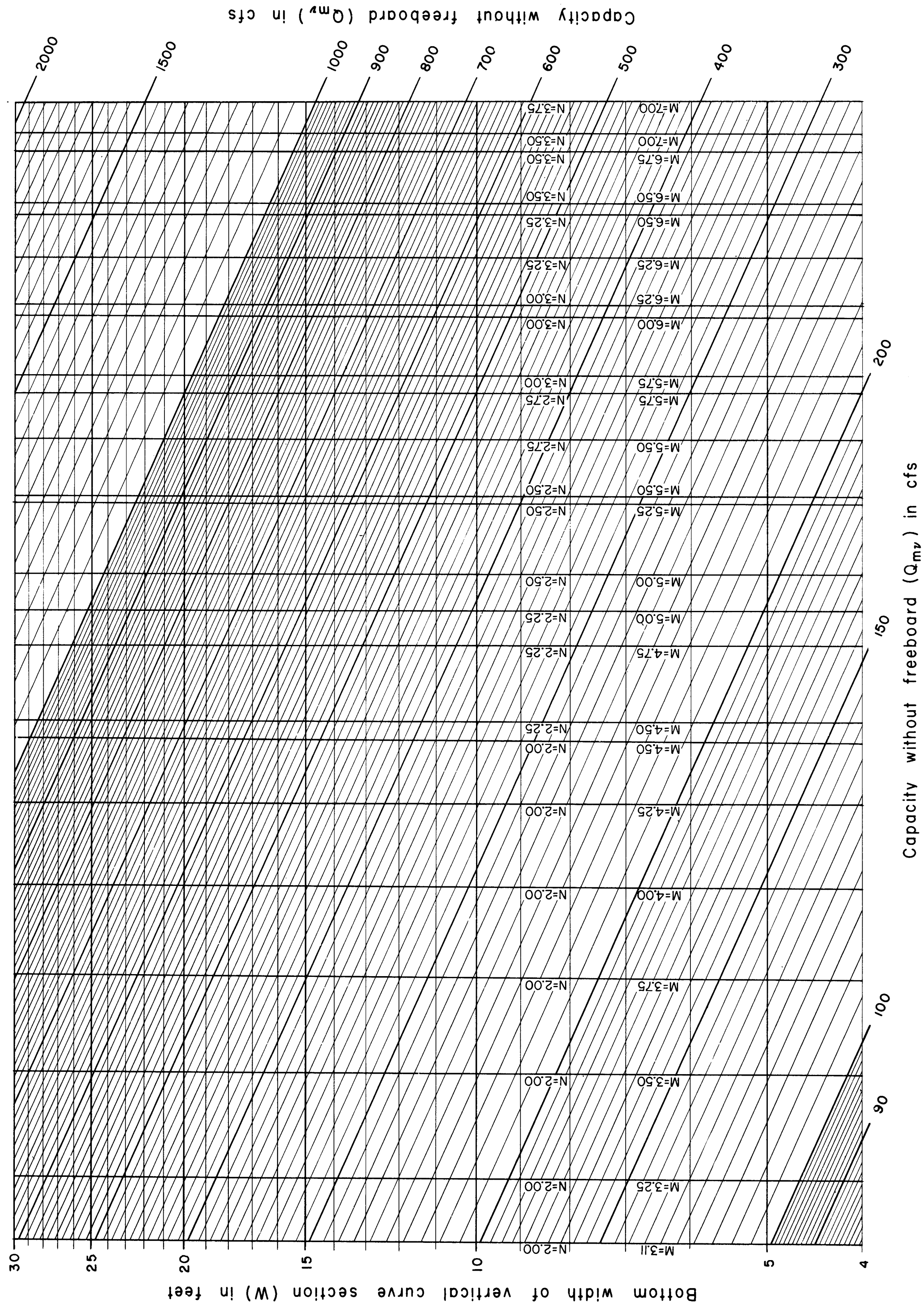
STANDARD DWG. NO.
ES-88
SHEET 8 OF 16
DATE 3-29-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

z = 5 feet



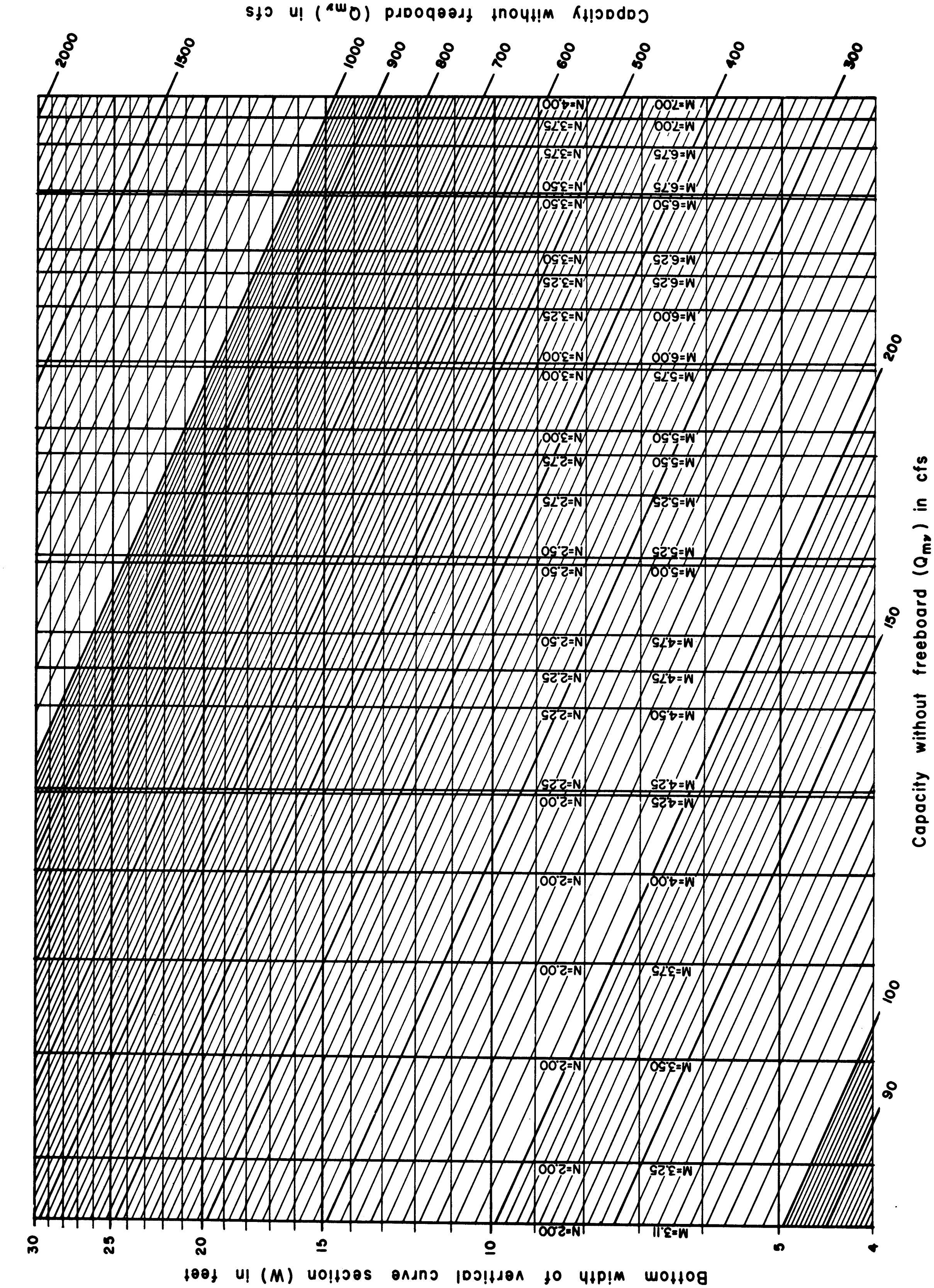
REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 9 OF 16 DATE 3-29-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

z = 4 feet



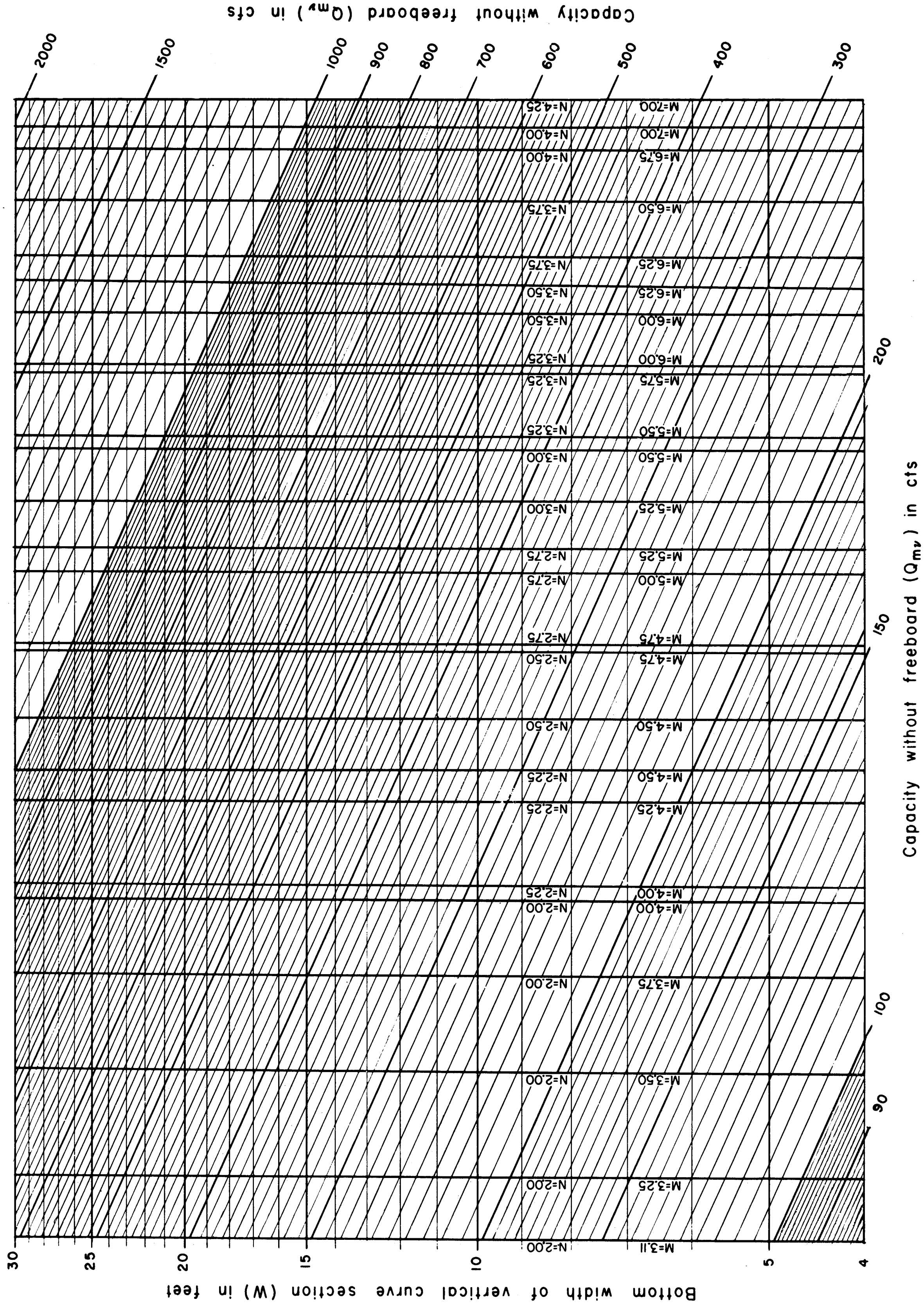
REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 10 OF 16 DATE 3-29-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

z = 3 feet



REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-88 SHEET 11 OF 16 DATE 3-29-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Upper and Lower Vertical Curves and Value of s_v

REFER TO SHEETS 1, 3, AND 4 FOR DRAWINGS, DEFINITIONS, AND OTHER VALUES.

GENERAL FORMULAS

The value of s_v for vertical curve sections terminating with any slope s_o can be obtained by the solution of the quadratic equation:

$$16s_o\, s_v^2 + \left[M + z - N\,\sec(\tan^{-1}s_o) - 50s_o^2\right] s_v + s_o(25s_o^2 - z) = 0$$

When s_v is imaginary then no lower vertical curve is required.

Values of s_v for channels having 3 to 1 slope may be read from sheet 4.

EXAMPLE

Given: Vertical curve section as shown by drawing on sheet 1 with the following dimensions: $M = 4.5$, $N = 2.0$, $z = 8.0$, $s_o = 1/3$.

Determine: The coordinates of the upper and lower curves of the vertical curve section and the slope s_v.

Solution: Solving for the slope s_v; The slope s_v for vertical curve sections terminating with slope $s_o = 1/3$ can be read from Table 3b, sheet 4. $s_v = 0.2760$.

When s_v is imaginary then $M < 3.11$ ft and no lower vertical curve is required and $y_1 = 1$ ft and $x_1 = 6$ ft. See sheet 1 and Table 3a, sheet 3.

SOLVING FOR COORDINATES OF UPPER VERTICAL CURVE

The coordinates of the upper vertical curve are given by the equation:

$$36y = x^2$$

Values of x_1 and y_1 for any channel slope s_o are given by the equations:

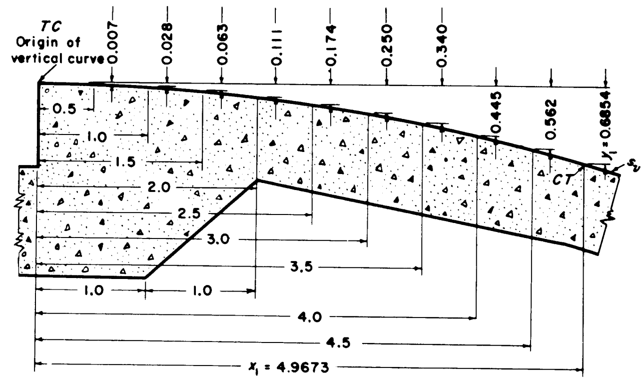
$$x_1 = 18s_v$$
$$y_1 = 9s_v^2$$

Values of x_1 and y_1 for channels having 3 to 1 slope may be read from sheet 4.

Table A

Coordinates of upper vertical curve, $s_v = 0.2760$

x in ft.	y in ft.
0.5	0.007
1.0	0.028
1.5	0.063
2.0	0.111
2.5	0.174
3.0	0.250
3.5	0.340
4.0	0.445
4.5	0.562
x_1 = 4.9673	0.6854 = y_1



All dimensions are in feet. Values of x_1 and y_1 may be read from Table 3b, sheet 4

SOLVING FOR VALUES OF x_2 AND y_2

Values of x_2 and y_2 for any channel slope s_o are given by the equations:

$$x_2 = \frac{1}{s_o}\left[M + z - N\,\sec(\tan^{-1}s_o)\right] - 50s_o + 32s_v$$
$$y_2 = z + 16s_v^2 - 25s_o^2$$

Values of x_2 and y_2 for channels having 3 to 1 slope may be read from sheet 4.

The values x_2 and y_2 may be read from Sheet 4 for channels having 3 to 1 bottom slope.

$x_2 = 23.339$ ft
$y_2 = 6.4407$ ft

SOLVING FOR COORDINATES OF LOWER VERTICAL CURVE

The coordinates of the lower vertical curve may be obtained from sheets **13, 14, and 15.** The coordinates of the lower vertical curve are given by the equation:

$$y = 0.01x^2 + s_v x$$

Values of x_3 and y_3 for any channel slope s_v are given by the equations:

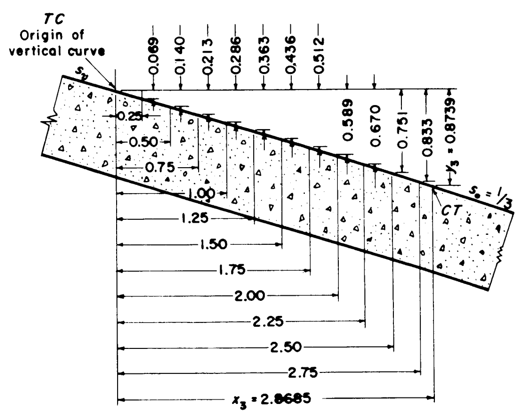
$$x_3 = 50(s_o - s_v)$$
$$y_3 = 25(s_o^2 - s_v^2)$$

Values of x_3 and y_3 for channels having 3 to 1 slope may be read from sheet 4.

Table B

Coordinates of lower vertical curve, $s_v = 0.2760$

x in ft.	y in ft.
0	0
0.25	0.069
0.50	0.140
0.75	0.213
1.00	0.286
1.25	0.363
1.50	0.436
1.75	0.512
2.00	0.589
2.25	0.670
2.50	0.751
2.75	0.833
x_3=2.8685	0.8739 = y_3



All dimensions are in feet. Values of x_3 and y_3 may be read from Table 3b, sheet 4

REFERENCE

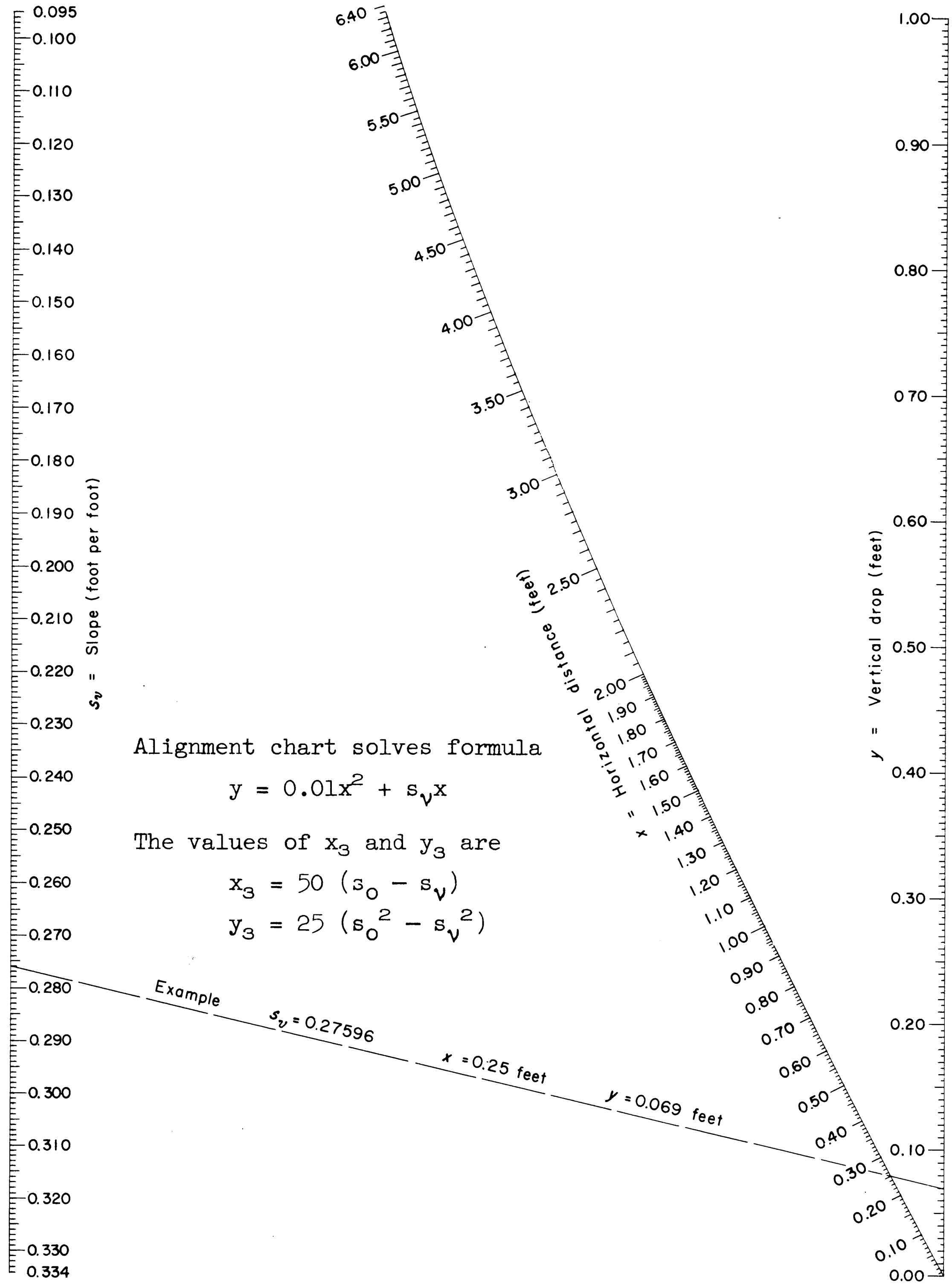
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DESIGN SECTION

STANDARD DWG. NO.
ES- 88
SHEET 12 OF 16
DATE 12-9-54

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Lower Vertical Curves and Value of s_v



Alignment chart solves formula

$$y = 0.01x^2 + s_v x$$

The values of x_3 and y_3 are

$$x_3 = 50\ (s_o - s_v)$$

$$y_3 = 25\ (s_o^2 - s_v^2)$$

REFERENCE:	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES- 88 SHEET 13 OF 16 DATE January 1954

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Lower Vertical Curves and Value of s_v

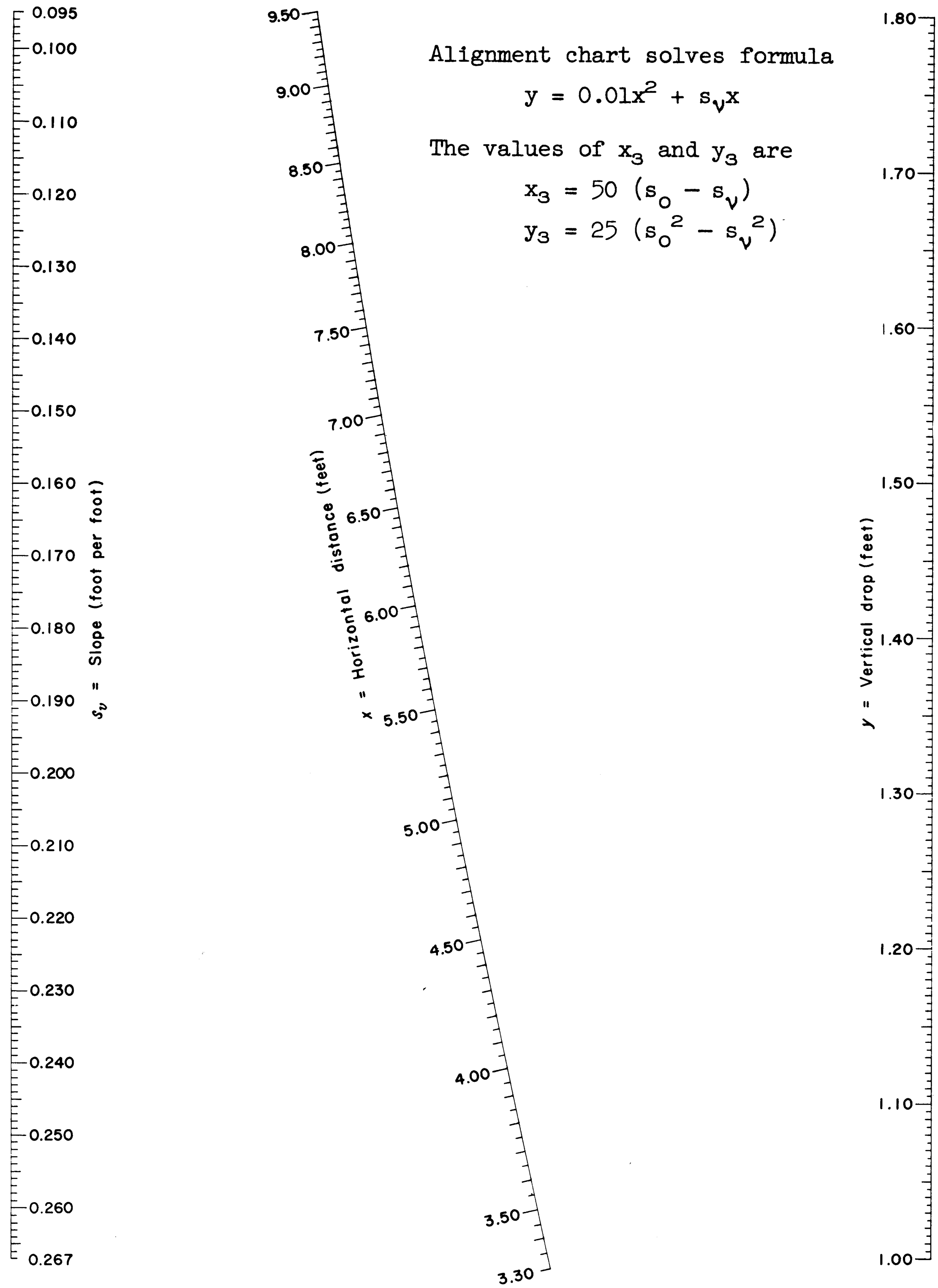
Alignment chart solves formula

$$y = 0.01x^2 + s_v x$$

The values of x_3 and y_3 are

$$x_3 = 50\ (s_o - s_v)$$

$$y_3 = 25\ (s_o^2 - s_v^2)$$



REFERENCE:

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

STANDARD DWG. NO.
ES-88
SHEET 14 OF 16
DATE January 1954

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Lower Vertical Curves and Value of s_v

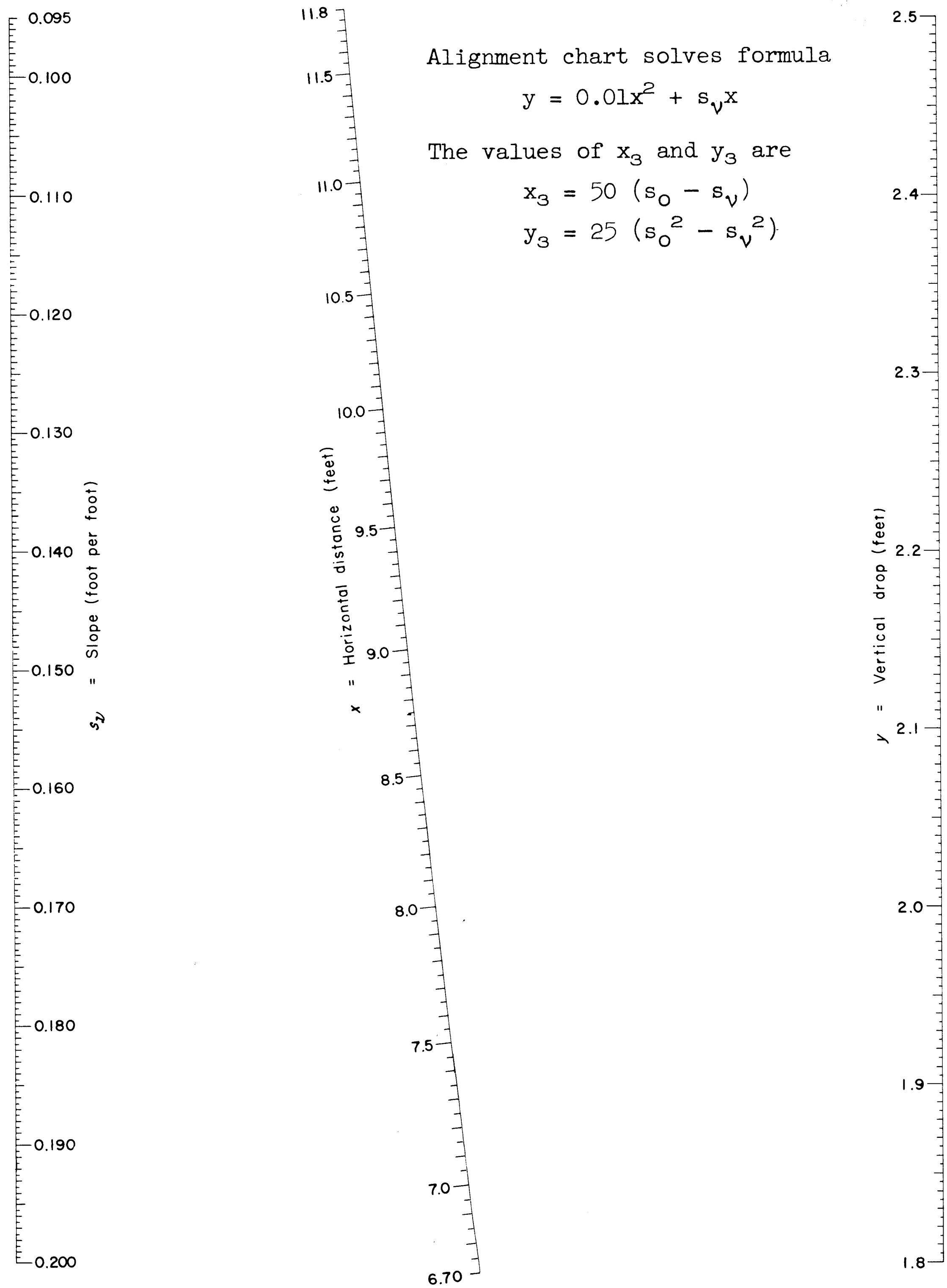
Alignment chart solves formula

$$y = 0.01x^2 + s_v x$$

The values of x_3 and y_3 are

$$x_3 = 50\,(s_o - s_v)$$

$$y_3 = 25\,(s_o^2 - s_v^2)$$



REFERENCE:
This nomogram 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-88
SHEET 15 OF 16
DATE January 1954

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS: Example

EXAMPLE

Given: A design discharge, Q_r = 320 cfs, is to be conveyed by a chute having a width, W = 12 ft, and a 3 to 1 slope. The vertical distance from the crest of the inlet to the floor of the SAF outlet is Z = 33 ft. The inlet will require no freeboard for waves.

Determine:
1. The recommended required capacity of the chute: (i) Q_{fr}; (ii) q_{fr}
2. The required dimensions of the vertical curve section having a vertical drop of $\mathfrak{z}$ = 8 ft
3. The capacity of the vertical curve section: (i) Q_{sv}; (ii) q_{sv}
4. The critical depth of flow, d_c, corresponding to the discharge, Q_{fr}
5. The depth of flow without air entrainment at section N for the discharges: (i) Q_{fr}; (ii) Q_{sv}

Solution:
1. The recommended required capacity of the chute is

(i) $$Q_{fr} = (1.20 + 0.003\ Z)\ Q_r$$

$$Q_{fr} = \left[1.20 + (0.003)(33)\right] 320 = 415.68 \text{ cfs}$$

(ii) $$q_{fr} = \frac{Q_{fr}}{W} = \frac{415.68}{12} = 34.63 \text{ cfs/ft}$$

2. (a) Read on sheet 6, for $\mathfrak{z}$ = 8 ft, at W = 12 ft and Q_{fr} = 415.68 cfs the required dimensions

$$M = 4.50 \text{ ft} \quad \text{and } N = 2.00 \text{ ft}$$

as the dimensions which are capable of conveying 415.68 cfs

(b) This determination can also be made by reading from table 3b, sheet 4, for $\mathfrak{z}$ = 8 ft and a q_{fr} = 34.63 cfs/ft. For M = 4.50 ft and N = 2.00 ft, q_{mv} = 35.16 cfs/ft which is greater than the required capacity q_{fr} = 34.63 cfs/ft. The dimensions x_1, y_1, x_2, y_2, x_3, y_3, and s_v may be read from this same table. The coordinates, x and y, of the vertical curves may be determined as shown by sheets 12, 13, 14, and 15.

3. The capacity of the vertical curve section is given by the equation

(i) $$q_{mv} = (1.20 + 0.003\ Z)\ q_{sv}$$

$$q_{sv} = \frac{35.16}{1.20 + (0.003)(33)} = 27.06 \text{ cfs/ft}$$

(ii) $$Q_{sv} = q_{sv}\ W = (27.06)(12) = 324.7 \text{ cfs}$$

4. The critical depth of flow may be read from ES-24 of the Engineering Handbook, Hydraulics, Section 5. When Q = 415.68 cfs or q = 34.63 cfs/ft, read d_c = 3.36 ft on line z/b = 0. The actual depth of flow at the origin of the upper vertical curve having a discharge of 415.68 cfs is less than d_c or 3.36 ft and greater than 0.715 d_c or (0.715)(3.36) = 2.40 ft. The actual depth of flow is dependent on the approach conditions and the upper vertical curve and a closer evaluation of its value is not proposed.

5. The depth of flow without air entrainment may be read from ES-78

(i) Interpolating between W = 10 ft and W = 15 ft for W = 12.0 ft read on sheet 11 (W = 10) and sheet 13 (W = 15) at q = 34.63 cfs/ft and y = 8 ft

(W = 10) d = 1.283 ft
(W = 15) d = 1.280 ft

The depth of flow without air entrainment at section N for the discharge Q_{fr} = 415.68 cfs is

$$d = 1.282 \text{ ft}$$

(ii) Interpolating between W = 10 ft and W = 15 ft for W = 12.0 ft read on sheet 11 (W = 10) and sheet 13 (W = 15) at q = 27.06 cfs/ft and y = 8 ft

(W = 10) d = 1.029 ft
(W = 15) d = 1.023 ft

The depth of flow without air entrainment at section N for the discharge Q_{sv} = 324.7 cfs is

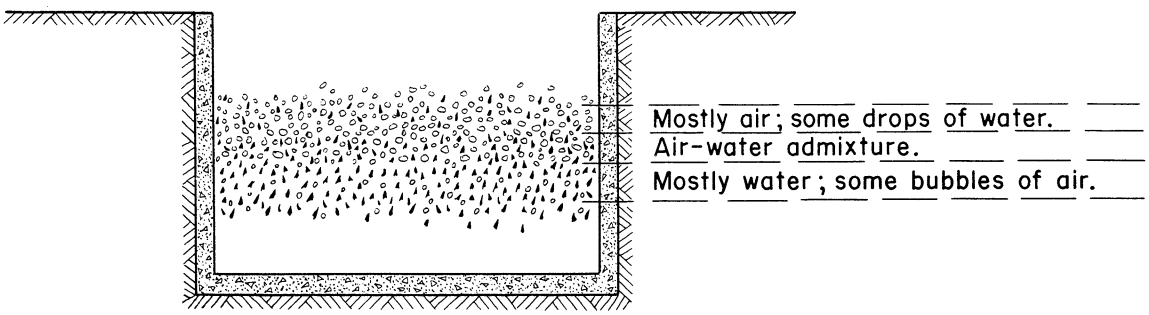
$$d = 1.027 \text{ ft}$$

CHANNELS

Function of Channels. (See ES-78, page 2.143, for nomenclature.) The function of the channel is to convey and guide all discharges equal to or less than the design discharge to a lower elevation without erosion.

Freeboard. Freeboard of the steep channel is defined in the same manner as for the vertical curve sections at section N. (See page 2.121.)

Air Entrainment. Depths of flow will be evaluated for water-air admixtures because of air entrainment. When flow in a steep chute is allowed to accelerate over a sufficient distance, air is mixed with the water and "air entrainment" results. This phenomenon is also known as "white water," "air bulking," "bulking of water," or "self-aeration." It can be observed also in waterfalls and swift streams. A water surface in the usual sense does not exist, especially at the higher velocities, for there is considerable spray or small droplets through the upper portion of flow. Because of this condition, the definition of water surface is somewhat arbitrary. The foamy admixture does not extend to the lower portion of the flow, or bottom of the channel, except on very long and steep slopes (slopes of the order of 4 to 1 and greater). (See Fig. 8.)



Schematic Drawing Showing Distribution of
Air and Water in Air-water Admixture

FIGURE 8

The air entrainment for good inlet-flow conditions normally starts along the sidewalls of the steep channel and progresses obliquely towards the axis of the chute. In wide chutes, air entrainment tends to begin across the entire section. The mechanics of air entrainment is a continuing process of entrainment and release of air. Velocity, the distance traveled, and the roughness of the channel are factors which contribute to the development of this phenomenon. Air entrainment is reduced when cross section and volume of flow are increased while other factors are held constant. The initial entrainment of air depends on entrance conditions. If excessive turbulence exists at the entrance of the vertical curve section, entrained air will occur throughout the length of the channel of the chute. If good inlet conditions exist, air entrainment will not occur for some distance downstream.

Only scanty information on air entrainment is available to the design engineer. D. B. Gumensky[1] states that fair results are obtained in determining actual velocities v of flow in a steep, open channel by using a roughness coefficient of n = 0.008 for concrete in the varied-flow equation. This value of n is smaller than that used for concrete channels of flat slopes because the air-water admixture appears to have lower friction loss and the values of n = 0.012 to 0.015 do not appear to apply for the higher velocities of flow. The effect of evaluating n too small is to cause the determined depth of flow to be small and the velocity to be high. This results in an under-design of the required height of the channel walls and an over-design of the outlet. Conversely, the evaluation of an n too large causes an over-design of the channel wall height and under-design of the outlet. A fictitious depth of flow d is obtained by the formula

$$d = \frac{q}{v} \qquad 6.1$$

where q = actual discharge of water in cfs
v = actual velocity of admixture of air and water in ft/sec
d = fictitious depth of flow, or
= equivalent depth of flow of air-water admixture without the air in ft

This fictitious depth of flow d is the depth of water without air entrainment. The probable maximum amount of air entrainment for the discharge q and actual velocity v is given by

$$m = 0.005 \frac{v^2}{gd} \qquad 6.2$$

where $m = \frac{\text{volume of air in air-water admixture}}{\text{volume of water in air-water admixture}}$
v = actual velocity of water in ft/sec
g = acceleration due to gravity--32.16 ft/sec^2

The actual depth of flow d_a of the air-water admixture is

$$d_a = \rho d \qquad 6.3$$

where ρ = volume of air-water admixture per cubic foot of water in ft^3

The theory of water-surface profiles for flat-grade channels as found in the Engineering Handbook, Section 5, Hydraulics, Supplement A, should not be used for steep slopes. Flow on steep grades presents a distinctly different problem from flow on flat grades and should be so treated. The major reasons the theory of open-channel flow on steep sloped channels is different from that on flat-grade channels are:

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[1]Gumensky, D. B., Air Entrained in Fast Water Affects Design of Training Walls and Stilling Basins, Civil Engineering, page 35, Dec. 1949.

a. In the theory of flow on flat-grade channels, the assumption is made that the pressure below the surface is the product of the density and vertical depth. Actually, the pressure is a function of the slope as well.

b. The depth of flow for channels of flat slopes is taken to be the vertical depth of flow. The depth of flow for steep channels is perpendicular to the bottom slope.

c. Depths of flow in steep sloped channels need to be evaluated for water-air admixture because of air entrainment.

d. It is assumed that the water surface in the steep channel has a level surface in cross section. Particular attention needs to be given to whether or not this assumption is valid--that is, no standing waves are present--whenever the modified differential equation of varied flow for steep channels is used to evaluate water-surface profiles.

e. The assumption is tacitly made that the horizontal length of a flat-grade channel is equal to its true length. Channels of steep grades invalidate this assumption.

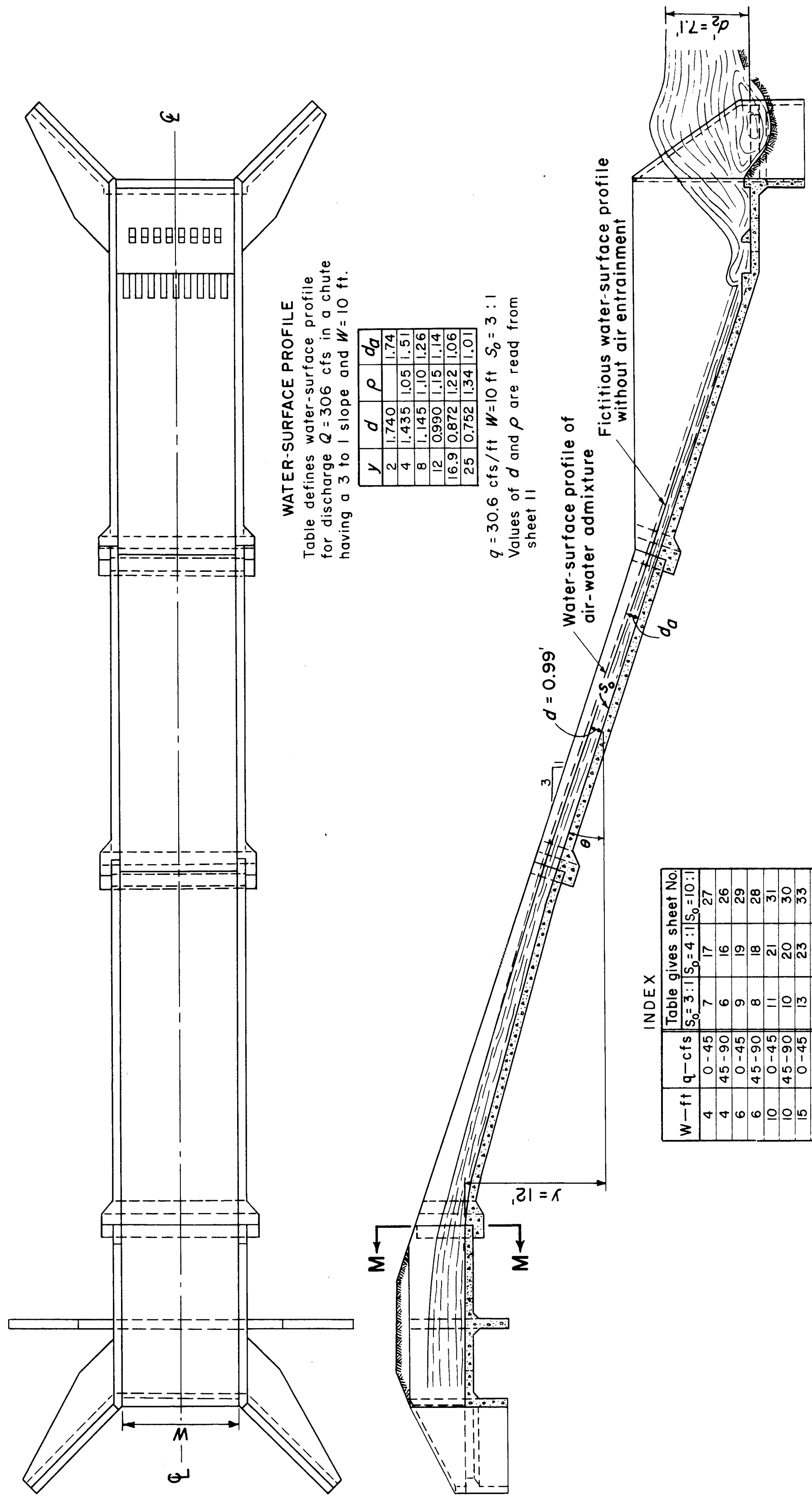
Water-surface profiles for accelerated supercritical flow in rectangular channels having a slope of 3 to 1 are given by ES-78, page 2.148 to 2.157. The probable maximum air entrainment ρ is also given in these drawings. Similar diagrams for channels having 4 to 1 and 10 to 1 slopes are given by ES-78, pages 2.158 to 2.177.

ES-147 gives water-surface profiles for 100 foot wide rectangular channels with slopes of 3 to 1, 4 to 1, and 10 to 1, pages 2.178 through 2.183. Since the influence of sidewall friction decreases with width, these drawings may be used with sufficient accuracy for all widths greater than about 50 feet.

Capacity. Since the actual depth of flow of the air-water admixture d_a in steep channels decreases only slightly for low discharges q after a vertical drop of 8 ft, the capacity without freeboard q_{mc} of the channel is taken as the capacity without freeboard q_{mN} of the vertical-curve section at section N. The capacity without freeboard q_{mc} for channels can be read from the table on page 2.186 of ES-84. The capacity without freeboard Q_{mc} may be read from ES-84, page 2.187.

CHUTE SPILLWAYS: WATER-SURFACE PROFILES; Accelerated supercritical flow

$S_o = 3:1$
$S_o = 4:1$
$S_o = 10:1$



WATER-SURFACE PROFILE

Table defines water-surface profile for discharge $Q = 306$ cfs in a chute having a 3 to 1 slope and $W = 10$ ft.

y	d	ρ	d_a
2	1.740		1.74
4	1.435	1.05	1.51
8	1.145	1.10	1.26
12	0.990	1.15	1.14
16.9	0.872	1.22	1.06
25	0.752	1.34	1.01

$q = 30.6$ cfs/ft $W = 10$ ft $S_o = 3:1$
Values of d and ρ are read from sheet 11

INDEX

W–ft	q–cfs	Table gives sheet No. $S_o = 3:1$	$S_o = 4:1$	$S_o = 10:1$
4	0-45	7	17	27
4	45-90	6	16	26
6	0-45	9	19	29
6	45-90	8	18	28
10	0-45	11	21	31
10	45-90	10	20	30
15	0-45	13	23	33
15	45-90	12	22	32
30	0-45	15	25	35
30	45-90	14	24	34

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
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STANDARD DWG. NO. ES - 78

DATE 1-12-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES; Definition of symbols.

DEFINITION OF SYMBOLS

d = Fictitious depth of flow, assuming no air entrainment, in a channel of slope as designated by the charts at a section located such that its bottom is a vertical distance of y ft below the bottom of the section at which critical depth occurs in ft

d_a = Actual depth of flow normal to channel bottom in the section at which d is evaluated in ft

d_c = Critical depth corresponding to the discharge Q in ft

y = Vertical drop from the bottom of the control section (at which critical depth occurs) to the channel bottom at the section where d is evaluated when the channel bottom has a slope as designated by the charts in ft

x = Horizontal distance of a channel having a bottom of slope as designated by the charts from the control section to the section at which d is evaluated in ft

W = Width of steep channel in ft

ρ = Volume of air-water admixture per cubic foot of water in ft^3

v = Actual velocity of water in channel of slope as designated by the charts at the section where d is evaluated in ft/sec

g = Acceleration due to gravity--32.2 ft/sec^2

Q = Discharge for which water-surface profile is determined in cfs

$Q_{c,d}$ = Critical discharge corresponding to the depth d in cfs

$Q_{n,d}$ = Normal discharge corresponding to the depth d in cfs. $Q_{n,d}$ is evaluated by the formula $Q_{n,d} = \frac{1.486}{n} ar^{2/3} s_o^{1/2}$

q = Discharge per foot width for which water-surface profile is determined in cfs/ft

θ = Angle the channel bottom makes with a horizontal plane = $\tan^{-1} s_o$

s_o = Slope of bottom of channel in ft/ft

n = Manning's coefficient of roughness

a = Channel area corresponding to the depth d in ft^2

r = Hydraulic radius corresponding to the depth d in ft

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-78 SHEET 2 OF 35 DATE 1-20-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES; Formulas.

FORMULAS AND VALUES

Differential equation of varied flow for flow on steep slopes

$$\frac{s_o}{\cos\theta}\frac{dx}{dd} = \frac{\left[\dfrac{\dfrac{Q}{W\sqrt{\cos\theta}}}{\dfrac{Q_{c,d}}{W}}\right]^2 - 1}{\left[\dfrac{\dfrac{Q}{W\sqrt{\cos\theta}}}{\dfrac{Q_{n,d}}{W}}\right]^2 - 1}$$

Actual velocity of flow in channel

$$v = \frac{q}{d}$$

Actual depth of flow is

$$d_a = \rho d$$

The air entrainment

$$\rho - 1 = 0.005\,\frac{v^2}{gd}\,{}^{*}$$

The value of the roughness coefficient used in computing the water-surface profiles as given by sheets 6 to 35 is

$$n = 0.008$$

The depth of flow at the control section is assumed to be the critical depth d_c corresponding to the discharge Q when water-surface profiles are evaluated. The actual depth of flow at the control section is d_c when the slope of the channel immediately downstream from the control section is critical s_c and can approach $0.715d_c$ as the slope of the channel immediately downstream approaches a fully aerated free overfall. The actual depth of flow at the control section d_a has a value in the closed interval $0.715d_c \leq d_a \leq d_c$ if no negative bed pressures exist in the reach immediately downstream from the control section. If negative bed pressures do exist the actual depth of flow at the control section may be greater or less than $0.715d_c$. The critical depth is used for evaluating water-surface profiles rather than any actual depth because of the curvilinear movement which exists at the control section. This curvilinear movement represents energy which is partially recoverable, either as depth of flow or kinetic energy, at a short distance downstream from the control section, probably within the distance of $x \leq 2d_c$. Since no evaluation of curvilinear movement has been made in the derivation of the differential equation, the energy head of the actual depth of flow and of the curvilinear movement is taken to be d_c at the control section. It is because of this curvilinear movement that no attempt is made to define water-surface profiles for vertical drops less than one foot ($y < 1.0$ ft). Furthermore, for the high values of q's shown by the diagrams, the corresponding d's are undoubtedly greater than the true depth of flow when the value of y is small. The derivation of the differential equation is based on the assumptions that uniform velocities and discharges occur at all cross sections; i.e., no standing waves occur. Corrections have been made in the derivation to measure depth of flow perpendicular to the slope and to account for the effect of the steep slope on the hydrostatic head. These diagrams are to be used for accelerated supercritical flows in prismatic rectangular channels having the designated slope. Interpolated values for other widths and slopes than those shown can generally be used. Values of y or d may be evaluated by extrapolation when s_o is in the interval $0.333 < s_o \leq 0.5$.

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*Gumensky, D. B., Air Entrained in Fast Water Affects Design of Training Walls and Stilling Basins, Civil Engineering, p. 35, December 1949.

CHUTE SPILLWAYS: WATER SURFACE-PROFILES; Examples

EXAMPLE 1

Given: A chute channel with a width of 10 ft (W = 10 ft) and a discharge of 200 cfs nas a depth of flow without air entrainment of 1.0 ft at section 1 (d_1 = 1.0 ft). The slope of the channel downstream from section 1 is 3 to 1. Good velocity and discharge distribution exist at section 1.

Determine: 1. The velocity of air-water admixture at section 2 which is 20 ft vertically downstream from section 1.
2. The air entrainment factor ρ of the air-water admixture at section 2.
3. The depth of flow of air-water admixture at section 2.

Solution: The slope upstream from section 1 is not given nor is it relevant to the solution of this example. The vertical drop y given by ES-78 is related to the control section as a datum for a rectangular prismatic channel of a constant slope s_o and constant q. Whenever a depth of flow is given at an unlocated section, as in this example, and the downstream slope to section 2 is constant and known, it becomes necessary to locate section 1 with respect to the common datum for the known slope and q to determine the location of section 2 with respect to the datum.

1a. Section 1 is located at a vertical distance of y_1 = 3.92 ft downstream from the control section when the channel has a 3 to 1 slope. This value y_1 = 3.92 ft is read at the intersection of q = Q/W = 200/10 = 20 cfs/ft and d = 1.0 ft.

1b. The location of section 2 is known to be 20 ft vertically downstream from section 1 or 20 + 3.92 = 23.92 ft vertically downstream from the control section if the channel slope is 3 to 1 and q = 20 cfs/ft. The depth of flow without air entrainment at section 2 is (see sheet 11) read at the intersection of q = 20 cfs/ft and y = 23.92 ft as

$$d_2 = 0.53 \text{ ft}$$

1c. The velocity of the air-water admixture at section 2 is

$$v_2 = \frac{q}{d_2} = \frac{20}{0.53} = 37.74 \text{ ft/sec}$$

2. The air entrainment factor ρ at section 2 is read on sheet 11 at y_2 = 23.92 ft q = 20 cfs/ft as

$$\rho_2 = 1.42$$

3. The depth of air-water admixture at section 2 is

$$d_{a2} = \rho_2 d_2 = 1.42 \times 0.53 = 0.752 \text{ ft}$$

EXAMPLE 2

METHOD OF INTERPOLATING FOR VALUES OF
(A) y
(B) d
WHEN WIDTH W AND SLOPE s_o ARE NOT GIVEN BY CHART

Given: A chute channel having a width of 20 ft and a depth of flow without air entrainment d = 1.0 ft at section 1. The channel is discharging q = 40 cfs/ft and has a bottom slope of 3.5 to 1 or s_o = 0.2857.

Determine: The depth of flow without air entrainment at section 2 located 18 ft vertically downstream from section 1.

Solution: The charts of ES-78 are similar and nearly identical for various widths and slopes.

A. When widths W of channels are to be considered for which no chart value is given, interpolated values of y may be used for a given slope.

A.1. The interpolated value of y for width W = 20 ft and slope 3 to 1 is obtained in the following manner.

1a. From sheet 13 (W = 15 ft) at the intersection of q = 40 cfs/ft and d = 1.0 ft read the value

$$y_{A1a} = 22.4 \text{ ft}$$

1b. From sheet 15 (W = 30 ft) at the intersection of q = 40 cfs/ft and d = 1.0 ft read the value

$$y_{A1b} = 22.1 \text{ ft}$$

1c. The interpolated value of y for W = 20 ft and s_o = 0.333 at q = 40 cfs/ft and d = 1.0 ft is

$$y_{A1c} = y_{A1a} + \frac{20 - 15}{30 - 15}(y_{A1b} - y_{A1a}) = 22.3 \text{ ft}$$

(Concluded on Sheet 5)

CHUTE SPILLWAYS : WATER SURFACE PROFILES; Examples

(Continuation from Sheet 4)

A.2. The interpolated value of y for width W = 20 ft and slope 4 to 1 is similarly obtained.

2a. From sheet 23 (W = 15 ft) at the intersection of q = 40 cfs/ft and d = 1.0 ft read the value

$$y_{A2a} = 23.0 \text{ ft}$$

2b. From sheet 25 (W = 30 ft) at the intersection of q = 40 cfs/ft and d = 1.0 ft read the value

$$y_{A2b} = 22.7 \text{ ft}$$

2c. The interpolated value of y_{A2c} for W = 20 ft and s_o = 0.25 at q = 40 cfs/ft and d = 1.0 ft is

$$y_{A2c} = y_{A2a} + \frac{20 - 15}{30 - 15}(y_{A2b} - y_{A2a}) = 22.9 \text{ ft}$$

A.3. The interpolated value of y_1 for W = 20 ft and slope 3.5 to 1 at q = 40 cfs/ft and d = 1.0 ft is

$$y_1 = y_{A2c} + \frac{0.2857 - 0.25}{0.3333 - 0.25}(y_{A1c} - y_{A2c}) = 22.6 \text{ ft}$$

B. When widths W of channels are to be considered for which no chart value is given, interpolated values of d may be used for a given slope.

B.1. The interpolated value of d for width W = 20 ft and slope 3 to 1 is obtained in the following manner.

1a. From sheet 13 (W = 15 ft) at the intersection of q = 40 cfs/ft and $y_2 = 18 + y_1 = 40.6$ ft read the value

$$d_{B1a} = 0.805 \text{ ft}$$

1b. From sheet 15 (W = 30 ft) at the intersection of q = 40 cfs/ft and y_2 = 40.6 ft read the value

$$d_{B1b} = 0.800 \text{ ft}$$

1c. The interpolated value of d for W = 20 ft and s_o = 0.3333 at q = 40 cfs/ft and y_2 = 40.6 ft is

$$d_{B1c} = d_{B1a} + \frac{20 - 15}{30 - 15}(d_{B1b} - d_{B1a}) = 0.803 \text{ ft}$$

B.2. The interpolated value of d for width W = 20 ft and slope 4 to 1 is similarly obtained.

2a. From sheet 23 (W = 15 ft) at the intersection of q = 40 cfs/ft and y_2 = 40.6 ft read the value

$$d_{B2a} = 0.826 \text{ ft}$$

2b. From sheet 25 (W = 30 ft) at the intersection of q = 40 cfs/ft and y_2 = 40.6 ft read the value

$$d_{B2b} = 0.818 \text{ ft}$$

2c. The interpolated value of d_{B2c} for W = 20 ft and s_o = 0.25 at q = 40 cfs/ft and y_2 = 40.6 ft is

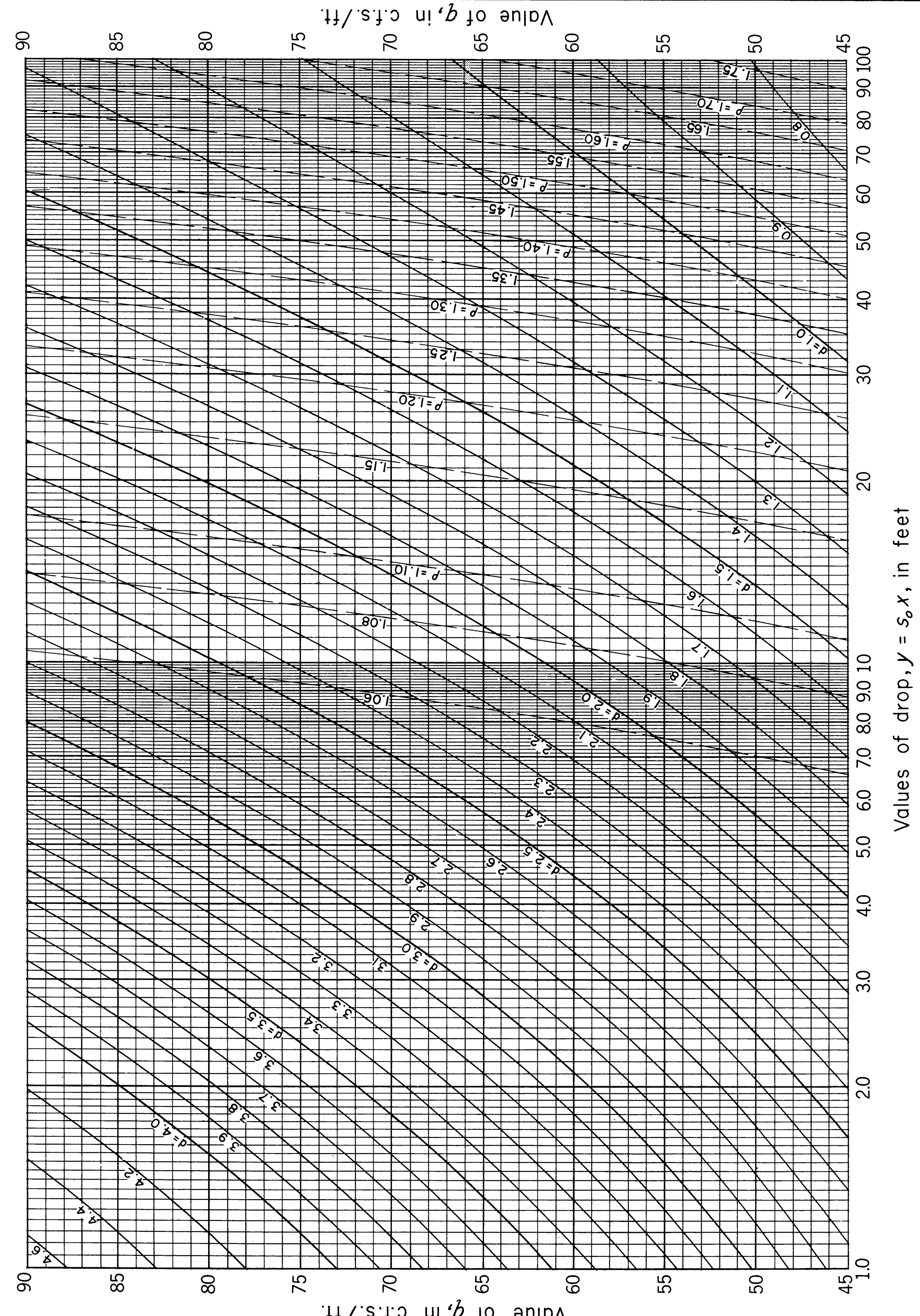
$$d_{B2c} = d_{B2a} + \frac{20 - 15}{30 - 15}(d_{B2b} - d_{B2a}) = 0.823 \text{ ft}$$

B.3. The interpolated value of d_2 for W = 20 ft and slope 3.5 to 1 at q = 40 cfs/ft and y_2 = 40.6 ft is

$$d_2 = d_{B2c} + \frac{0.2857 - 0.25}{0.3333 - 0.25}(d_{B1c} - d_{B2c}) = 0.814 \text{ ft}$$

2.148

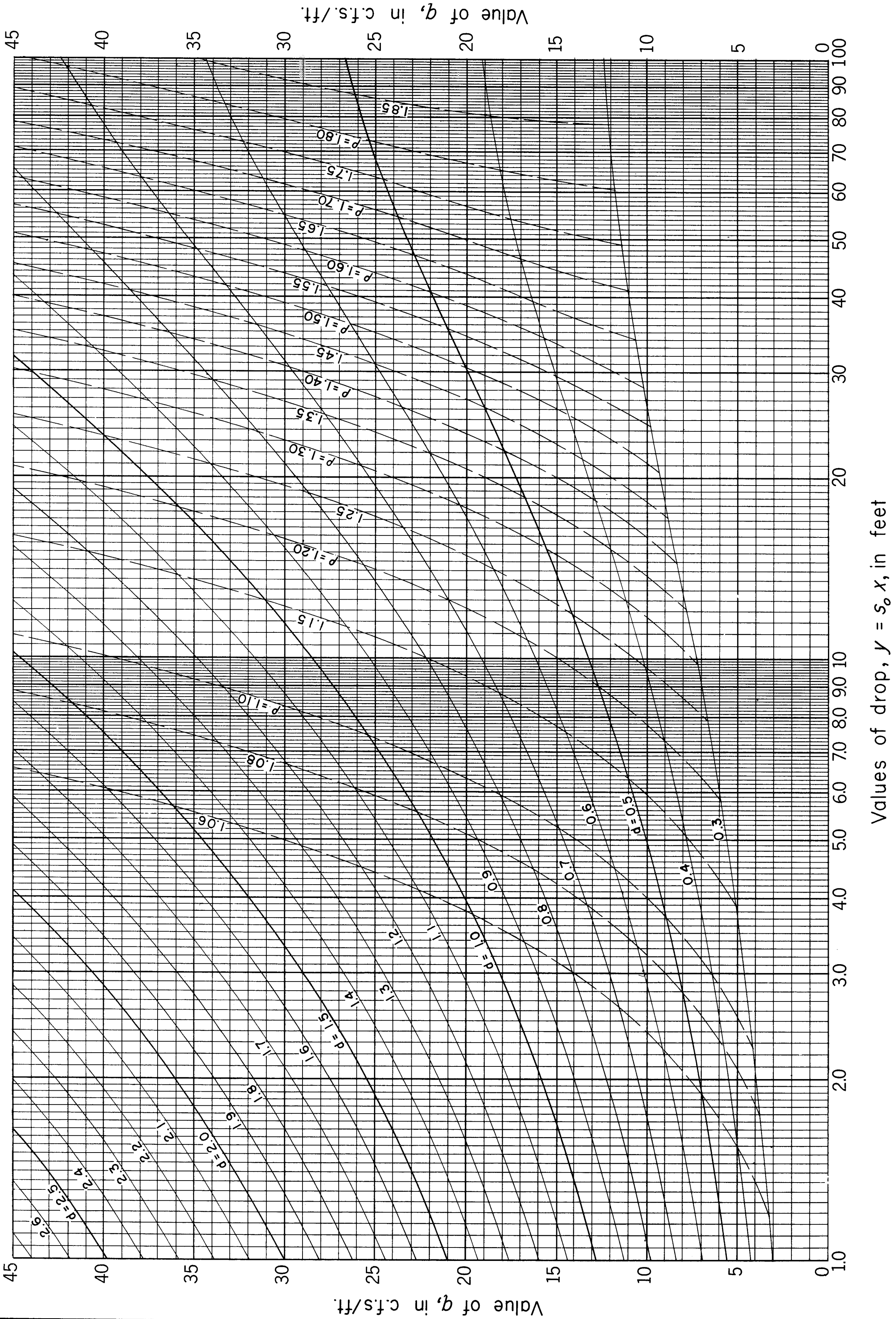
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.	W = 4 feet q = 45 to 90 s_o = 3:1



REFERENCE This diagram 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 – 78 SHEET 6 OF 35 DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 4 feet
q = 0 to 45
S_0 = 3 : 1



REFERENCE
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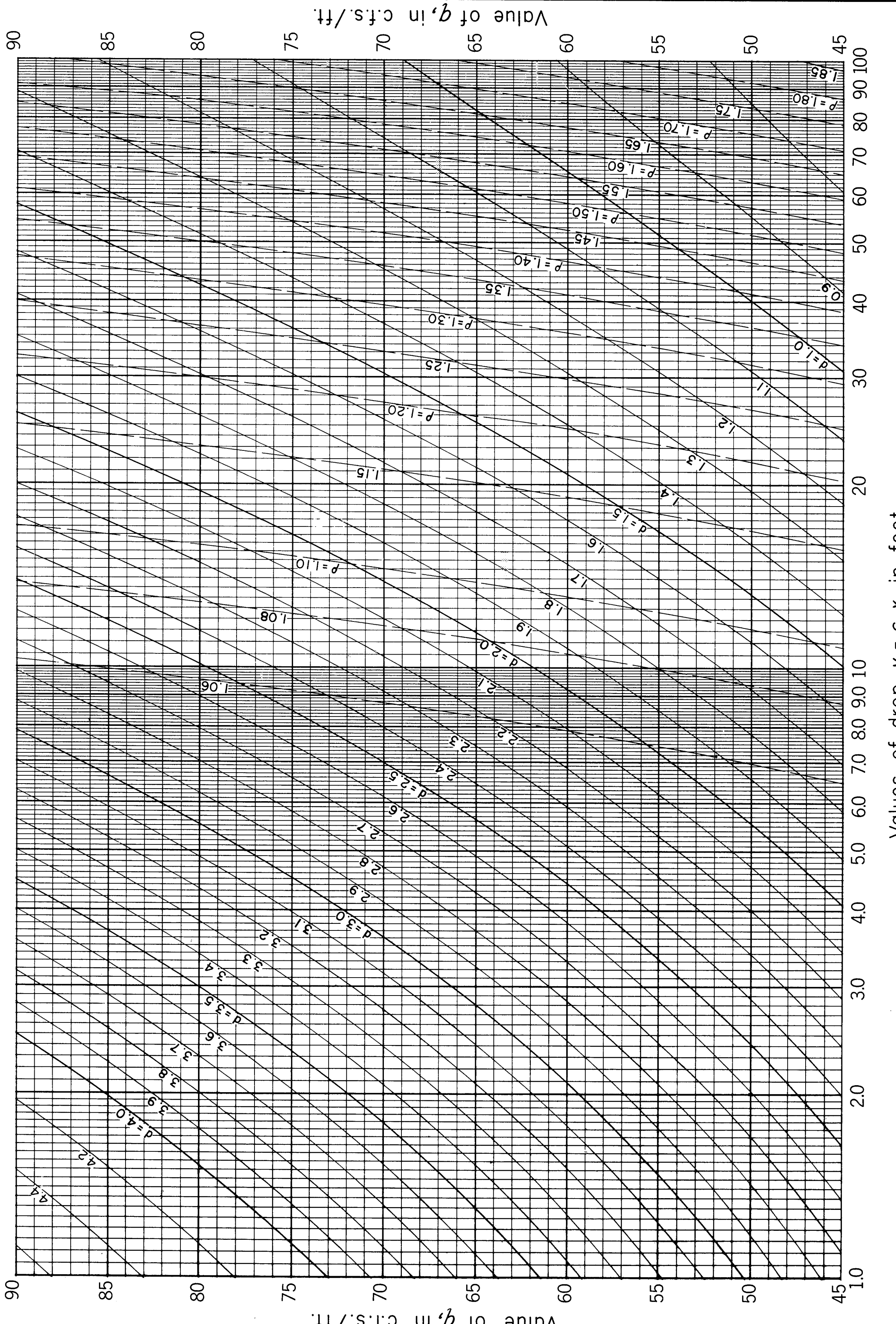
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 6 feet
q = 45 to 90
s_o = 3:1



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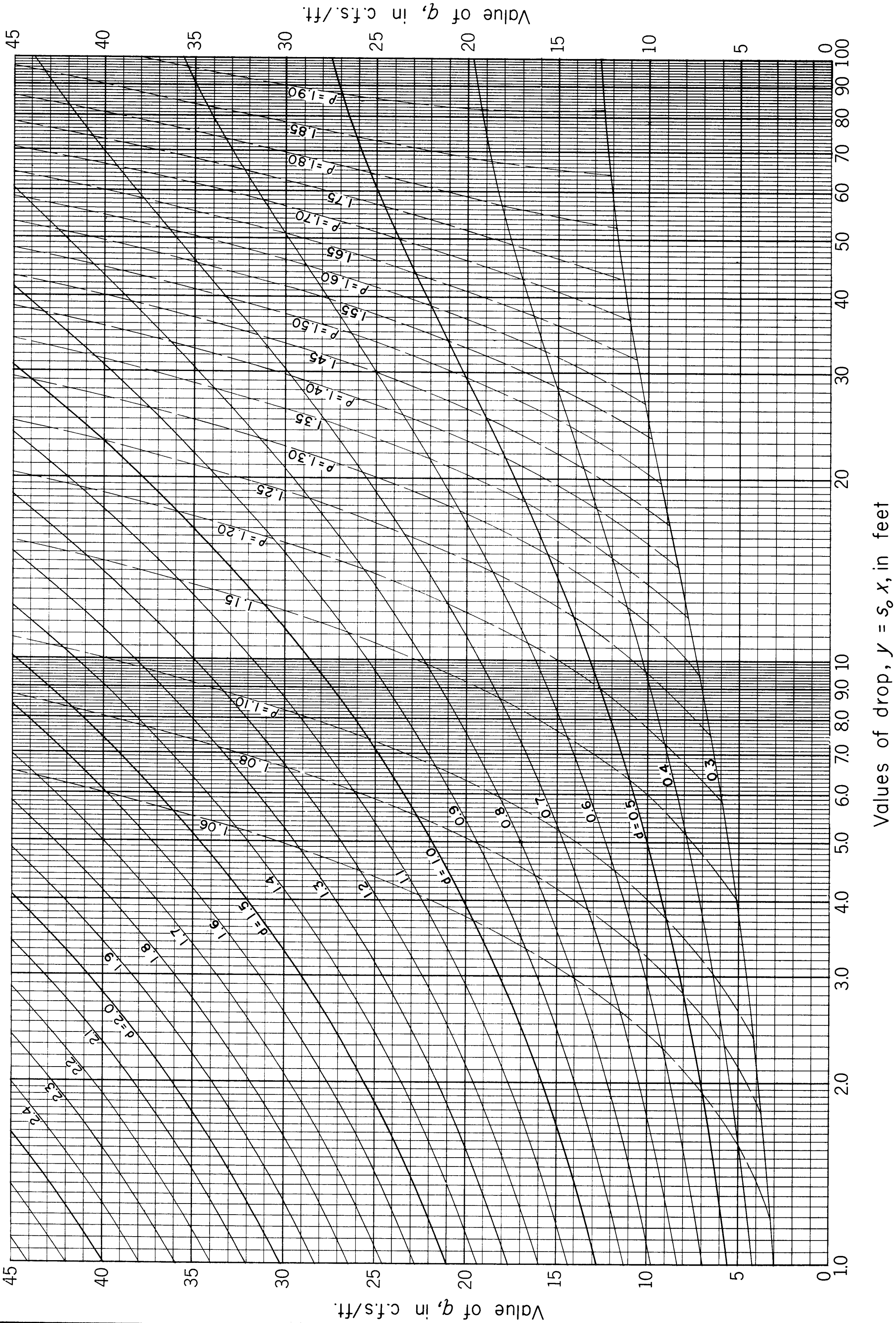
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 6 feet
q = 0 to 45
s_o = 3 : 1



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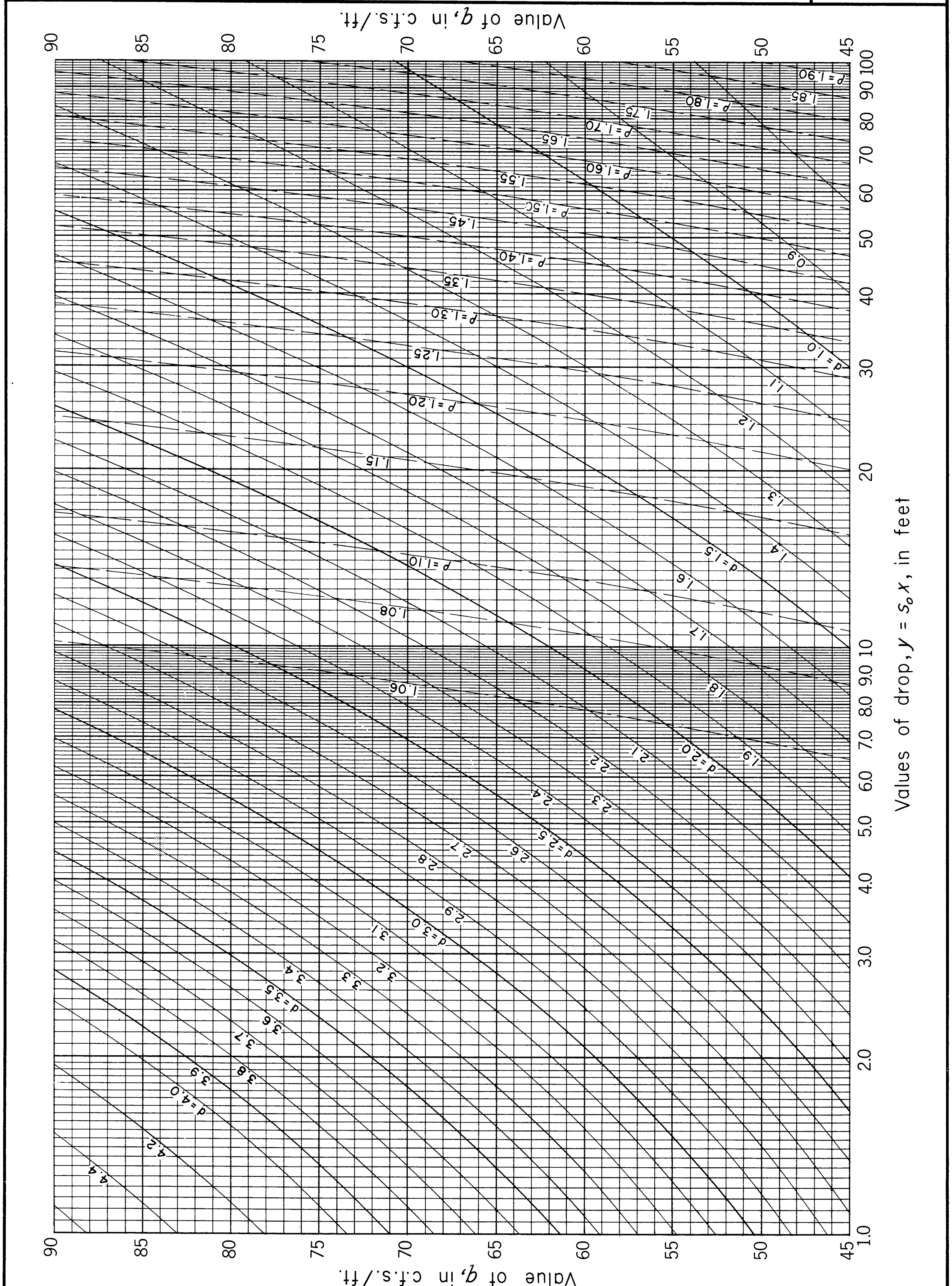
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 10 feet
q = 45 to 90
s_o = 3:1



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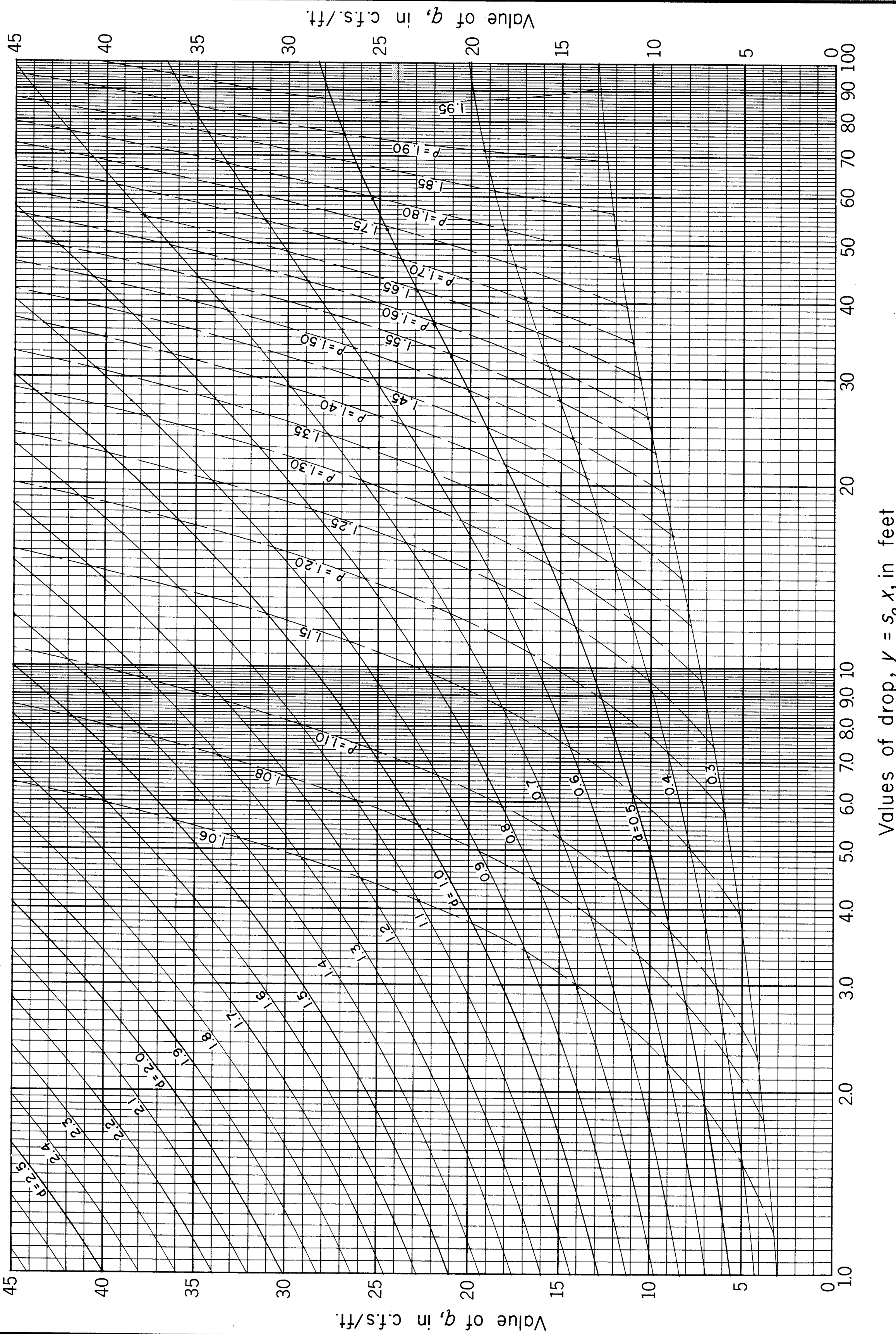
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 10 feet
q = 0 to 45
s_o = 3 : 1



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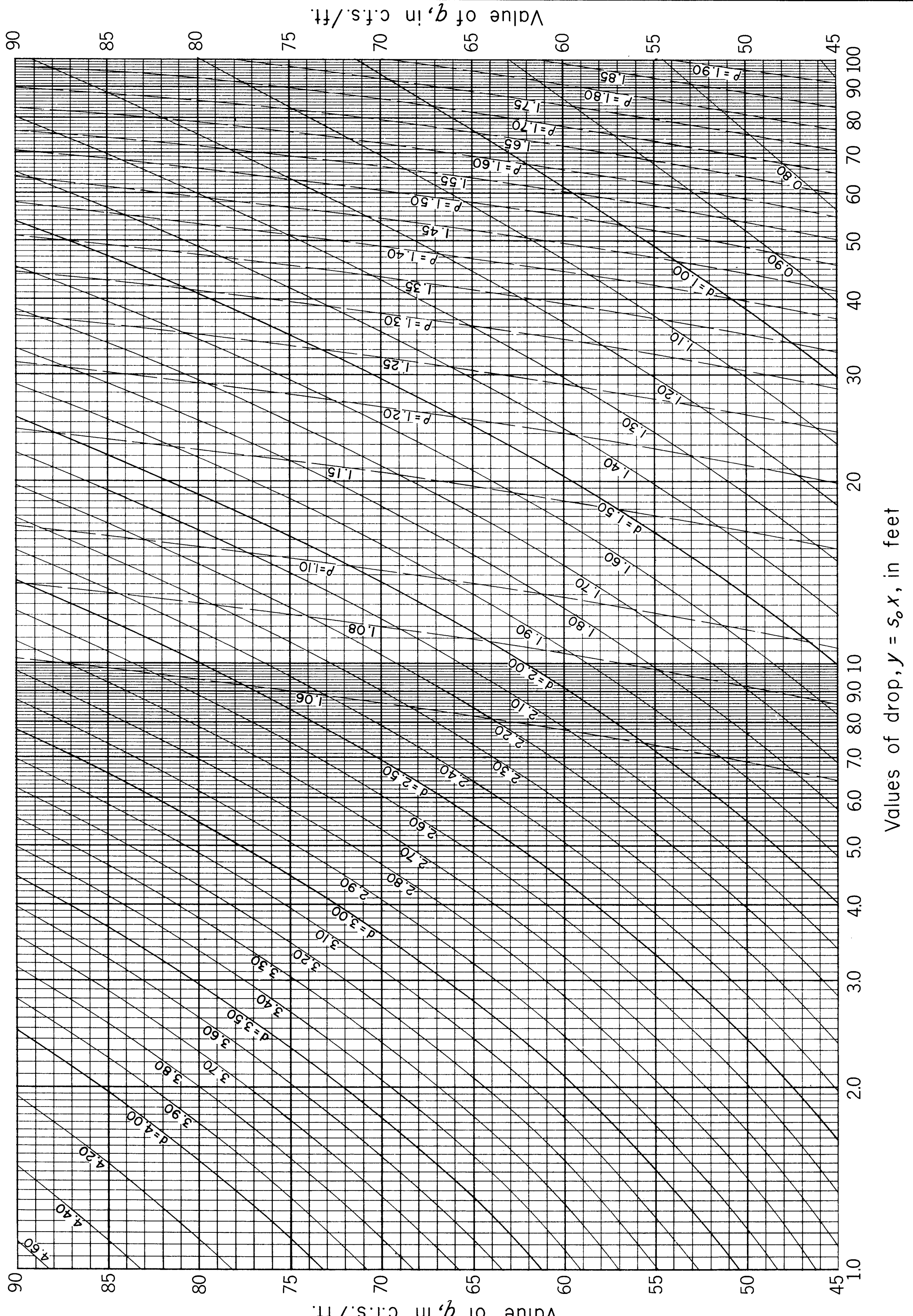
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 15 feet
q = 45 to 90
s_o = 3:1



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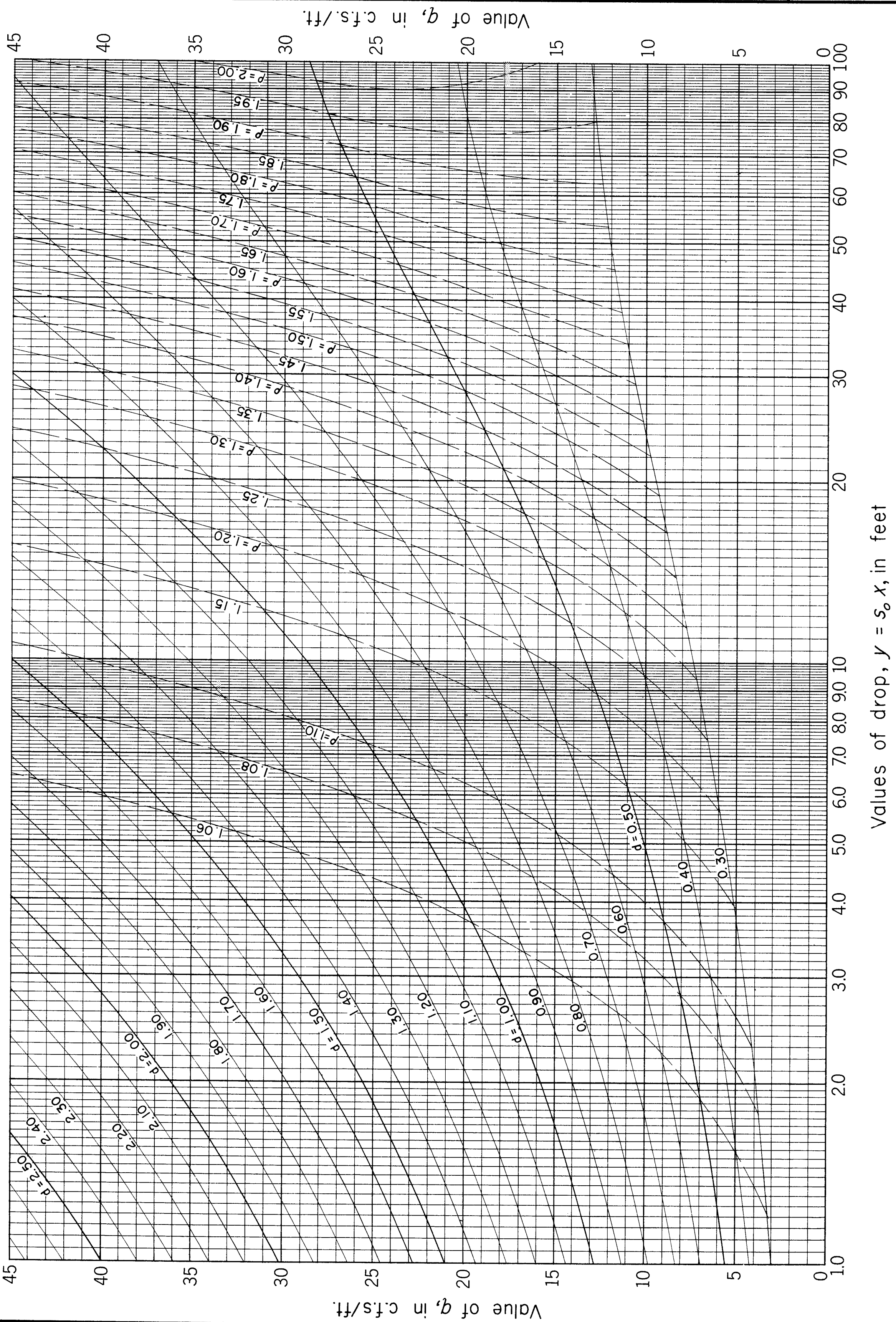
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 15 feet
q = 0 to 45
S_o = 3 : 1



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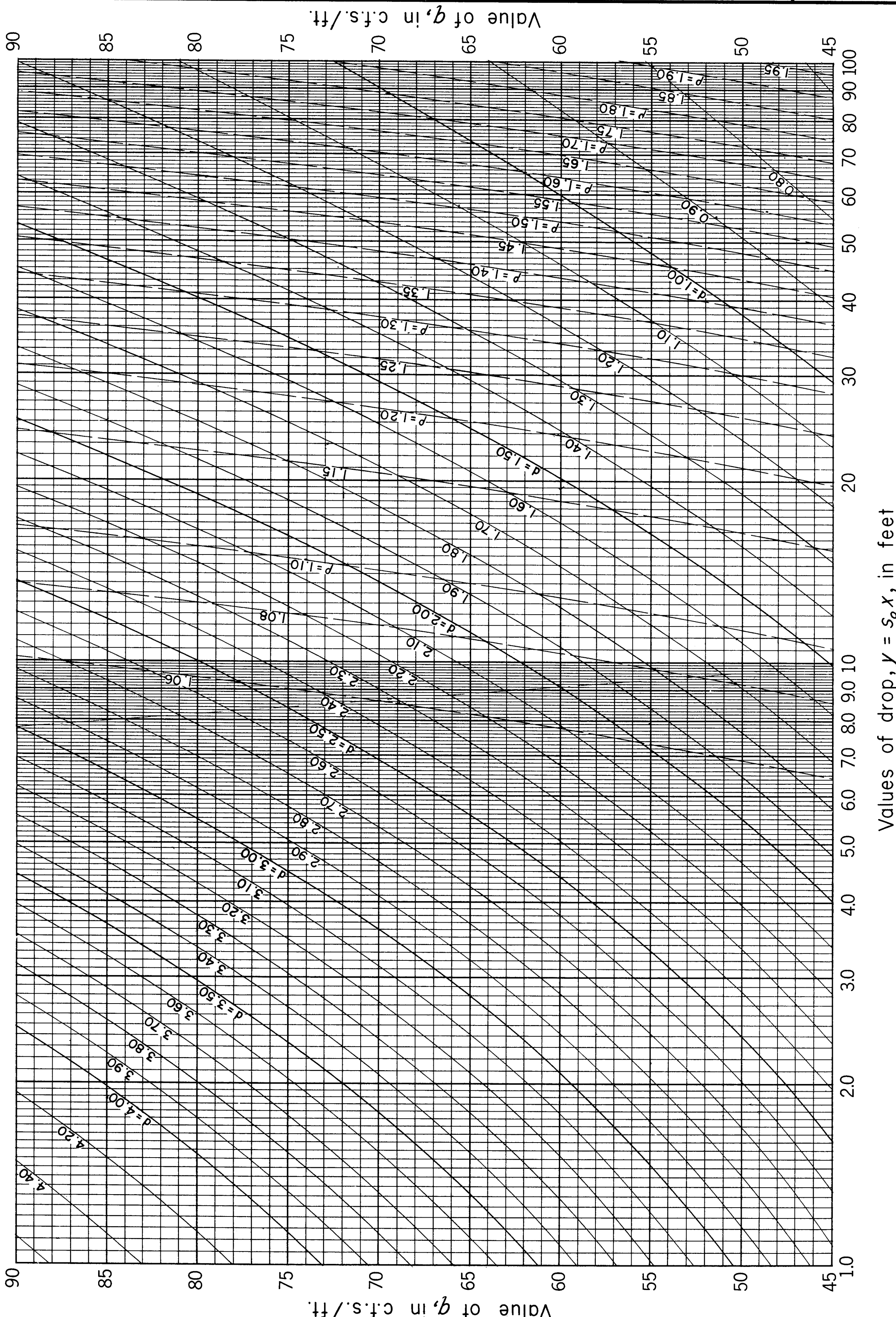
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 30 feet
q = 45 to 90
s_o = 3:1



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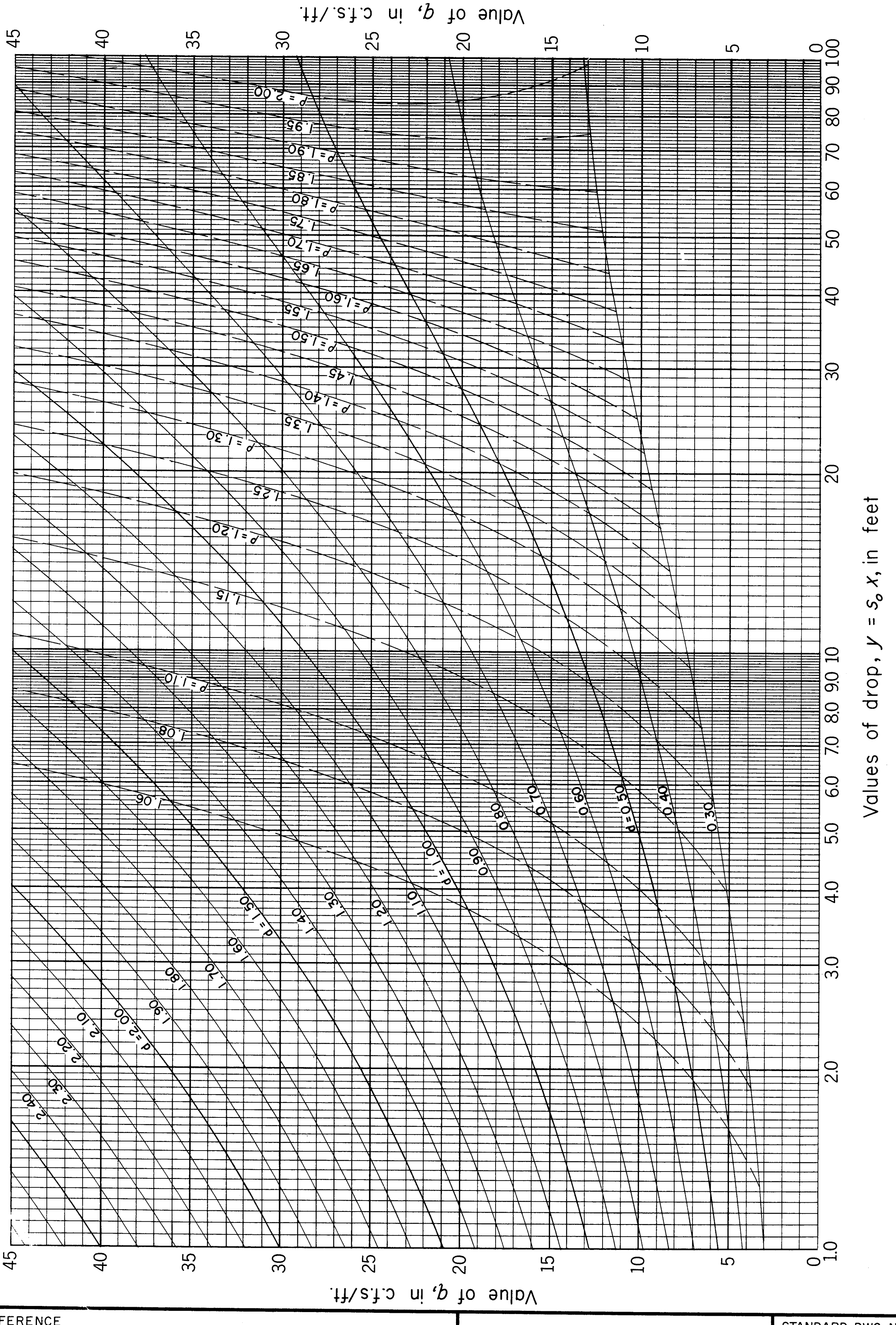
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 30 feet
q = 0 to 45
S_o = 3 : 1



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STANDARD DWG. NO.
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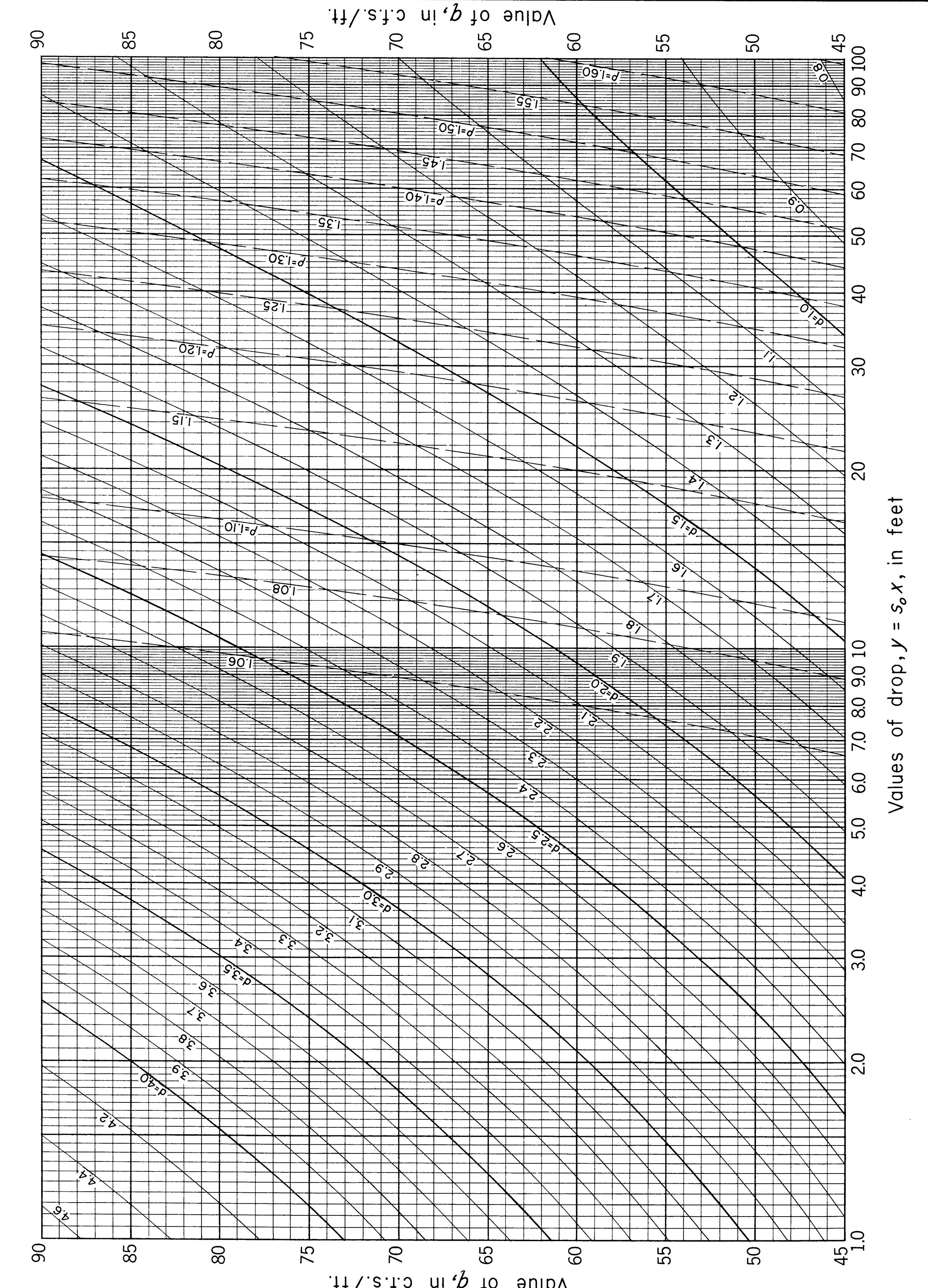
CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS: Accelerated supercritical flow.

W = 4 feet
q = 45 to 90
s_o = 4 : 1



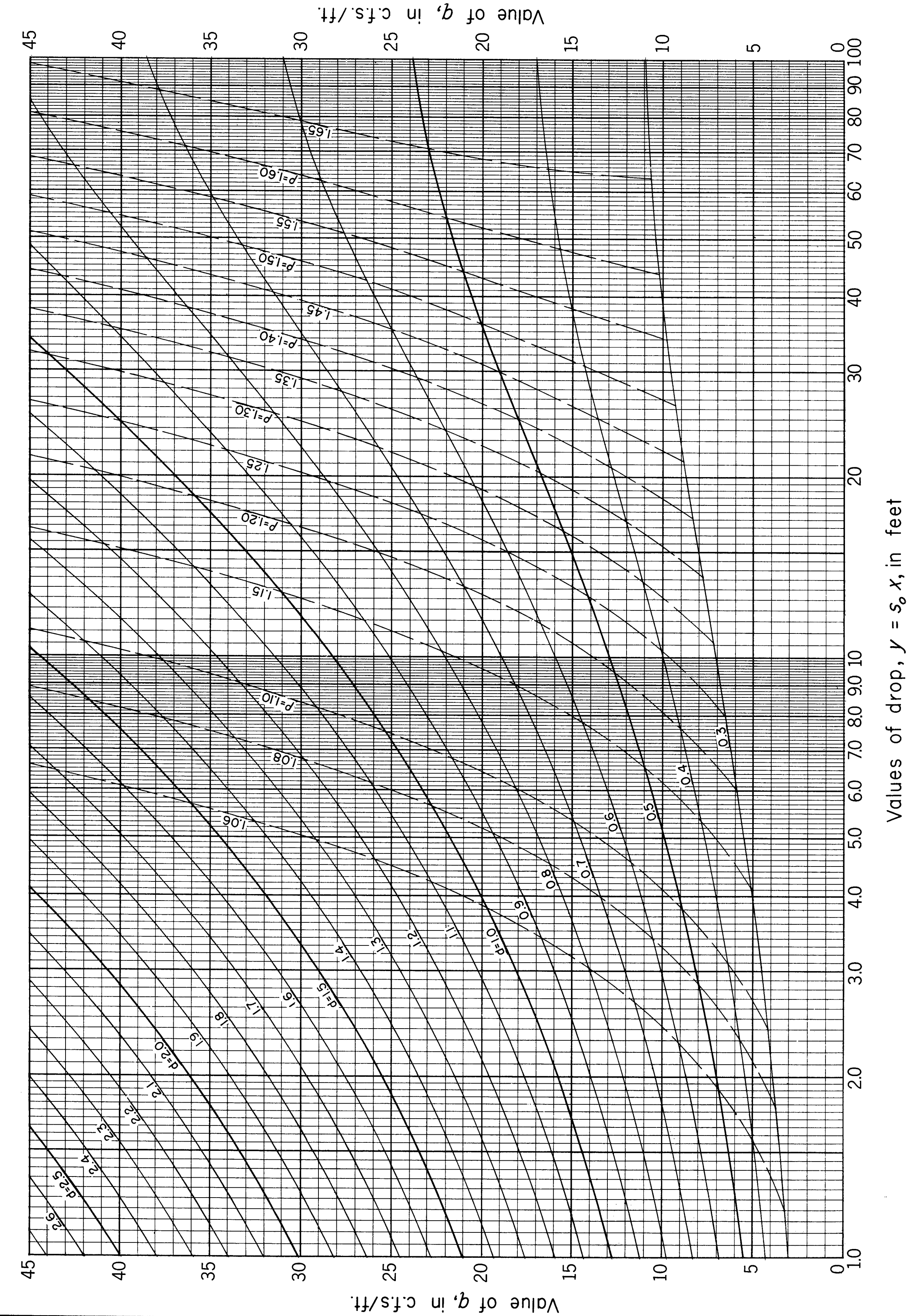
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 16 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 4 feet
q = 0 to 45
s_o = 4 : 1



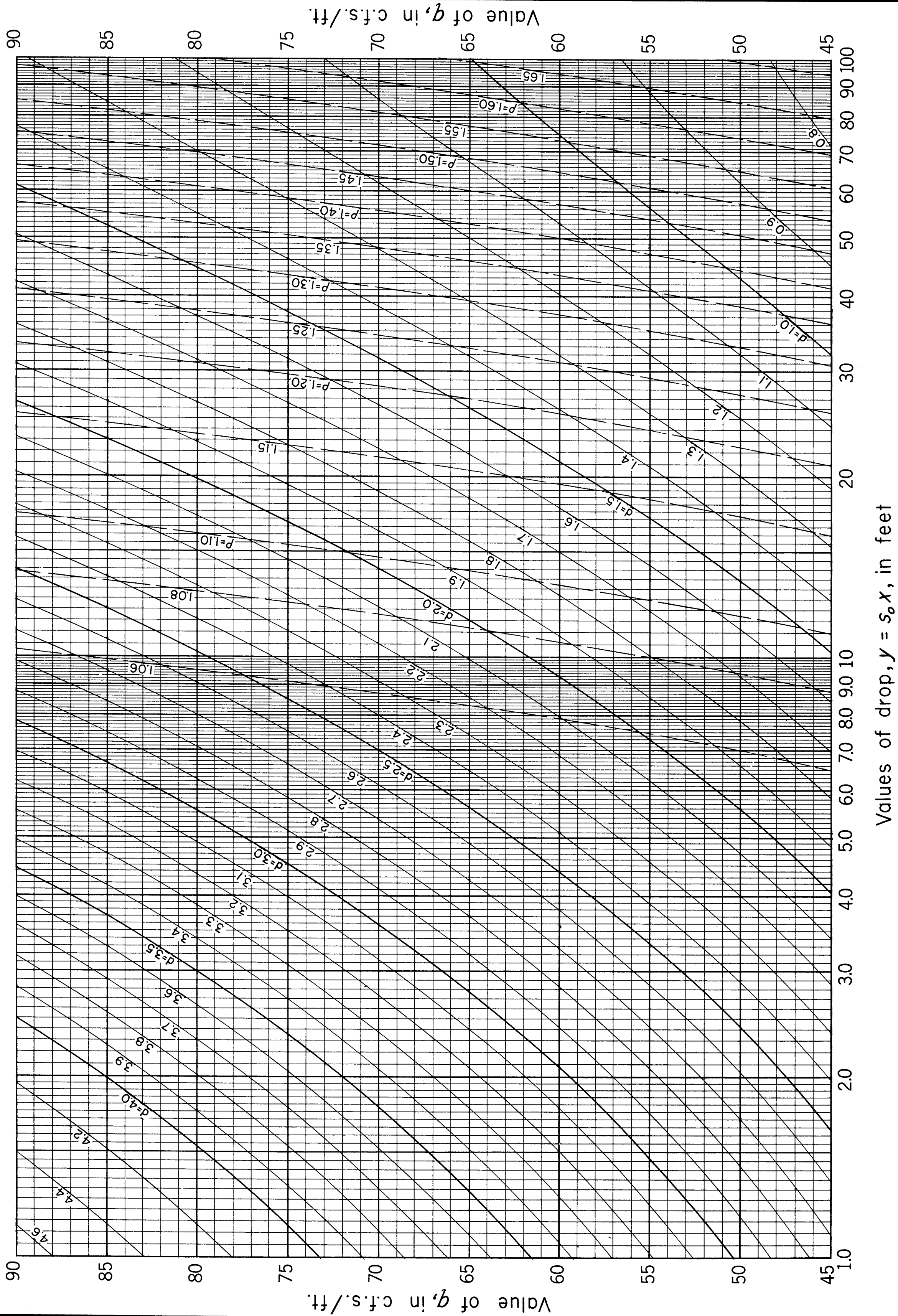
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 17 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 6 feet
q = 45 to 90
s_o = 4 : 1



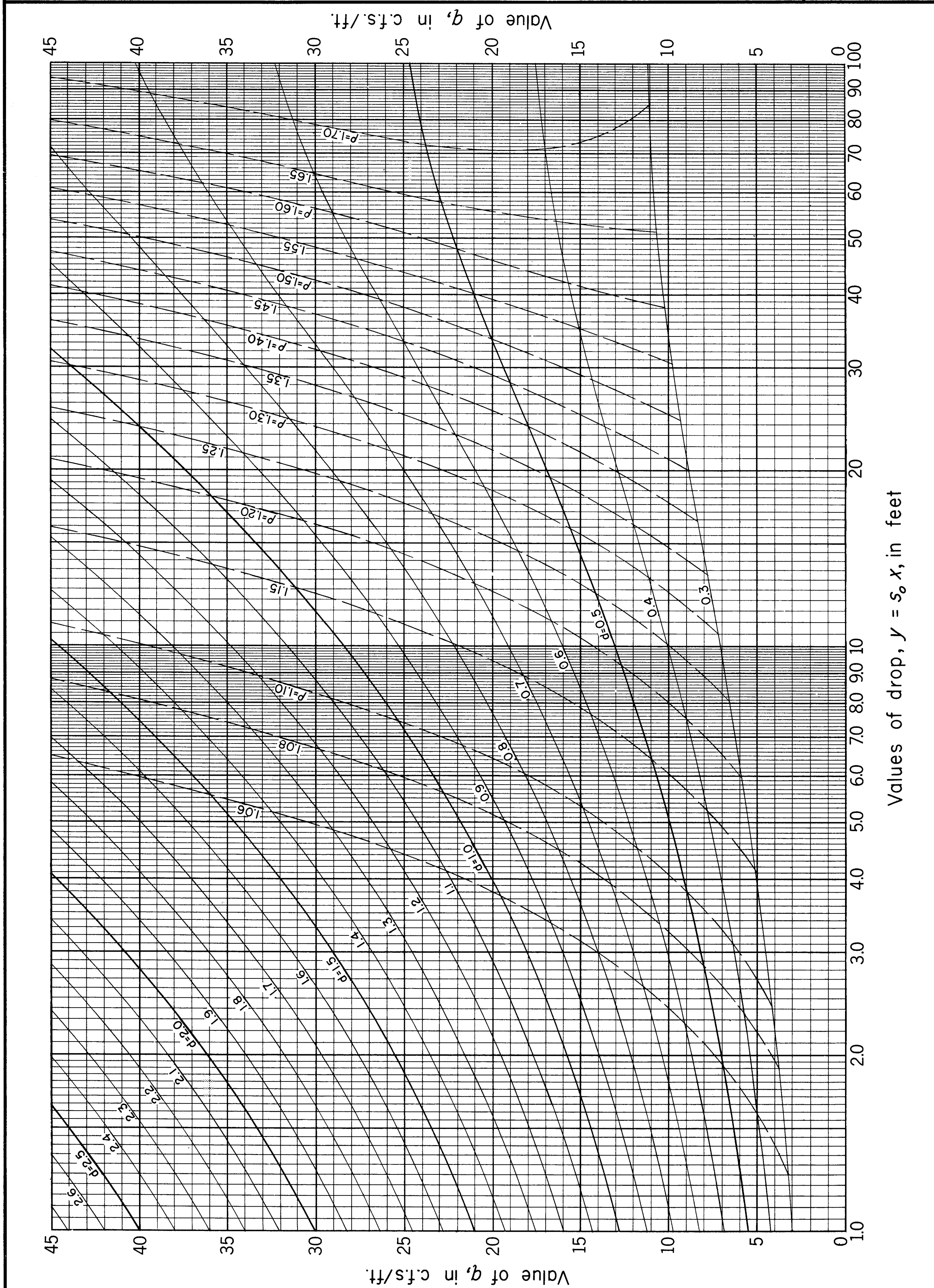
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 18 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 6 feet
q = 0 to 45
s_o = 4 : 1



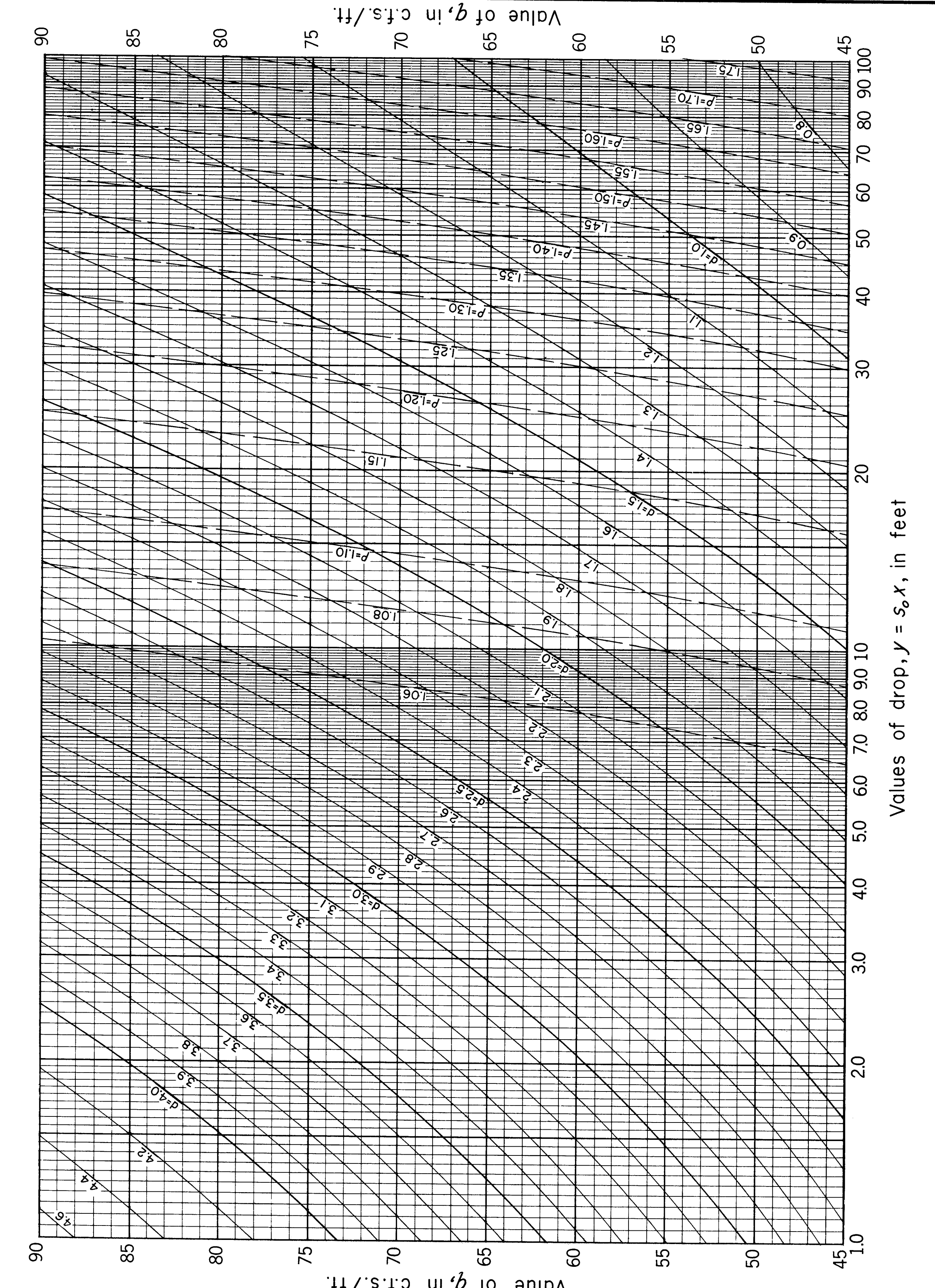
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 19 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 10 feet
q = 45 to 90
s_o = 4 : 1



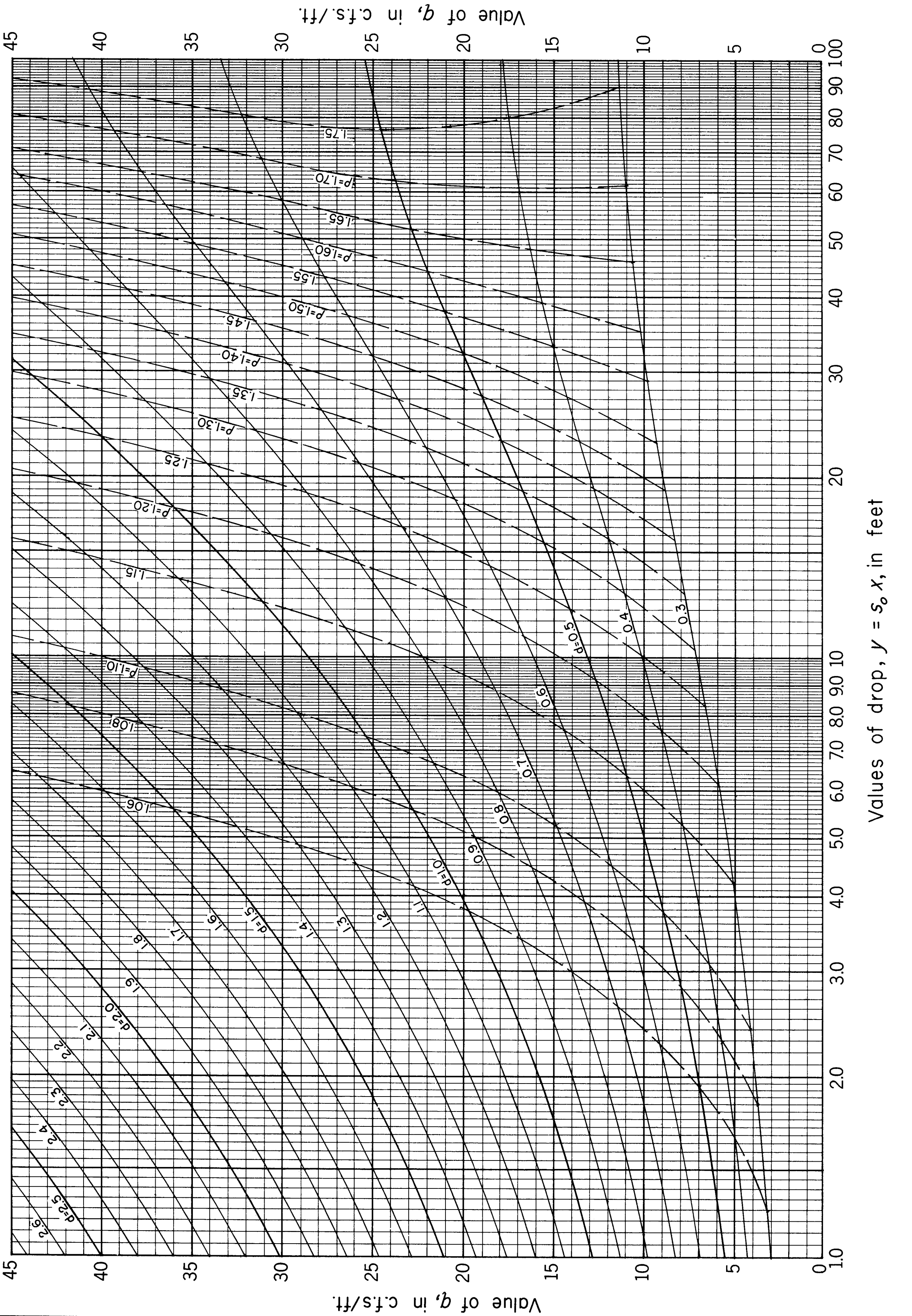
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 20 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 10 feet
q = 0 to 45
S_o = 4 : 1



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

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SOIL CONSERVATION SERVICE
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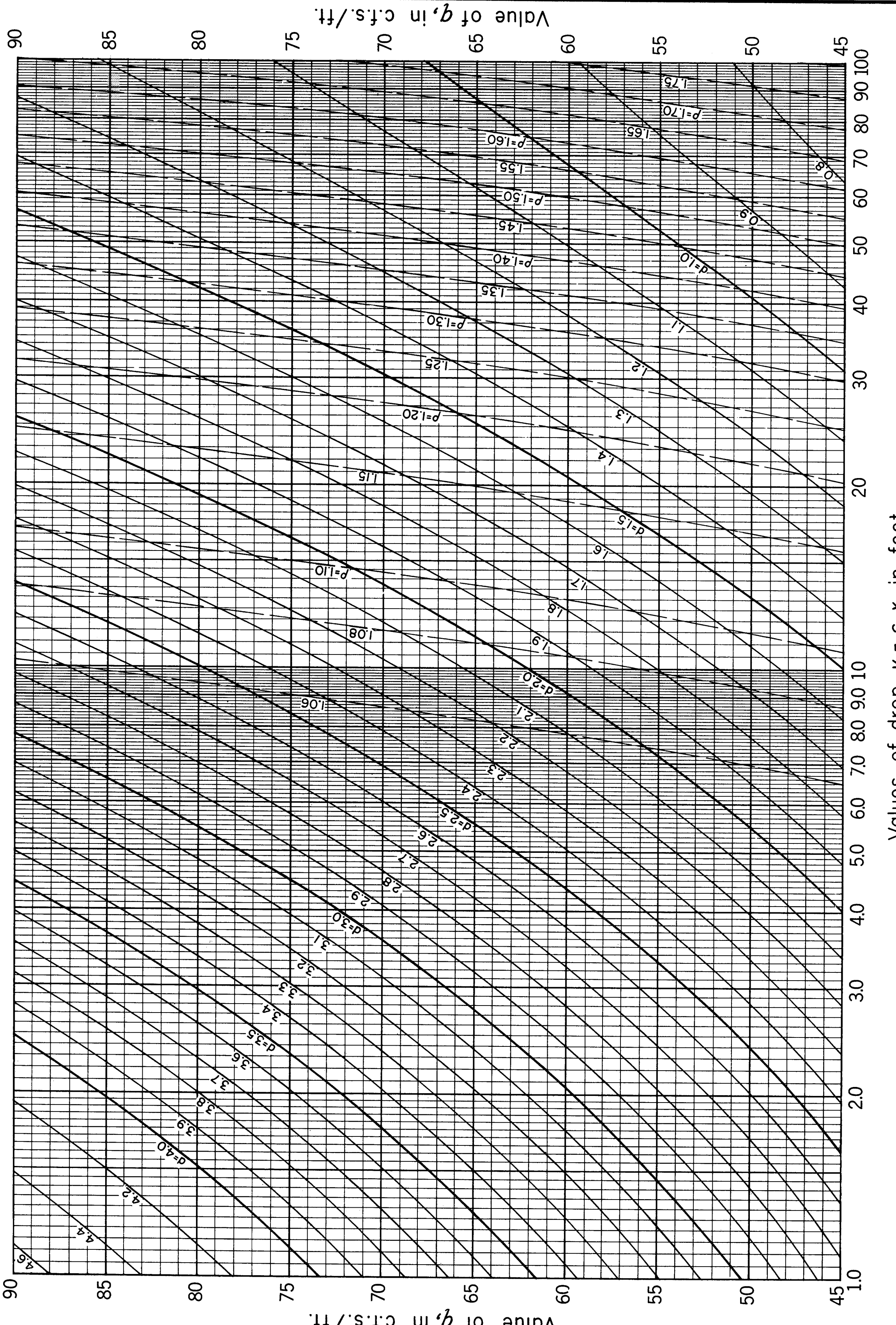
STANDARD DWG. NO.
ES - 78
SHEET 21 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 15 feet
q = 45 to 90
s_o = 4 : 1



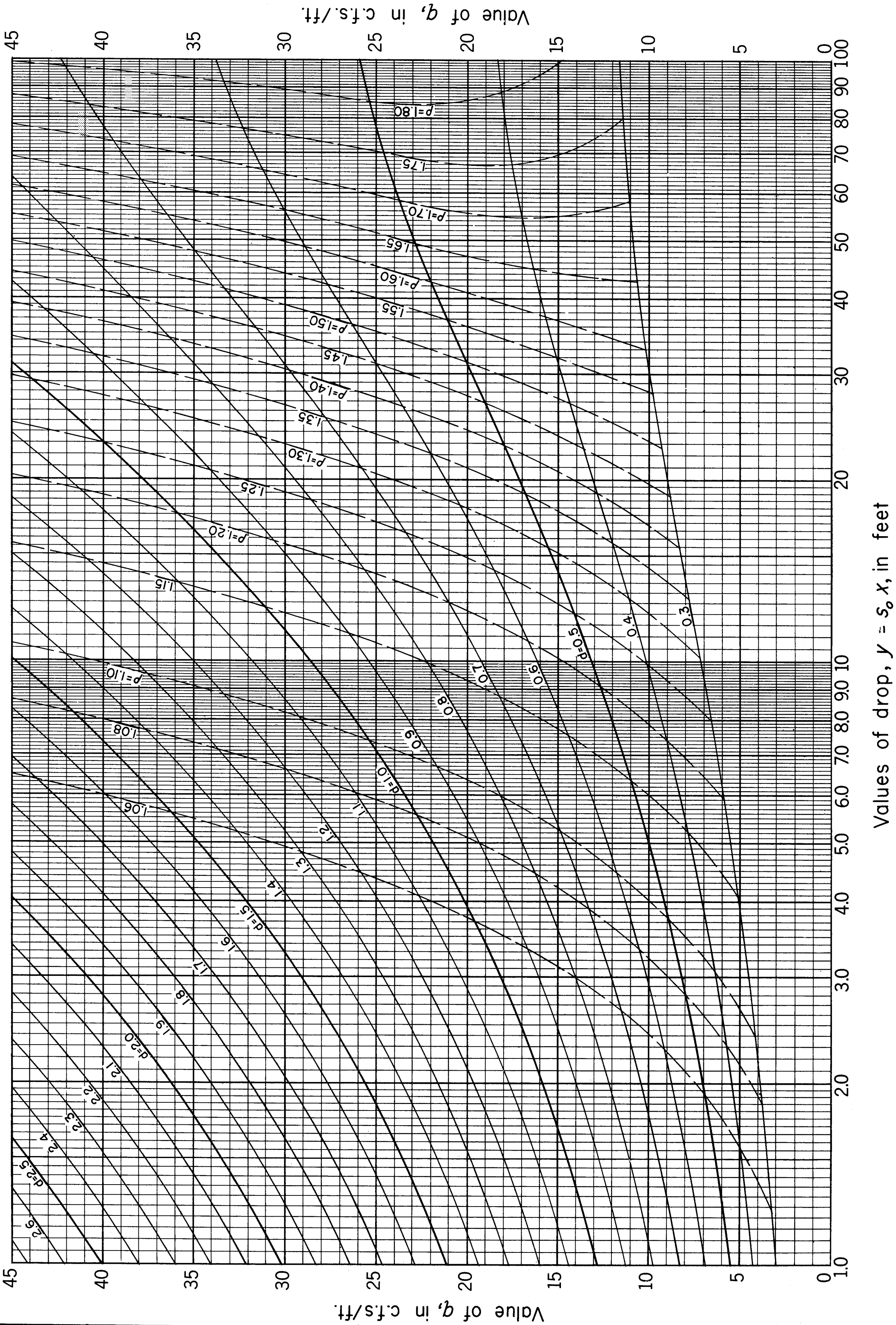
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 22 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 15 feet
q = 0 to 45
S_o = 4 : 1



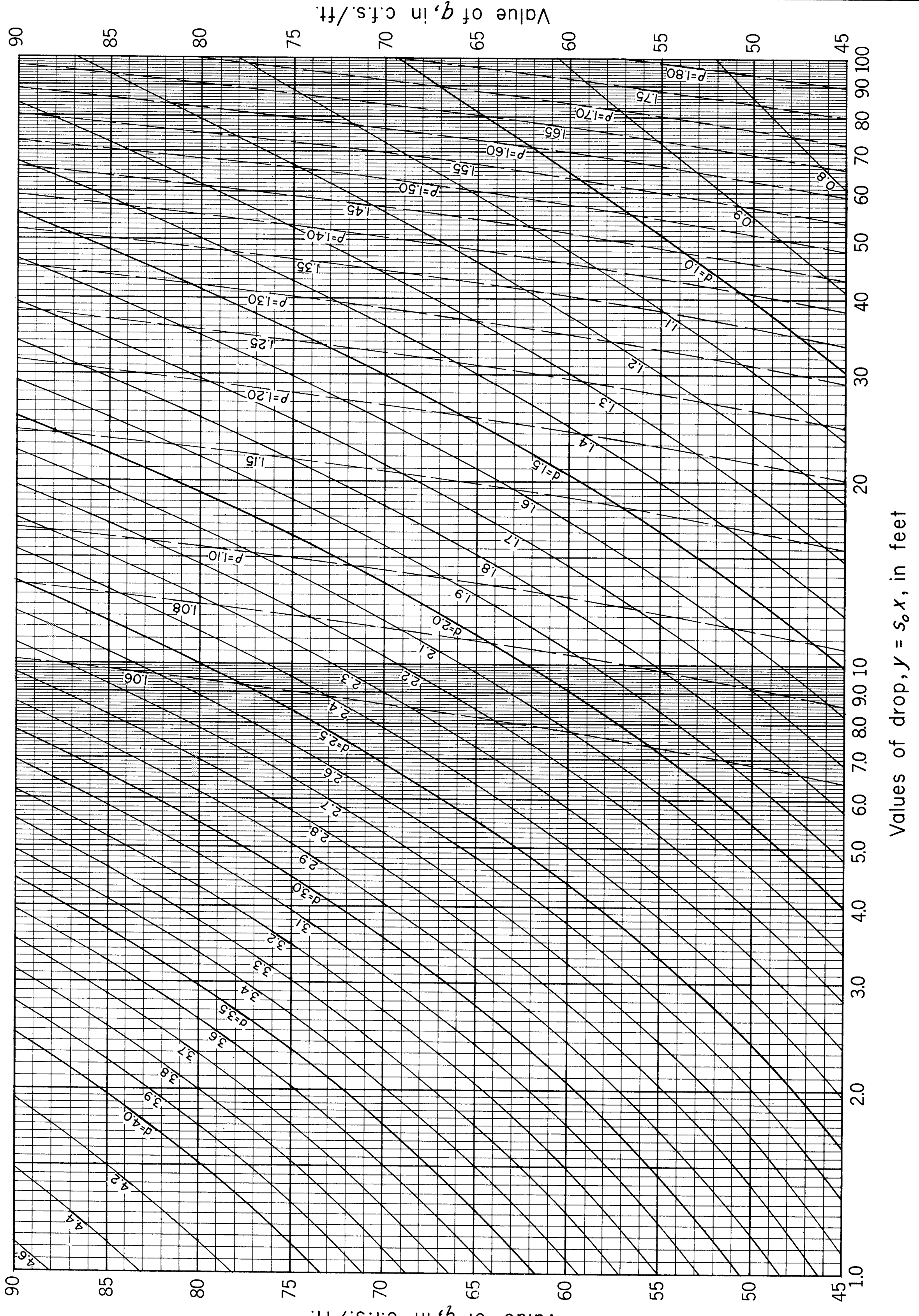
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 23 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 30 feet
q = 45 to 90
s_o = 4 : 1



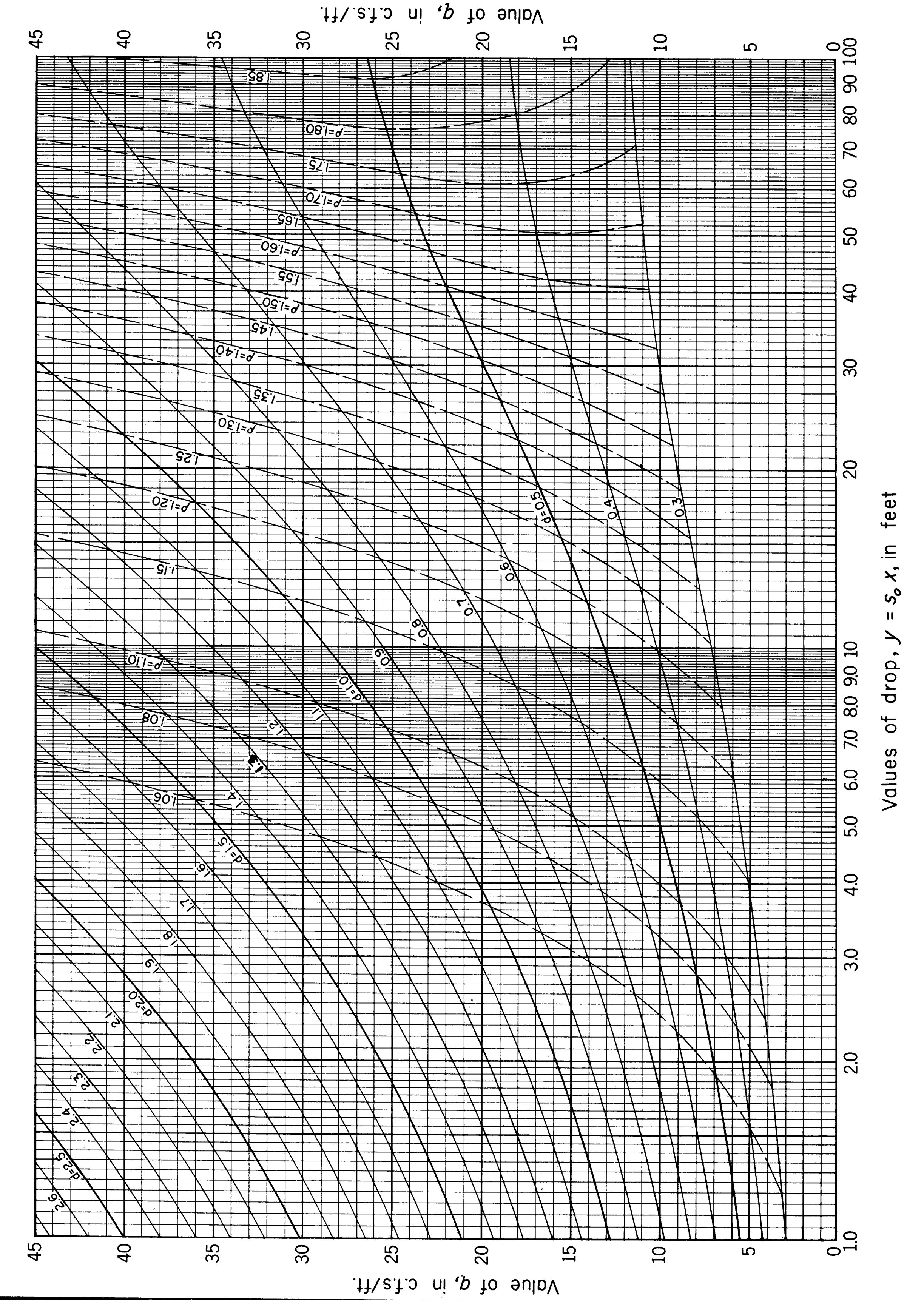
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 24 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 30 feet
q = 0 to 45
S_o = 4 : 1



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

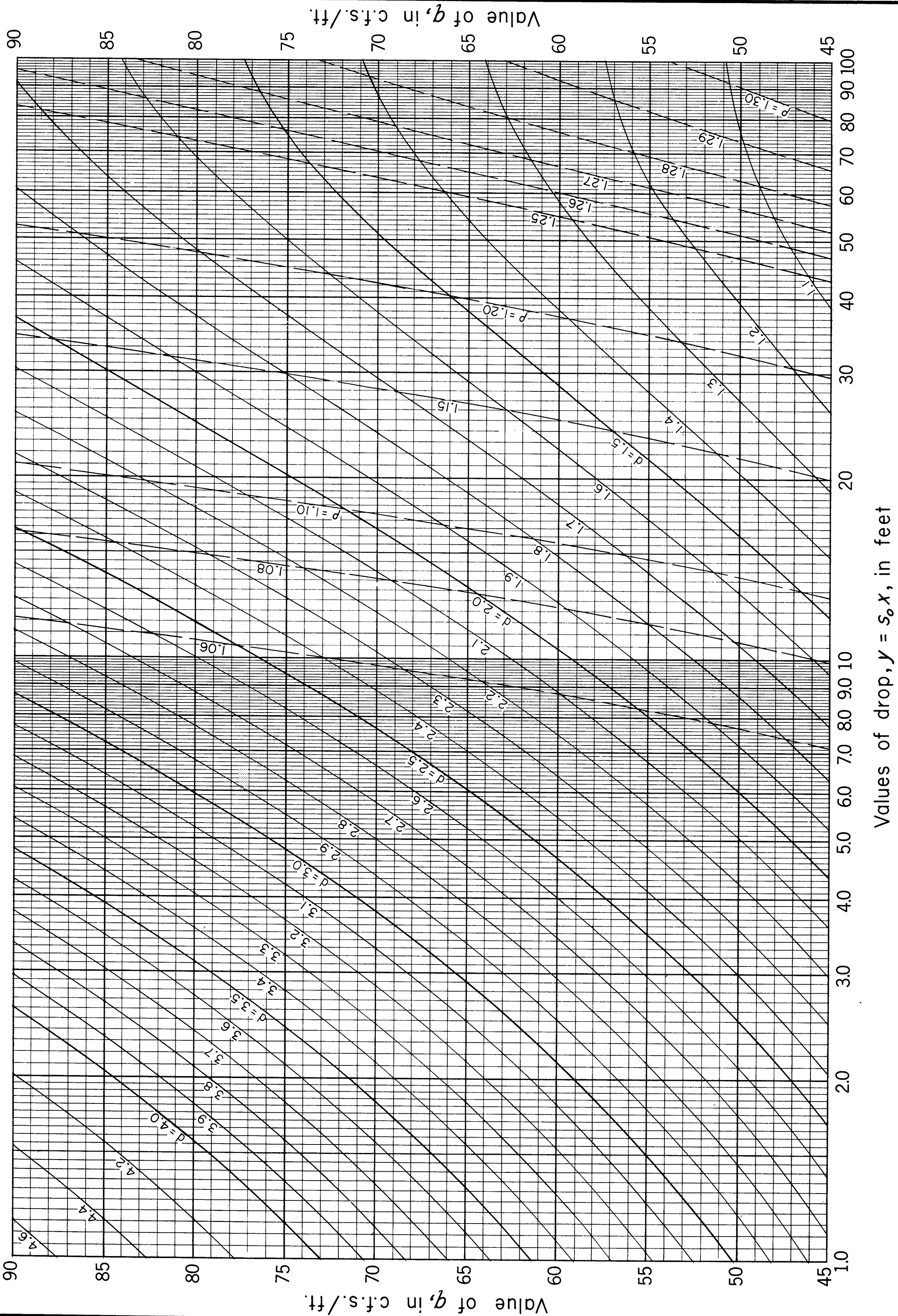
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.
ES - 78
SHEET 25 OF 35
DATE 1-14-55

Revised 10/77

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 4 feet
q = 45 to 90
s_o = 10 : 1



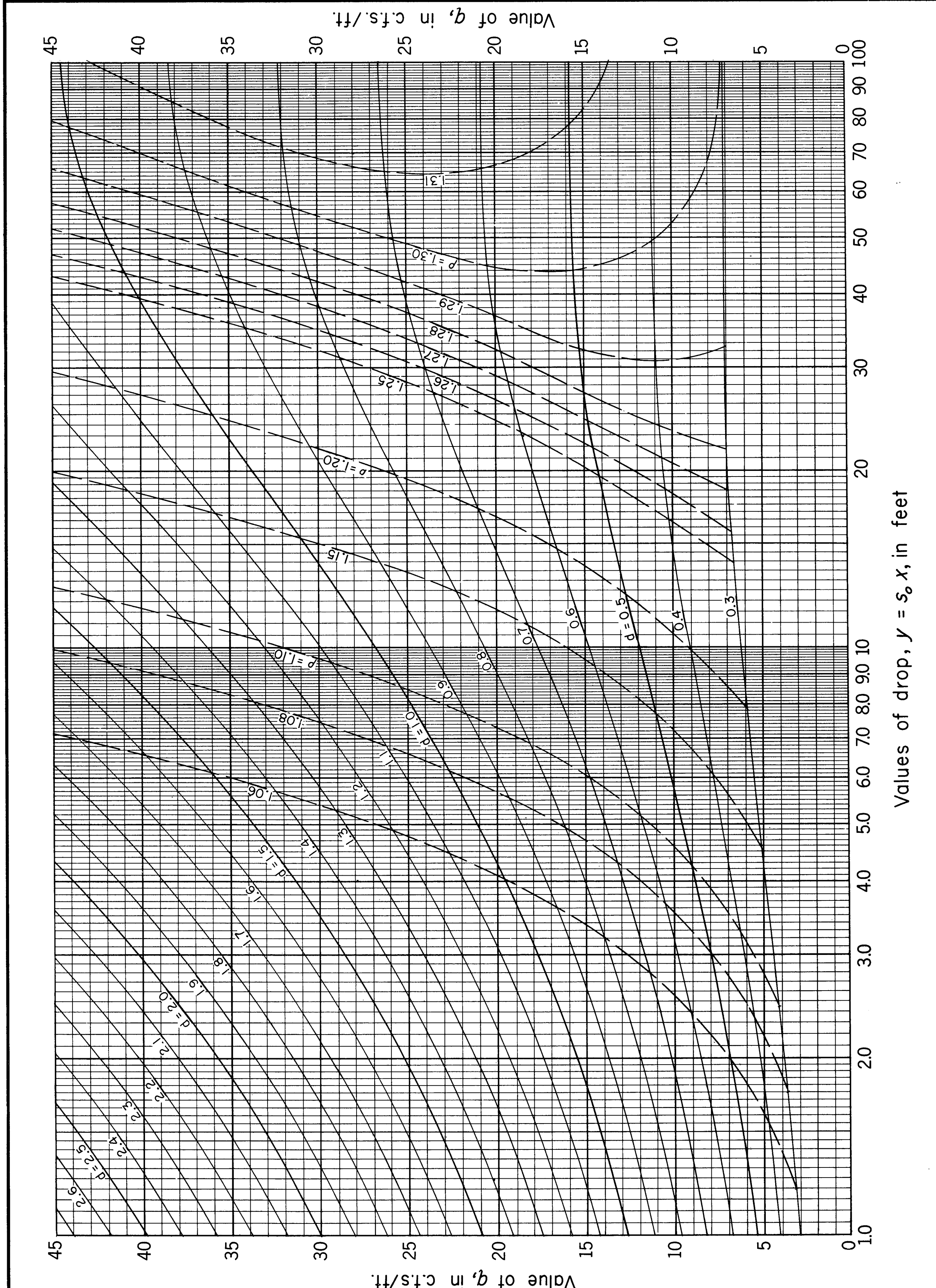
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 26 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 4 feet
q = 0 to 45
S_o = 10 : 1



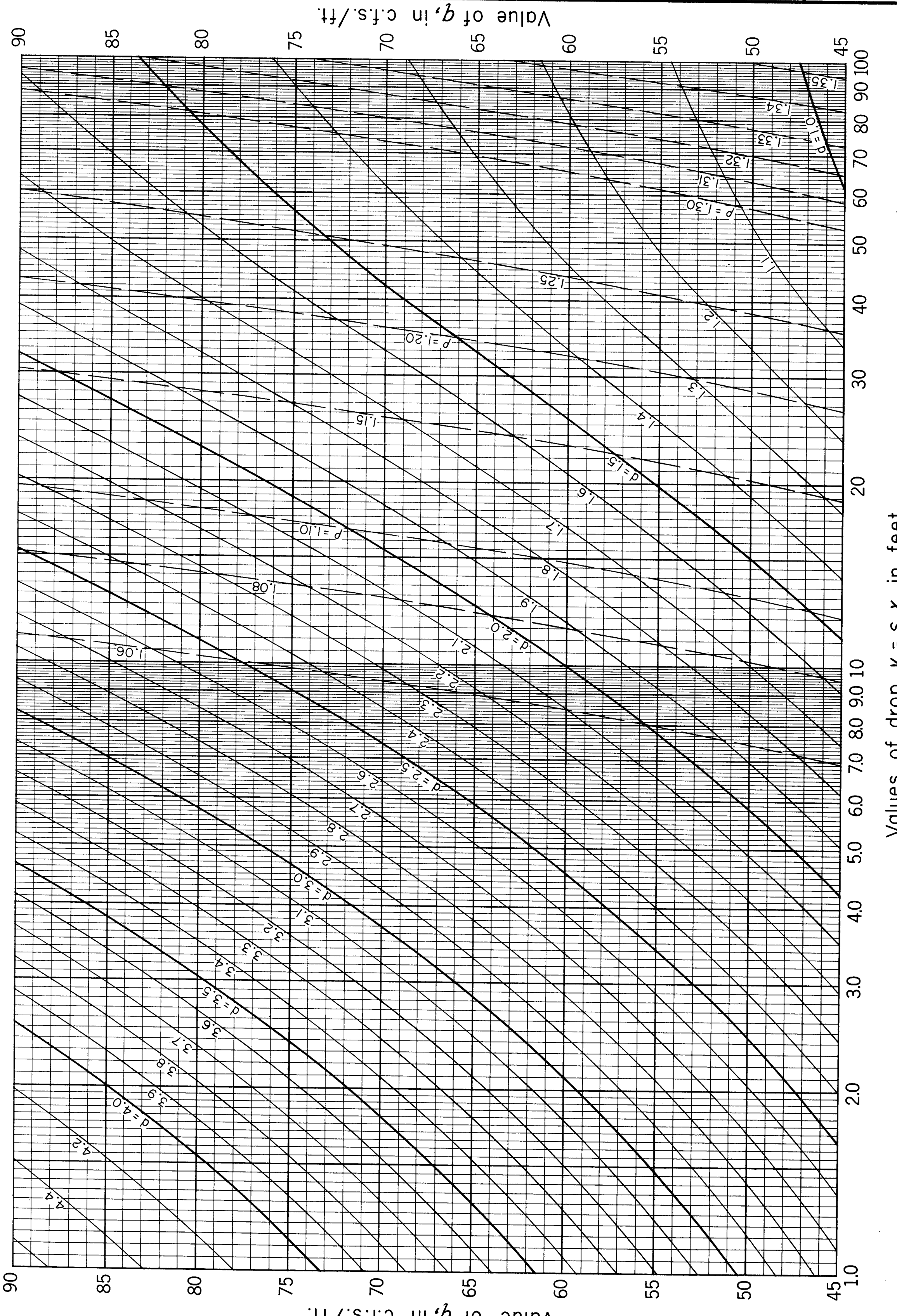
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 27 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 6 feet
q = 45 to 90
s_o = 10 : 1



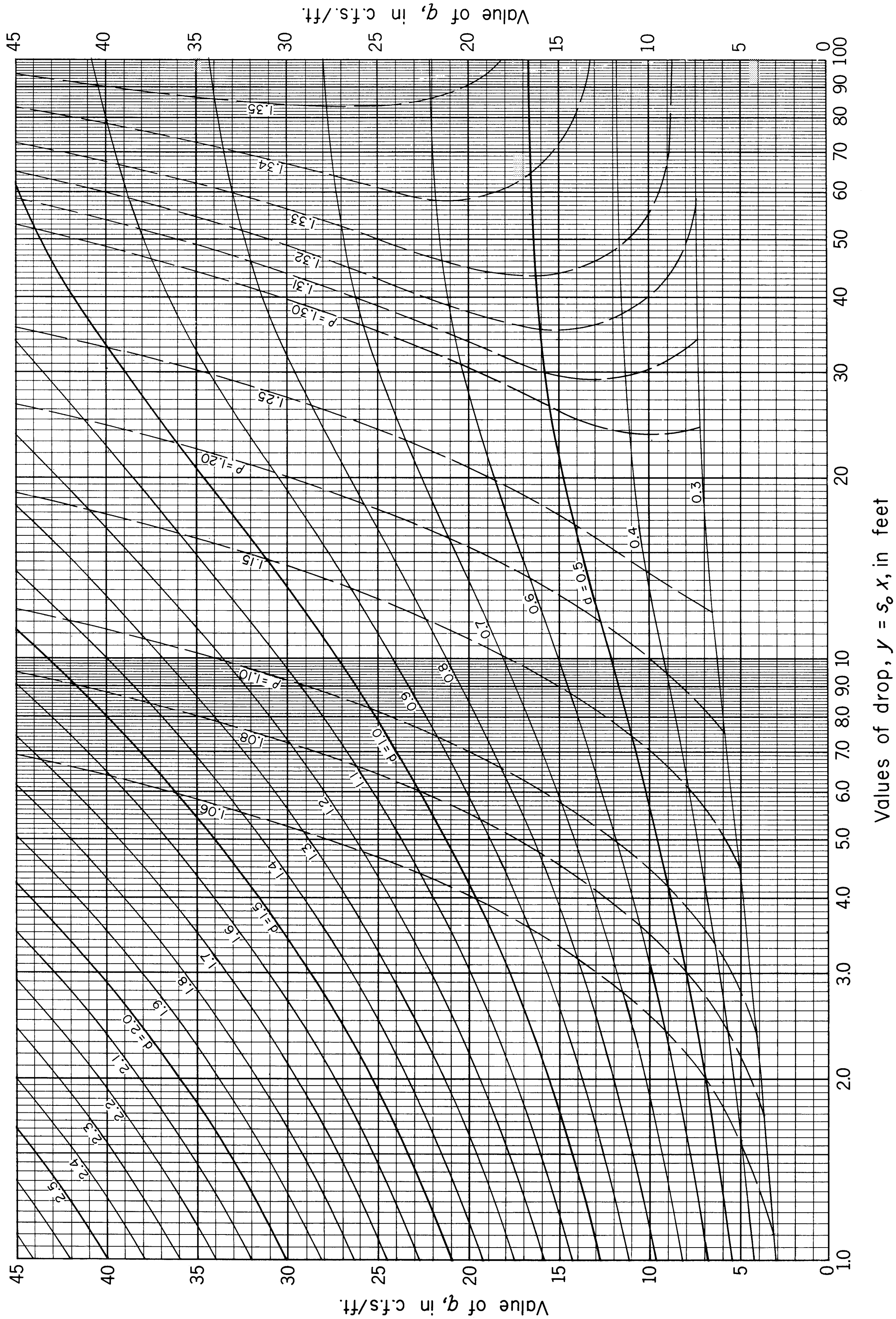
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 28 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 6 feet
q = 0 to 45
S_0 = 10 : 1



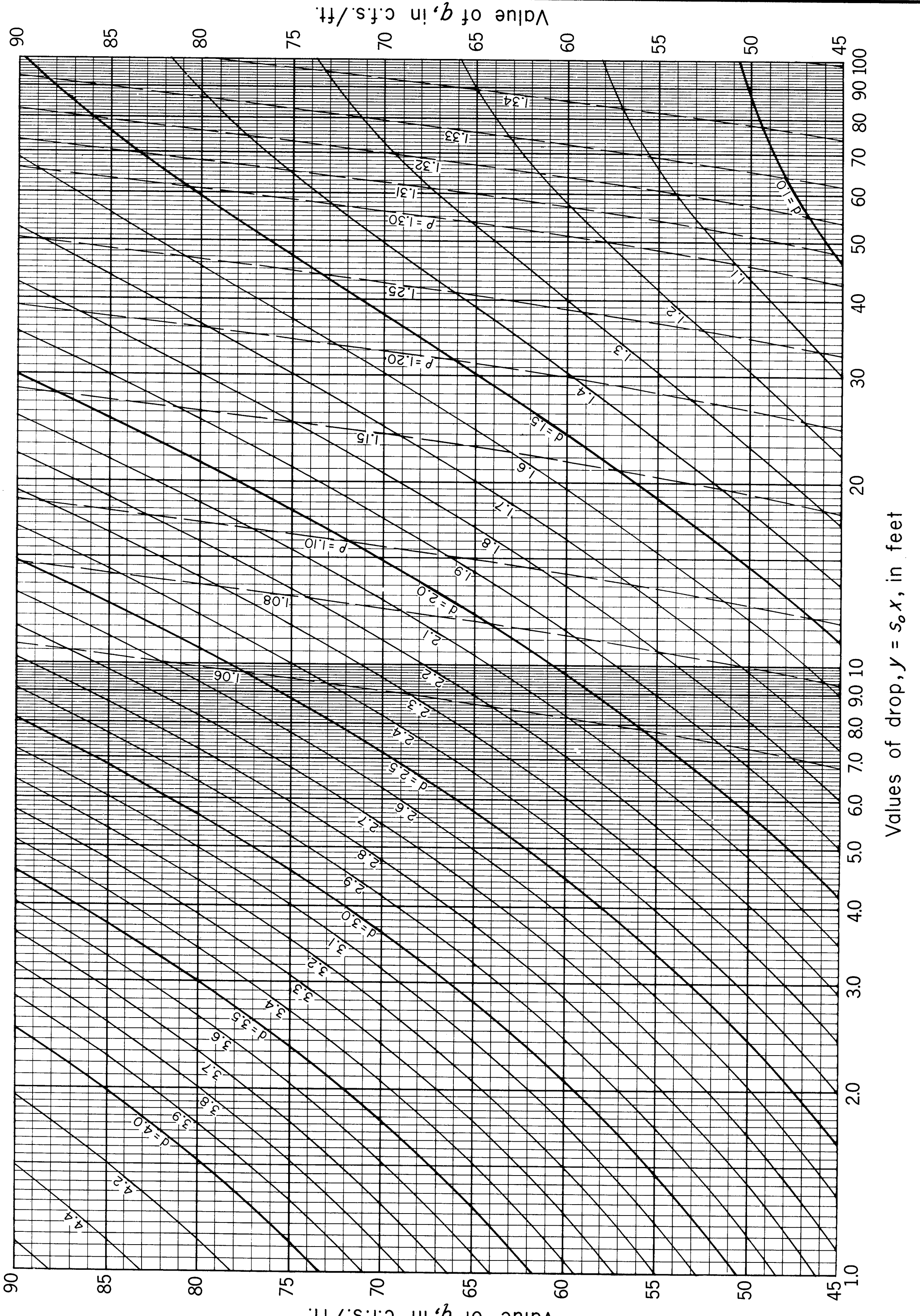
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 29 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 10 feet
q = 45 to 90
s_o = 10 : 1



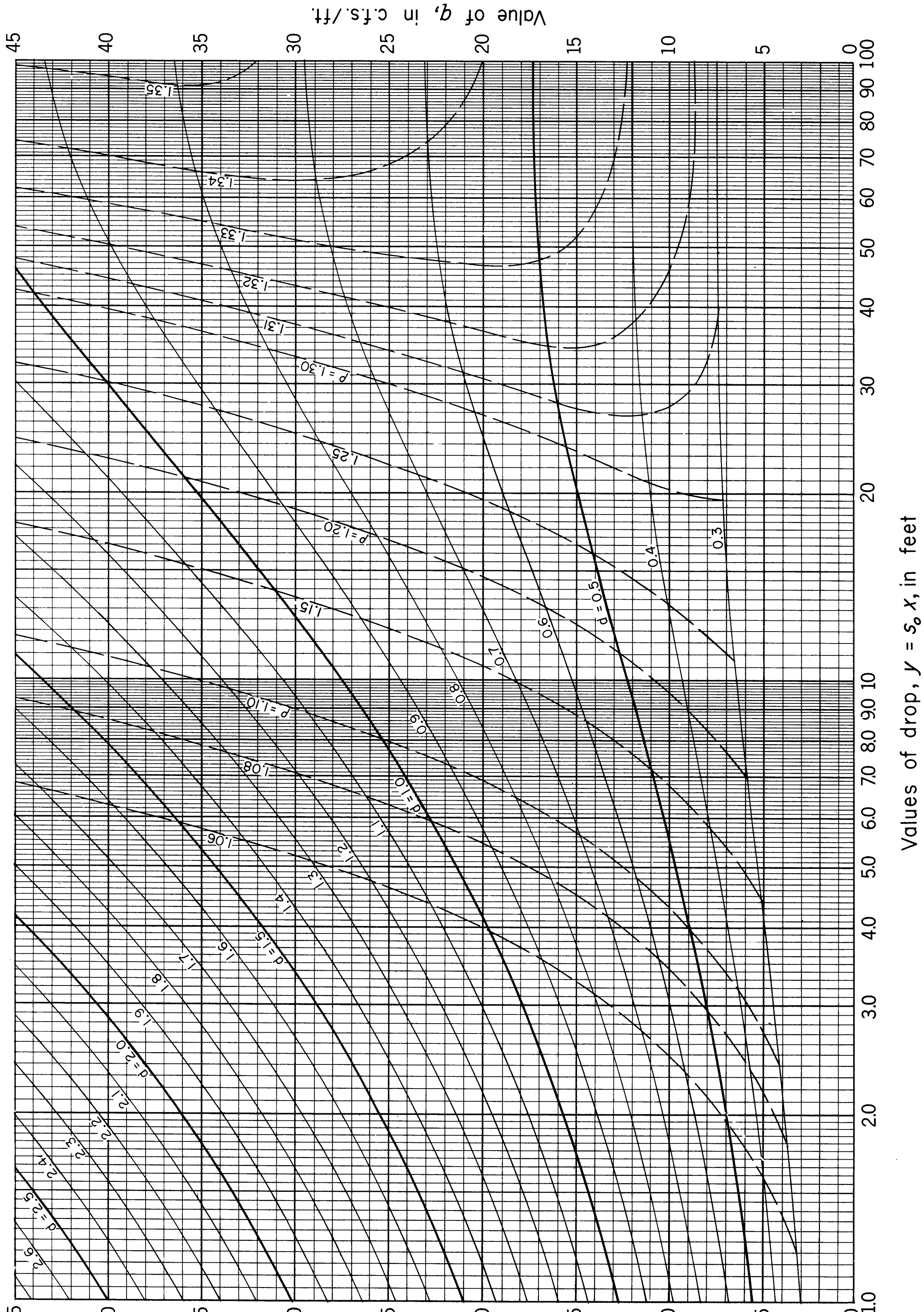
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 30 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 10 feet
q = 0 to 45
S_0 = 10 : 1



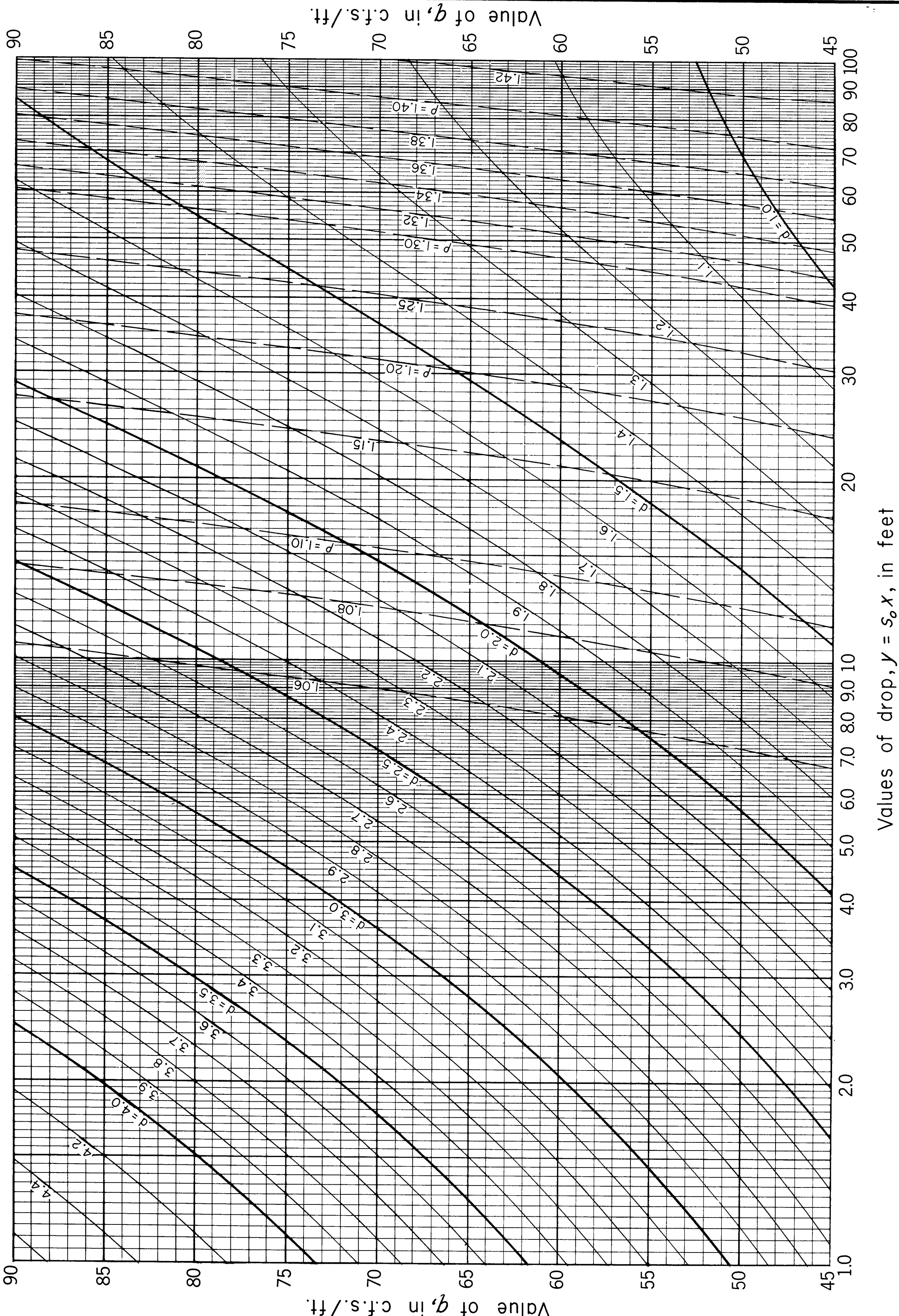
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 31 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 15 feet
q = 45 to 90
s_o = 10 : 1



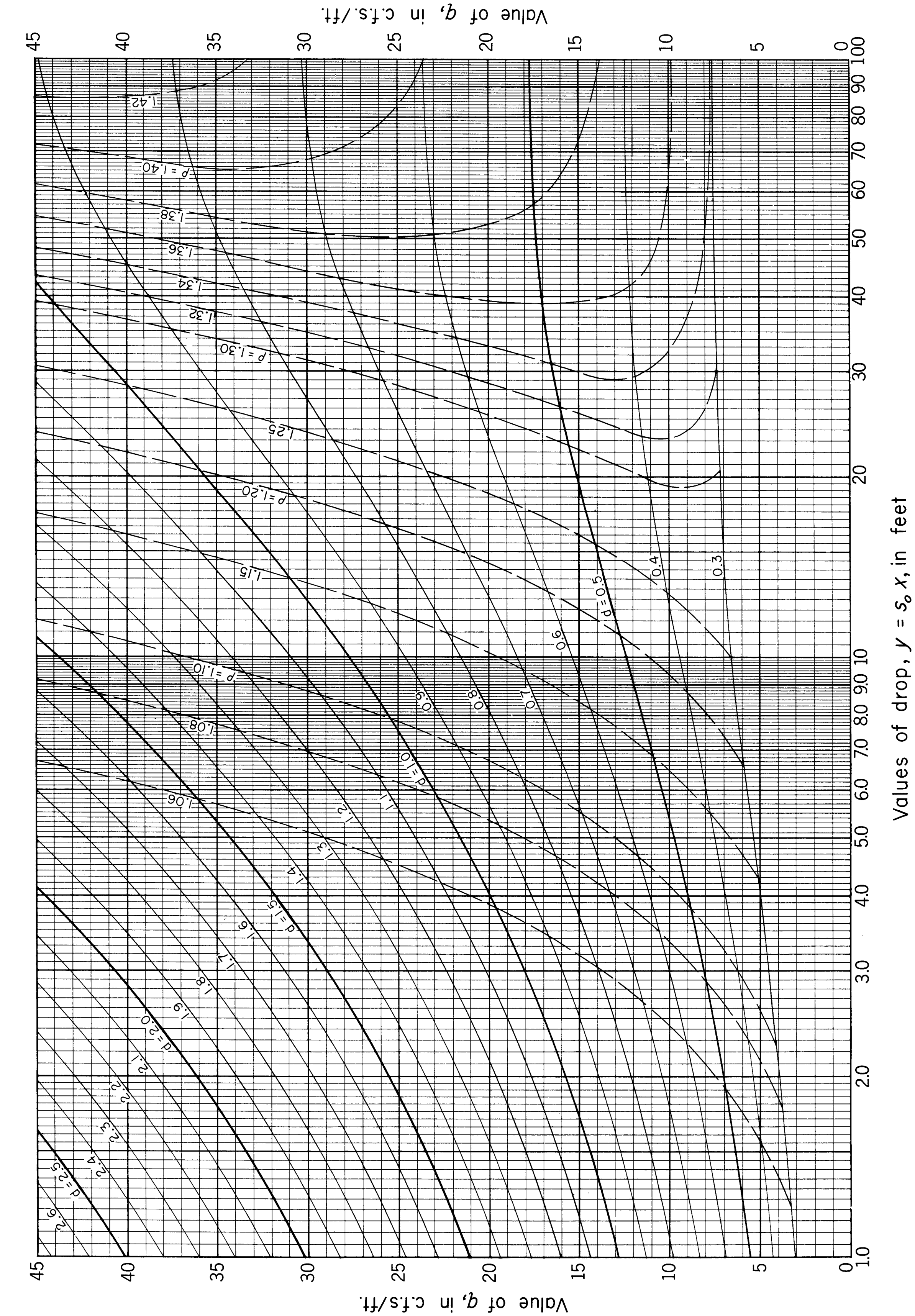
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 32 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 15 feet
q = 0 to 45
S_o = 10 : 1



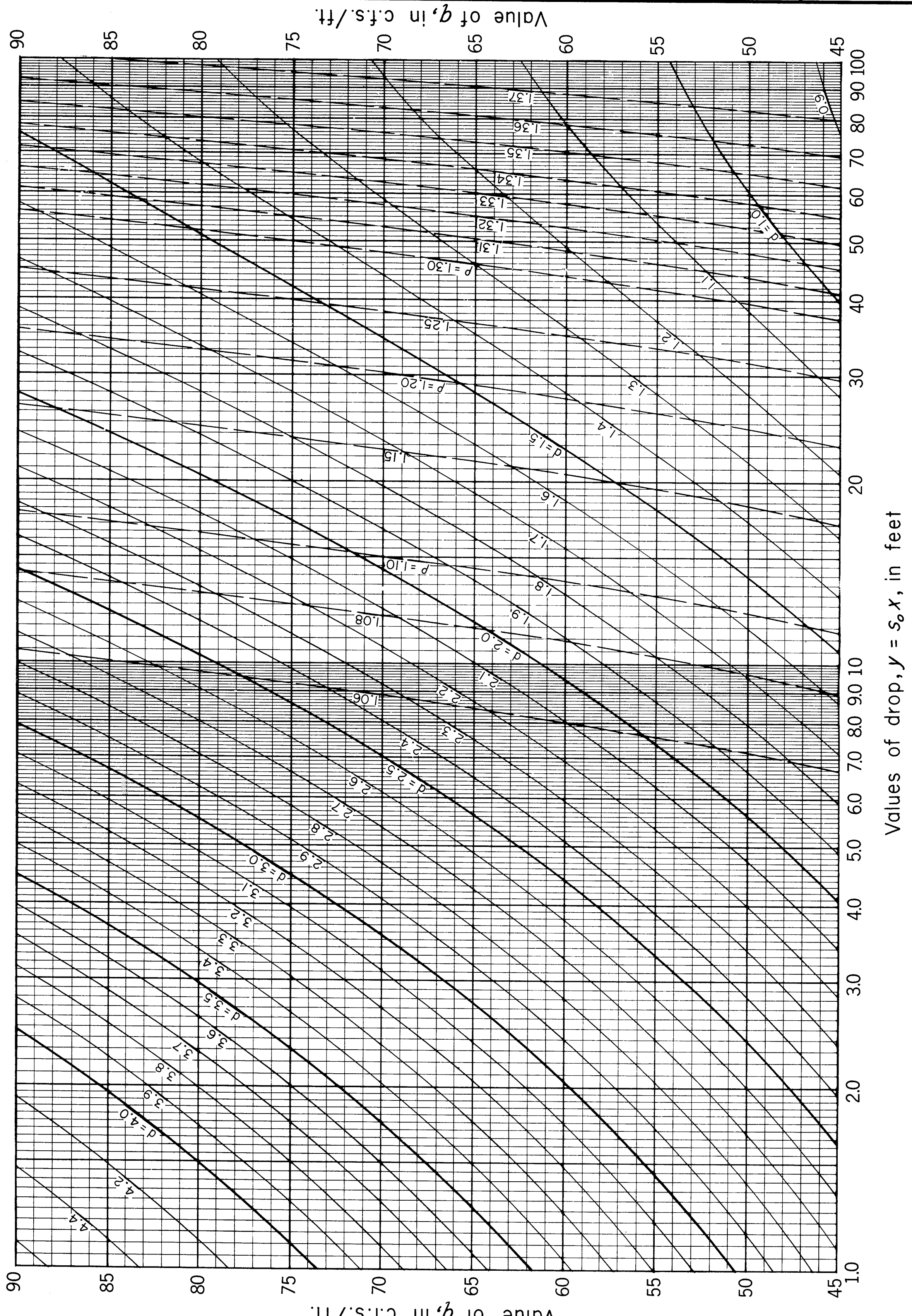
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES - 78
SHEET 33 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 30 feet
q = 45 to 90
s_o = 10 : 1



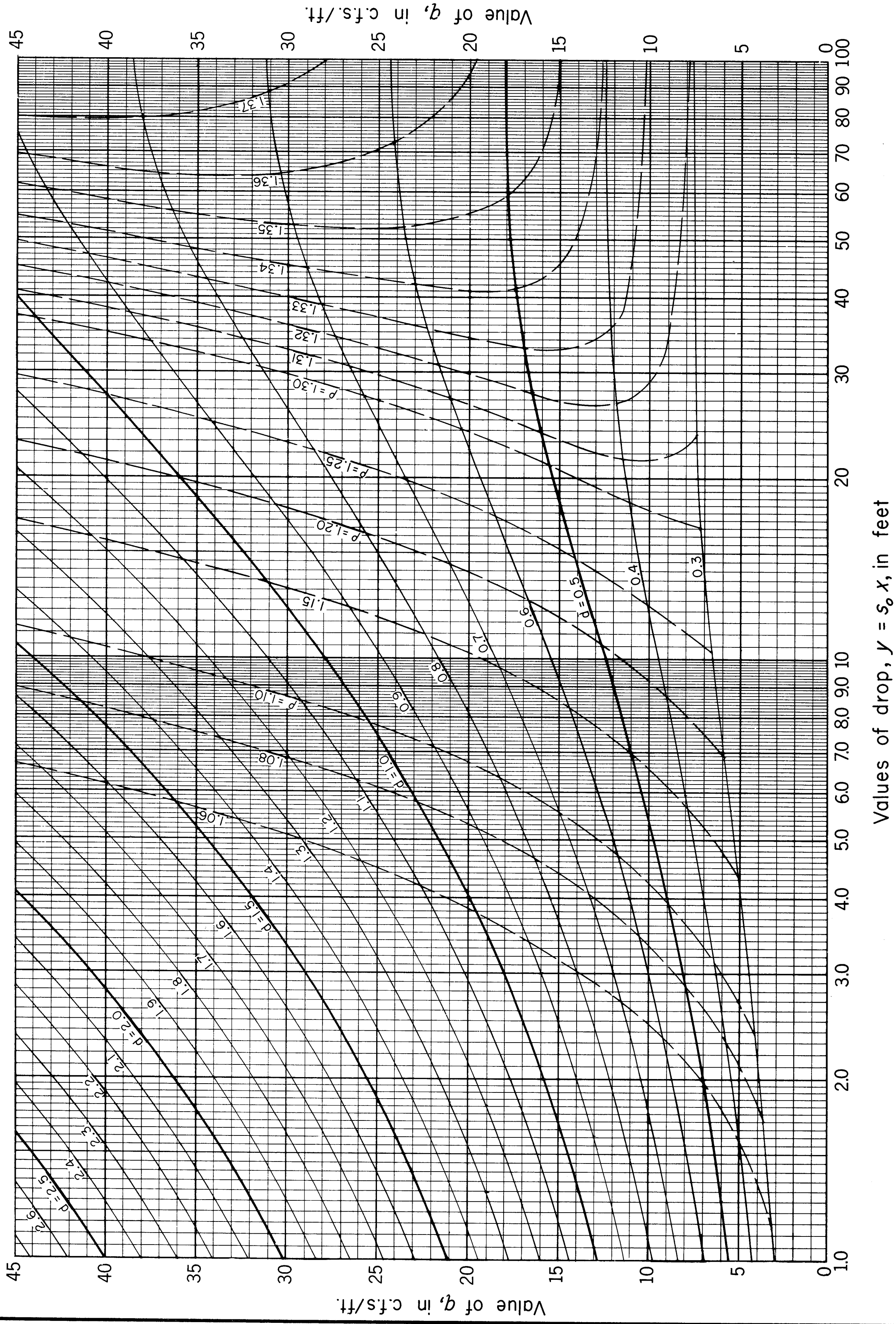
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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

STANDARD DWG. NO.
ES – 78
SHEET 34 OF 35
DATE 1-14-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W = 30 feet
q = 0 to 45
S_0 = 10 : 1



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

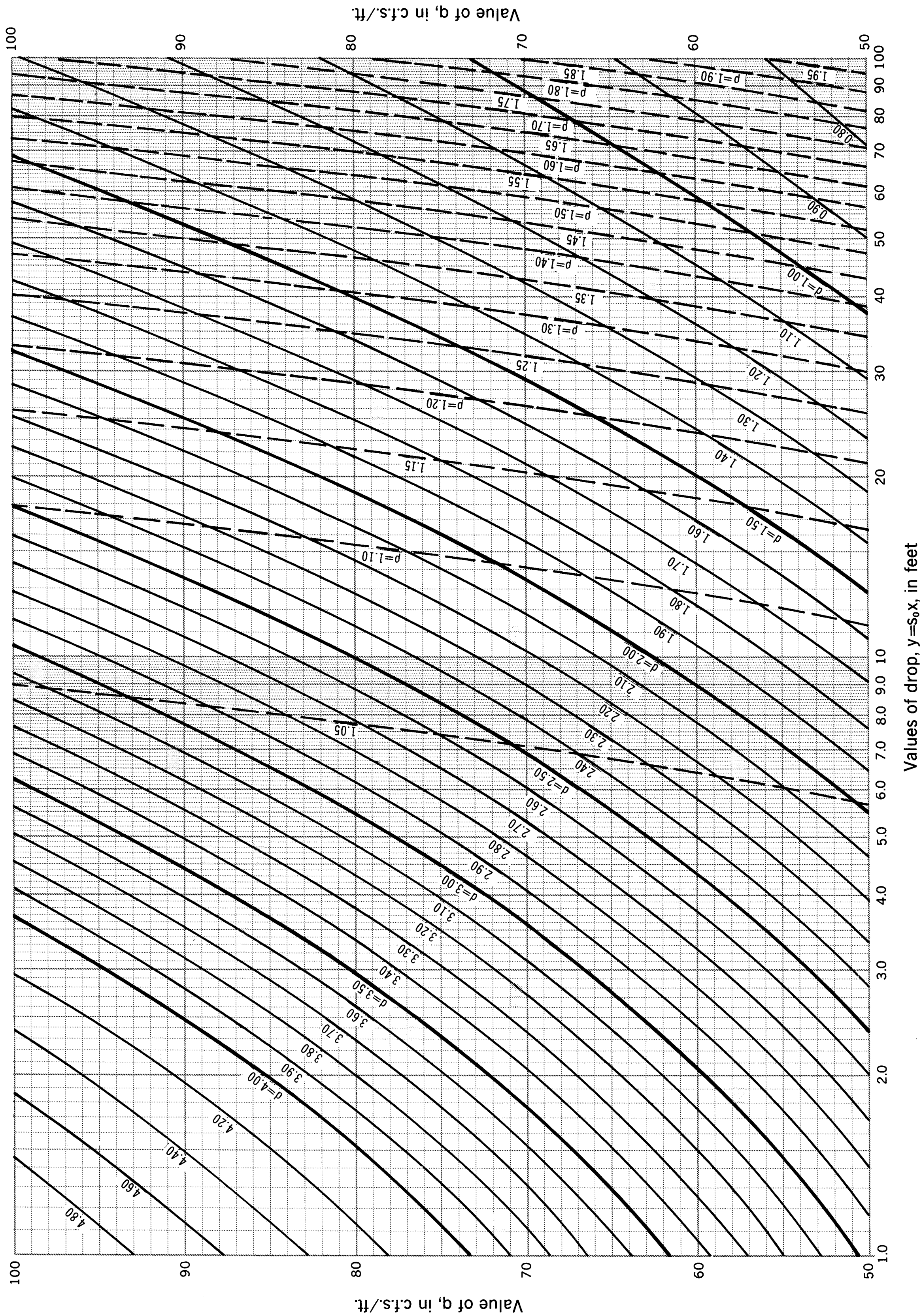
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.
ES - 78
SHEET 35 OF 35
DATE 1-14-55

2-178

CHUTE SPILLWAYS: WATER SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

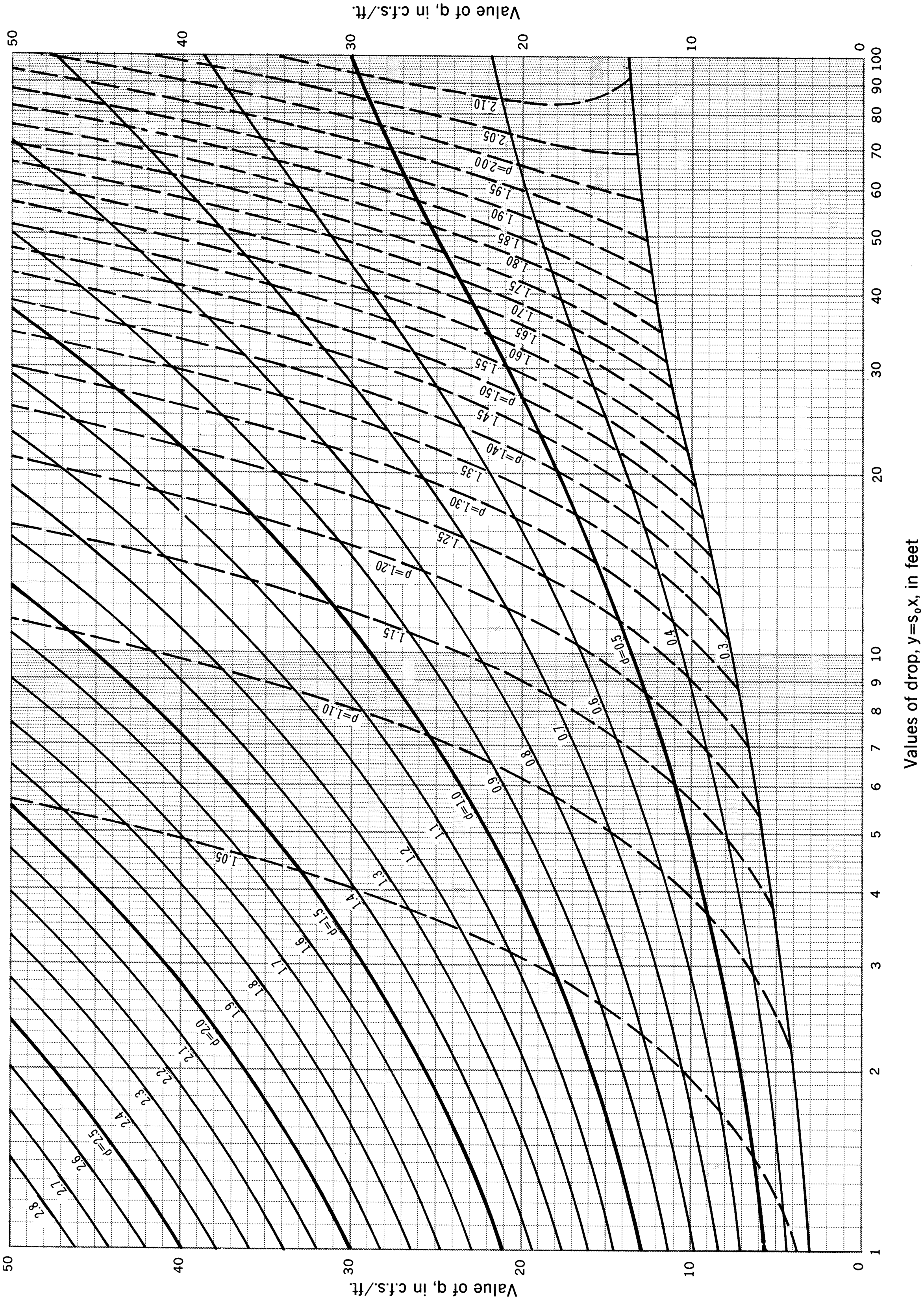
W=100 feet
q=50 to 100
s_0=3:1



REFERENCE		STANDARD DWG. NO.
ES-78	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT	ES-147 SHEET 1 OF 6 DATE 1-8-76

CHUTE SPILLWAYS: WATER SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

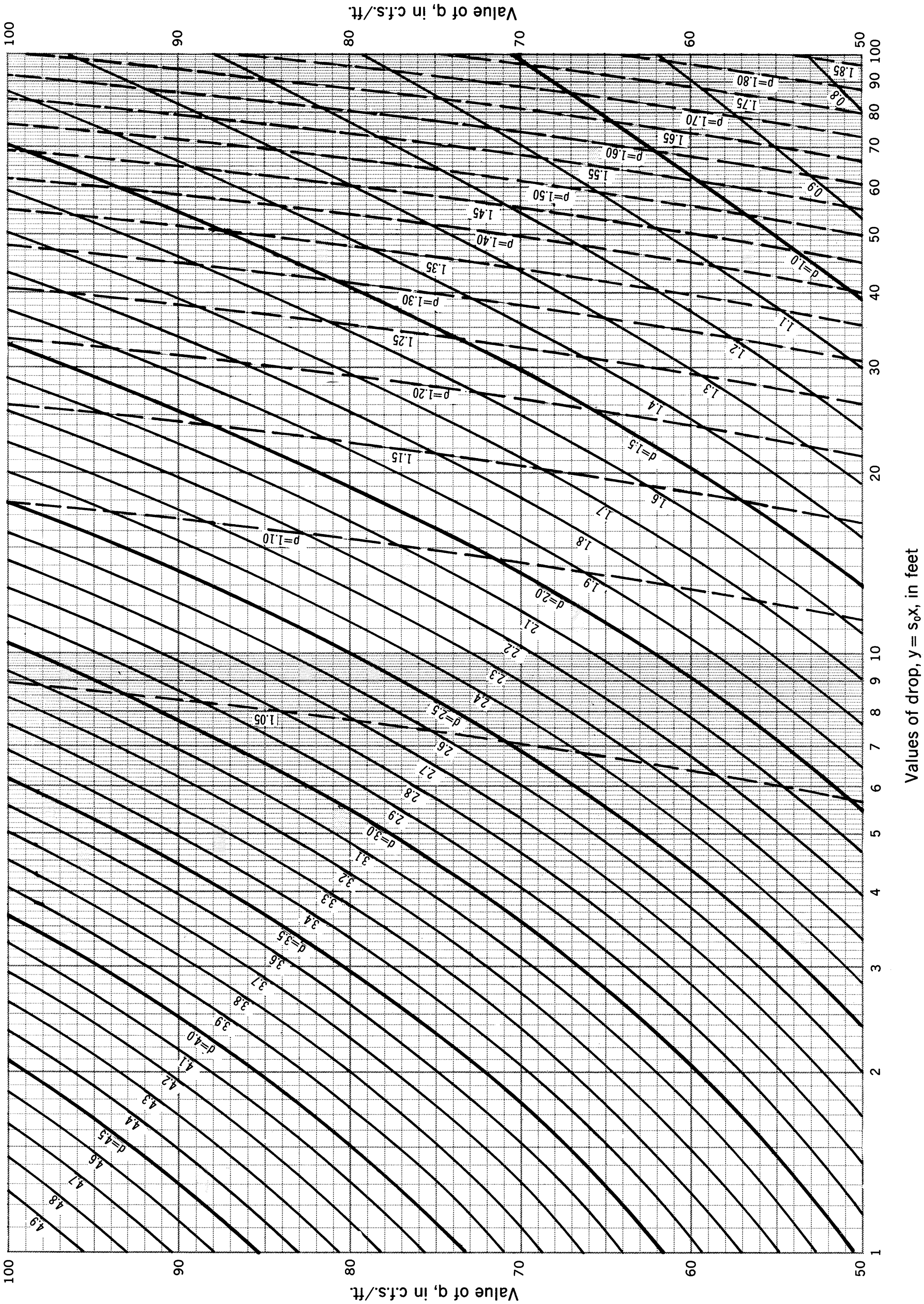
W=100 feet
q=4 to 50
s_0=3:1



REFERENCE		STANDARD DWG. NO.
ES-78	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT	ES-147 SHEET 2 OF 6 DATE 1-8-76

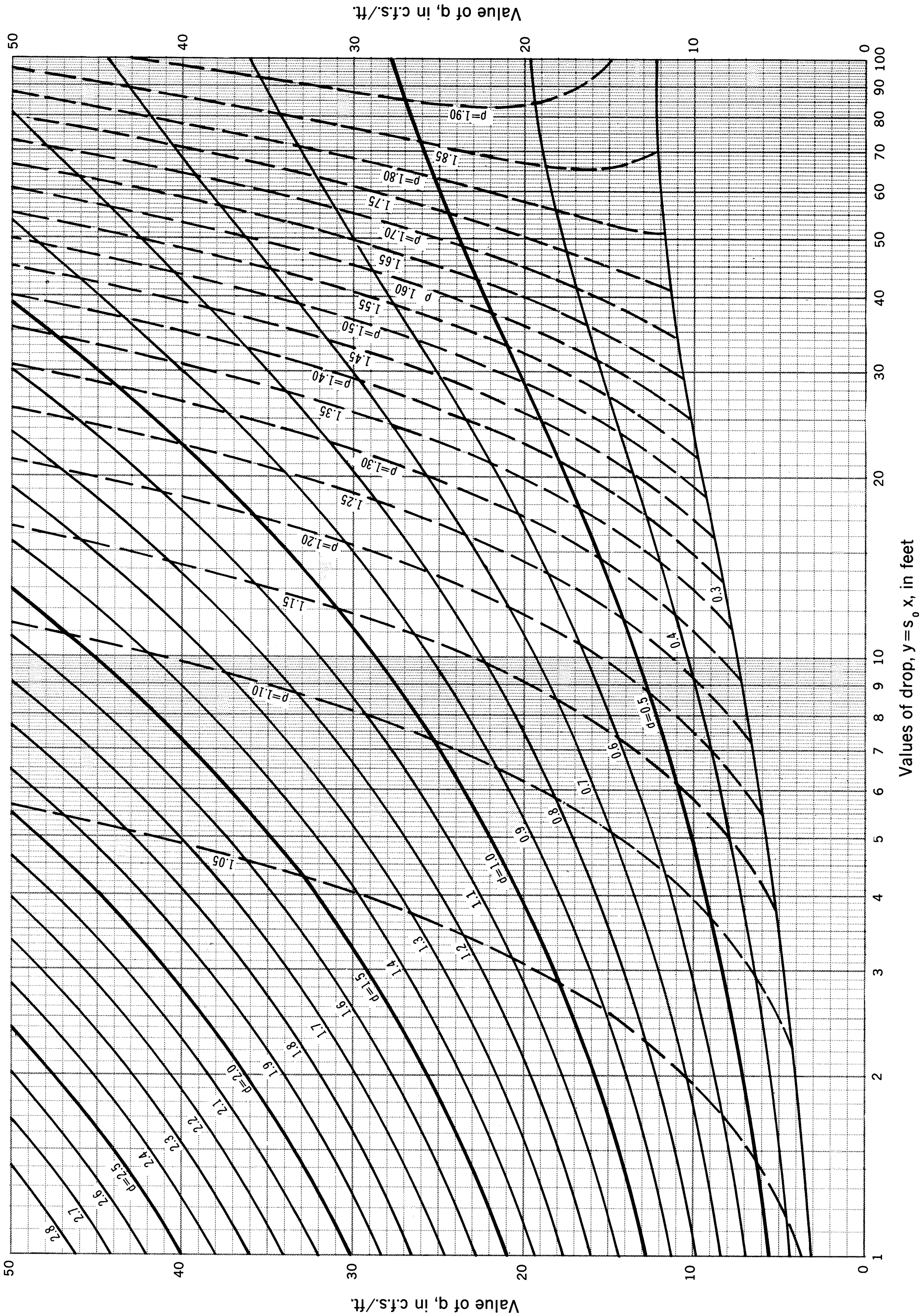
CHUTE SPILLWAYS: WATER SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W=100 feet
q=50 to 100
s_o=4:1



REFERENCE		STANDARD DWG. NO.
ES-78	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT	ES-147 SHEET 3 OF 6 DATE 1-8-76

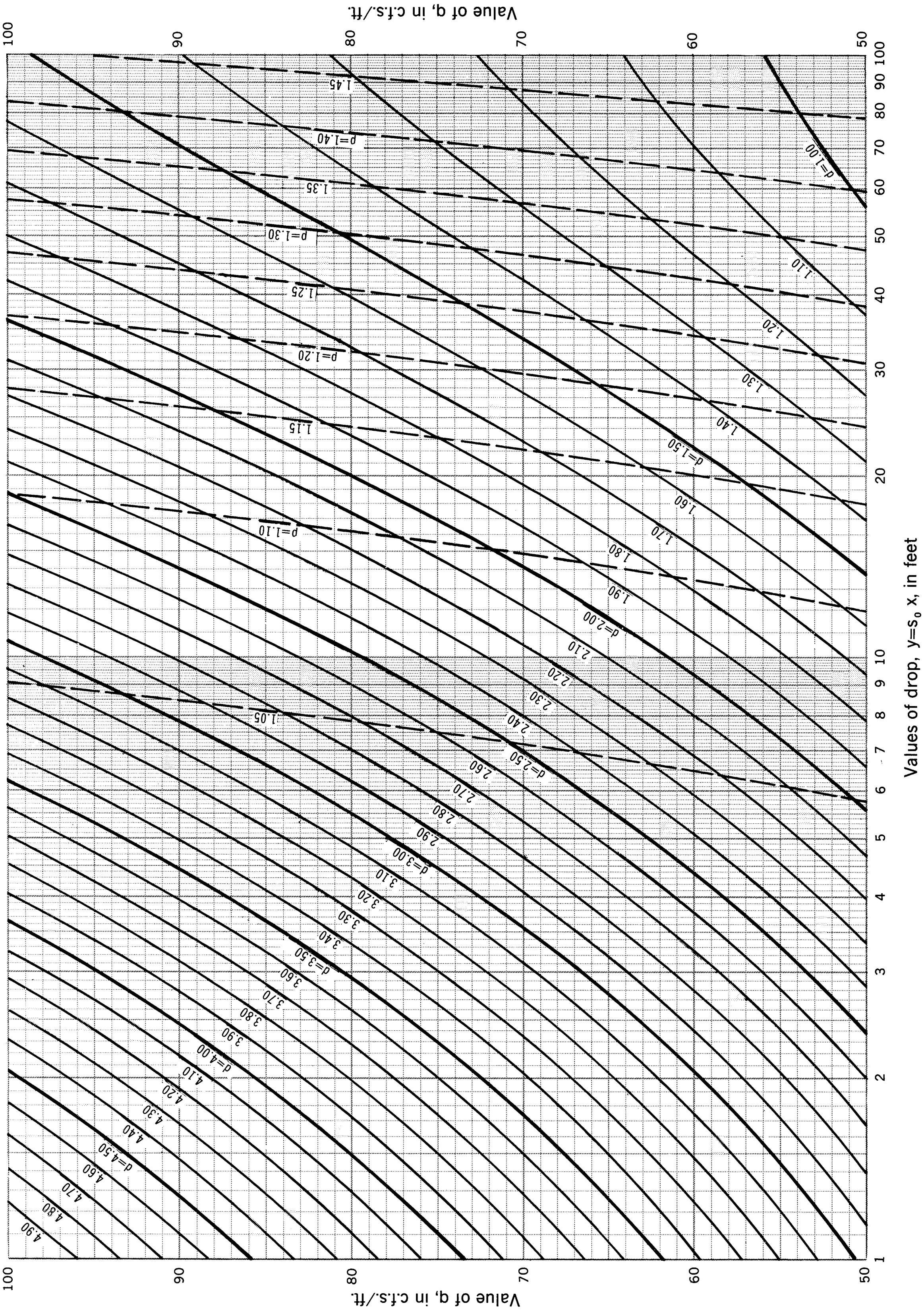
CHUTE SPILLWAYS: **WATER SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.**	W=100 feet q=4 to 50 s_0=4:1



REFERENCE ES-78	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT	STANDARD DWG. NO. ES-147 SHEET 4 OF 6 DATE 1-8-76

CHUTE SPILLWAYS: WATER SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

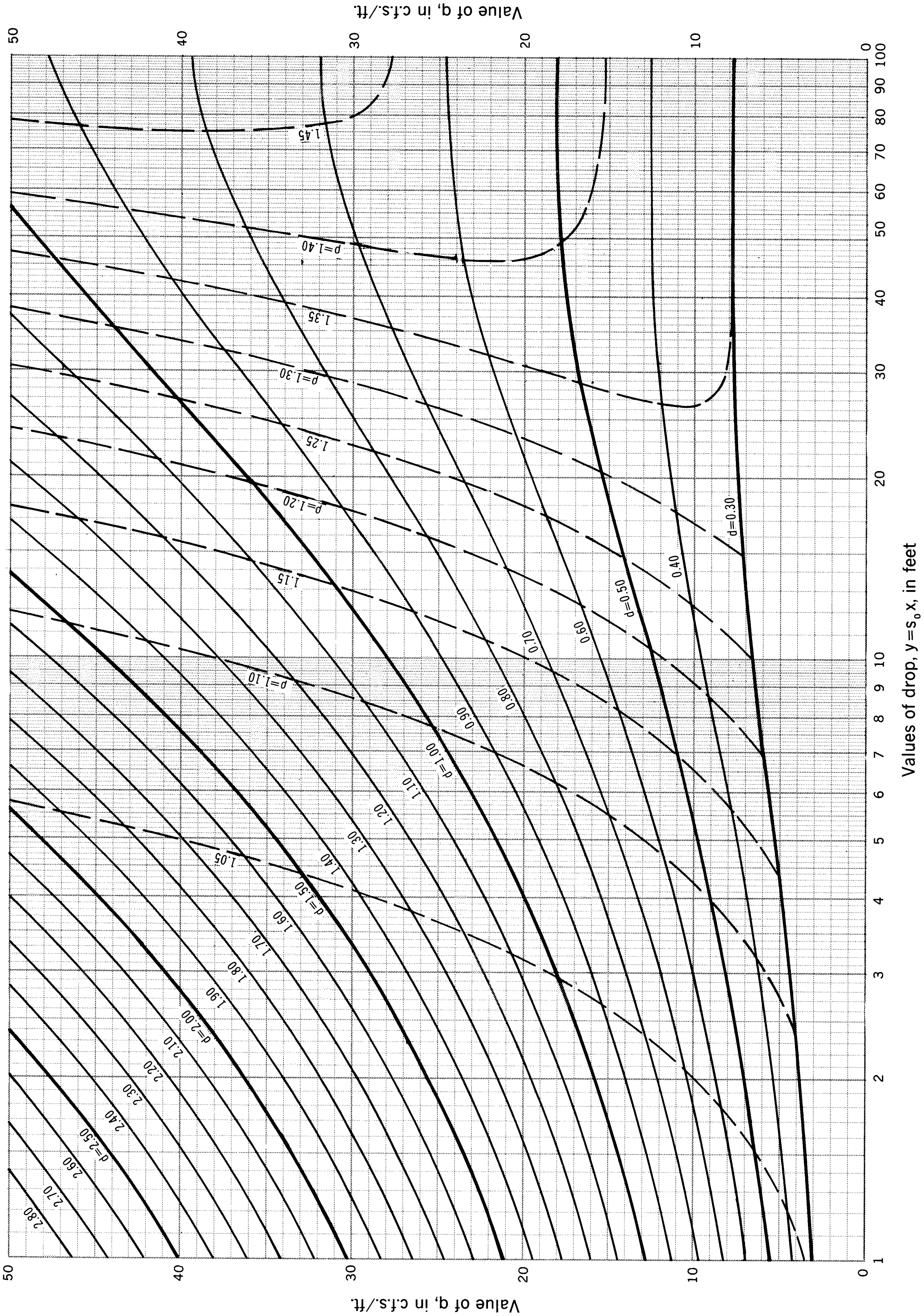
W=100 feet
q=50 to 100
s_0=10:1



REFERENCE		STANDARD DWG. NO.
ES-78	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT	ES-147 SHEET 5 OF 6 DATE 1-8-76

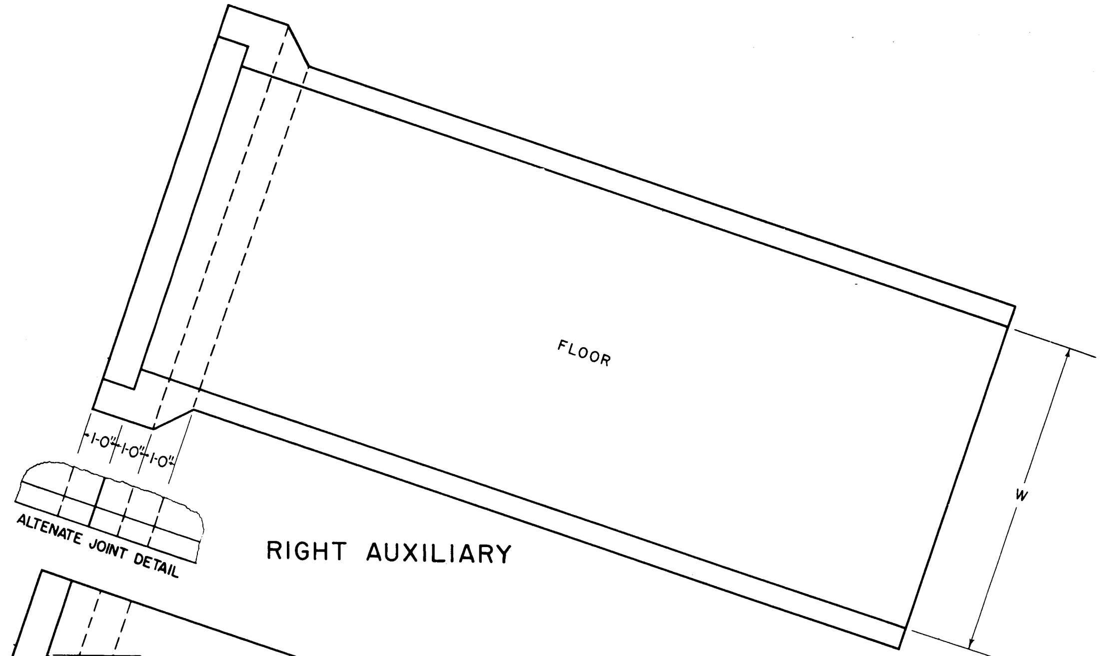
CHUTE SPILLWAYS: WATER SURFACE PROFILES FOR RECTANGULAR SECTIONS; Accelerated supercritical flow.

W=100 feet
q=4 to 50
s_0=10:1

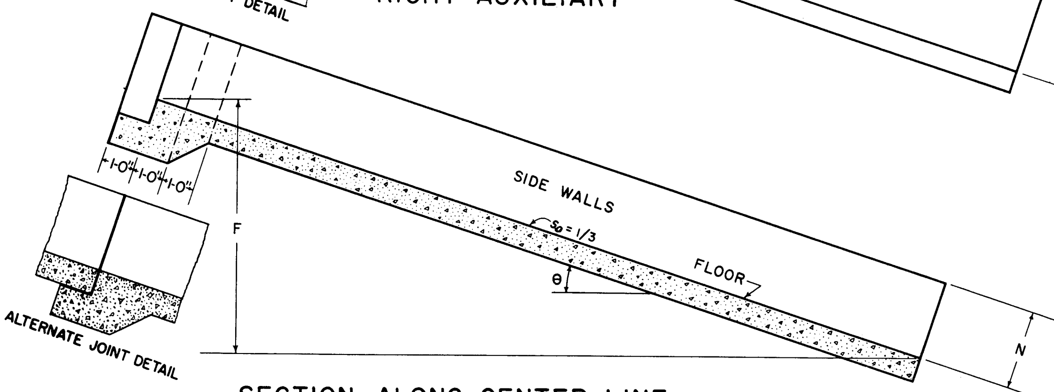


REFERENCE		STANDARD DWG. NO.
ES-78	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN UNIT	ES-147 SHEET 6 OF 6 DATE 1-8-76

CHUTE SPILLWAYS: CHANNELS
Layout

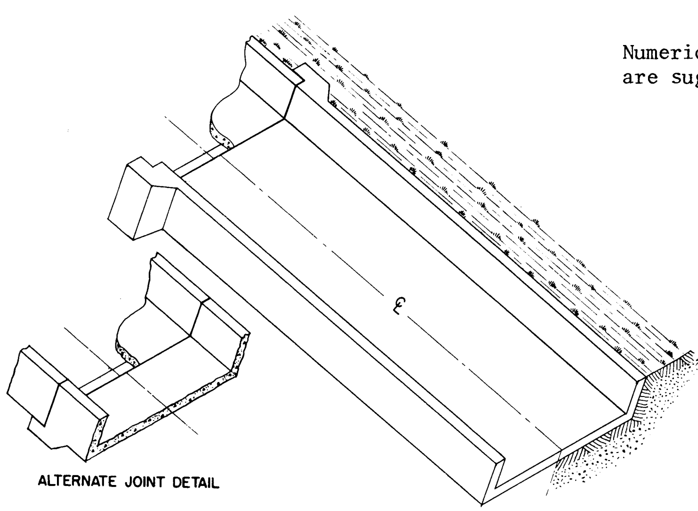


RIGHT AUXILIARY



SECTION ALONG CENTER LINE

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-84 SHEET 1 OF 4 DATE April 1954

Revised 10/77

CHUTE SPILLWAYS: CHANNELS; Definition of symbols and Formulas

Capacities of
Channel Sections

N	q_{mN}	N cos θ†
2.00	41.00	1.90
2.25	46.80	2.13
2.50	52.65	2.37
2.75	58.65	2.60
3.00	64.80	2.85
3.25	71.15	3.08
3.50		3.32
3.75		3.56
4.00		3.80
4.25		4.03

*Values of q_{mN} are for values of $\mathfrak{z}$ = 8 ft. For other values of $\mathfrak{z}$ see table 2, ES-88.
†Values are for channels of 3 to 1 slope.

DEFINITION OF SYMBOLS

- N = Height normal to slope s_o of sidewall of channel in ft
- Z = Vertical drop from crest of inlet to floor of outlet in ft
- D = Vertical distance from crest of inlet to top of floor at entrance of vertical curve section in ft. This is zero for straight inlets
- F = Vertical distance from upstream end to downstream end of channel in ft
- J = Height of sidewalls of SAF above floor in ft
- $\mathfrak{z}$ = Vertical drop of vertical curve section in ft
- W = Width of vertical curve section in ft
- n = Number of channel sections required
- θ = $\mathrm{Tan}^{-1}\, s_o$
- s_o = Slope of floor of channel in ft/ft
- Q_r = Design discharge in cfs
- Q_{fr} = Required capacity without freeboard in cfs
- q_{mc} = Capacity per foot width of channel without freeboard in cfs/ft

FORMULAS

$$F = Z + N \cos \theta - (J + \mathfrak{z} + D)$$

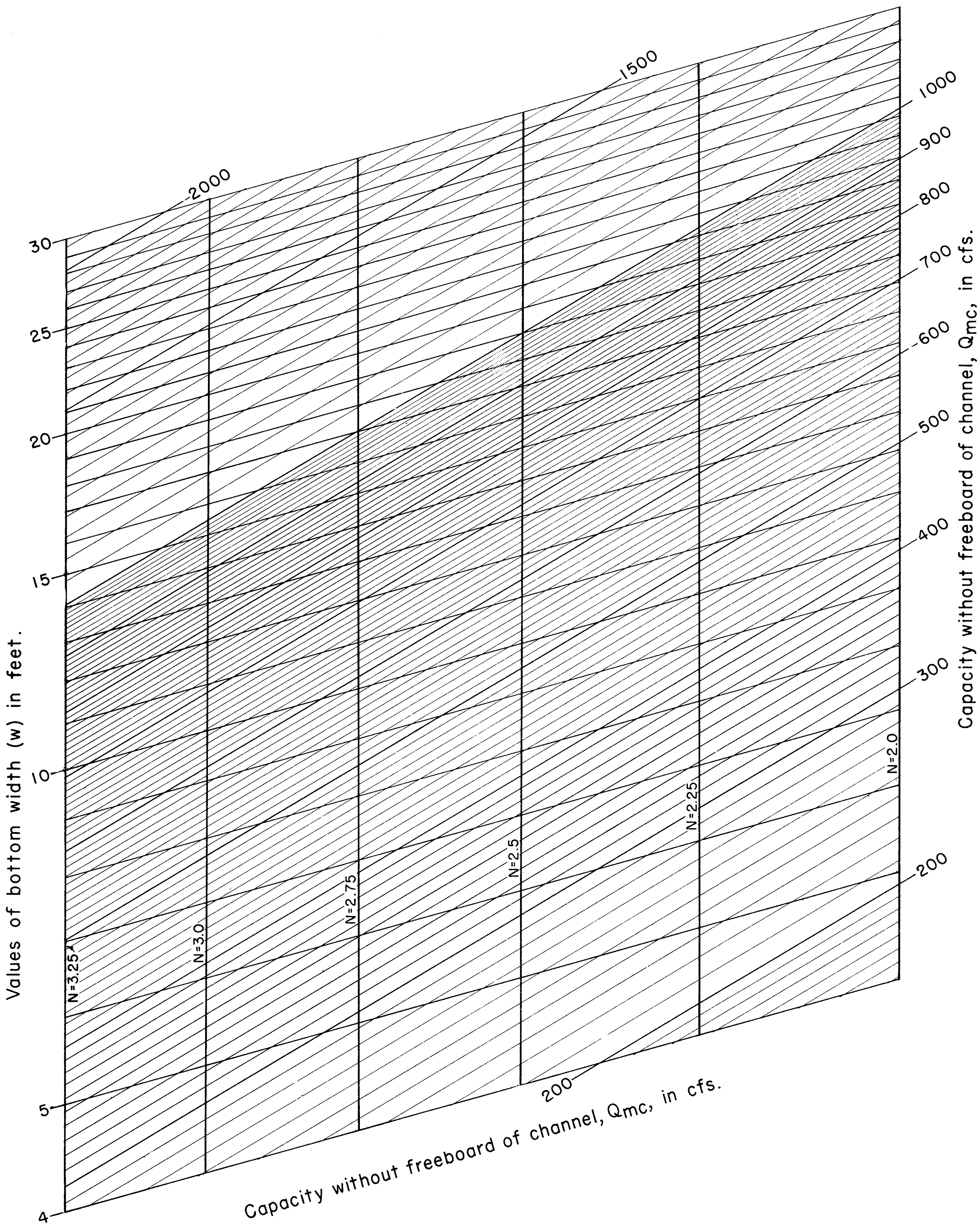
$$Q_{fr} = (1.20 + 0.003\, Z)\, Q_r$$

$$q_{mN} = q_{mc}$$

REFERENCE	U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-84 SHEET 2 OF 4 DATE March 1954

Revised 10/77

CHUTE SPILLWAYS: CHANNELS; Capacities Without Freeboard.



REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION-DESIGN SECTION	STANDARD DWG. NO. ES-84 SHEET 3 OF 4 DATE 5-3-54

Revised 10/77

CHUTE SPILLWAY: CHANNEL; Example

EXAMPLE

Given: A chute of width, W = 10 ft, has a design discharge, Q_r = 380 cfs, and a 3 to 1 slope. The chute has a vertical drop from the crest of the straight inlet to the floor of the outlet of Z = 47 ft. The vertical curve section has a vertical drop of z = 8 ft and the SAF outlet has the dimension J = 15 ft. The inlet will require no freeboard as a result of waves.

Determine:
1. The recommended required capacity of the chute: (i) Q_{fr}; (ii) q_{fr}
2. The required height of the sidewalls, N, of the channel
3. The vertical drop, F, required for the channel
4. The number of joints in the channel if they are spaced less than or equal to 9.5 ft (vertically) apart
5. The velocity and depth of flow with air entrainment and without air entrainment at the end of the channel section for the discharge Q_{fr}

Solution: 1. The recommended required capacity of the chute is

(i)
$$Q_{fr} = (1.20 + 0.003\ Z)\ Q_r$$
$$Q_{fr} = \left[1.20 + 0.003\ (47)\right] 380$$
$$Q_{fr} = 509.6 \text{ cfs}$$

(ii)
$$q_{fr} = \frac{Q_{fr}}{W} = \frac{509.6}{10} = 50.96 \text{ cfs/ft}$$

2. (a) The required height of the sidewalls of the channel mav be read from the table on sheet 2 as

$$N = 2.50 \text{ ft}$$

(b) The required height of the sidewalls of the channel may also be read on sheet 3 at the intersection of Q_{fr} = 509.6 cfs and W = 10 ft as

$$N = 2.50 \text{ ft}$$

3. The vertical drop of the channel is given by the formula (D = 0)

$$F = Z + N\cos\theta - (J + z)$$
$$F = 47 + 2.37 - (15 + 8)$$
$$F = 26.37 \text{ ft}$$

Values of $N\cos\theta$ when $\theta = \tan^{-1} 0.33333$ are given in the table on sheet 2.

4. The number of joints is

$$n = \frac{F}{9.5} = \frac{26.37}{9.5} = 2.77$$

Three joints are required.

5. The downstream end of the channel is located a vertical distance of z + F or 8 + 26.37 = 34.37 ft below the floor of the inlet. Read on ES-78 the intersection of q = 50.96 cfs and y = 34.37 ft the values

$$d = 1.066 \text{ ft}$$
$$\rho = 1.33$$

The velocity, v, of the air-water admixture is

$$v = \frac{q}{d} = \frac{50.96}{1.066} = 47.8 \text{ ft/sec}$$

The depth of water without air entrainment is

$$d = 1.066 \text{ ft}$$

The depth of air-water admixture, d_a, is

$$d_a = \rho\, d = (1.33)(1.066) = 1.42 \text{ ft}$$

SAF OUTLETS

The criteria for the dimensions of the SAF outlet were developed by Fred W. Blaisdell[1], Hydraulic Engineer, SCS, St. Anthony Falls Hydraulic Laboratory. These criteria are given as design formulas in ES-73, page 2.193, and ES-86, page 2.198. (See ES-73, page 2.193, for nomenclature.)

Function of SAF Outlet. The function of the SAF outlet is to convert, for all discharges equal to or less than the design discharge, supercritical velocities to subcritical velocities in a manner which will be nonerosive in erosible channels. Obviously, certain criteria will be required of the channels downstream from the outlet for its proper functioning. These requirements will be presented later.

Freeboard. The SAF outlet functions well for all discharges less than its capacity without freeboard. It will generally function quite well for greater discharges for short periods of flow. The freeboard recommended for SAF outlets is expressed in terms of the increased discharge f_r. (See Eq. 2.1, page 2.7.) The recommended required capacity of the SAF outlet without freeboard is Q_{fr} as defined by Eq. 2.2, page 2.7.

Hydraulic Criteria. The criteria for the SAF outlet are expressed by a graph having the coordinates v_1 and d_1. (See ES-73.) These criteria are applicable for a range of Froude's numbers from 3 to 300. The coordinate d_1 (entrance depth) is the fictitious depth of flow d as given by ES-78 and ES-86. As given by ES-78, the value of y is the vertical distance between the floors of the inlet and outlet of a chute spillway having a 3 to 1 slope. The depth of d_1 for chutes having bottom slopes other than 3 to 1, 4 to 1, and 10 to 1 may be calculated by the general differential equation given in ES-78, page 2.145 or interpolated using the diagrams of ES-78. The effect of air entrainment can be neglected in the design of SAF outlet. The coordinate v_1 is the entrance velocity as determined by ES-78 and the equation

$$v_1 = \frac{q}{d_1} \qquad 7.1$$

Knowing d_1 and v_1 make it possible to determine L_B and J from sheet 2 of ES-73. For Froude's numbers less than 20, the crest of the boil occurs in the stilling basin. For higher Froude's numbers, the crest occurs downstream from the endsill. The height J of the stilling basin sidewalls is sufficient to keep most splash in the basin. This height is not excessive in most cases.

The wingwalls can be used as retaining walls for earth. Their prime function, however, is to prevent eddies along each side of the downstream channel which would cause excessive scour. Wingwalls can be set parallel or perpendicular to the sidewalls if necessary, but the 45^o angle with the chute axis is the preferred location in terms of hydraulic functioning.

Knowing d_1 and v_1 make it possible to determine the dimensions of the endsill s and the required tailwater height d_2'. The endsill is used to

[1]Blaisdell, Fred W., Development and Hydraulic Design, Saint Anthony Falls Stilling Basin, Trans. ASCE, Vol. 113, p. 483, 1948.

deflect the bottom currents in the floor of the basin upward and off of the stream bed. It is also used to deflect the bottom currents of the roller, which are in an upstream direction, upward. This roller brings bed material from downstream and deposits it against the endsill. Because of this, a toe-wall of only nominal depth is required. The criterion of tailwater depth d_2' is a minimum requirement for the SAF outlet to function properly. When the tailwater depth is too low, the roller is forced away from the endsill of the outlet. When the tailwater is too great, the tailwater will flow in an eddy upstream along the sidewalls to re-enter the stilling basin and the outlet will not function properly. For those situations in which the tailwater can fluctuate in depth for a discharge equal to the required capacity without freeboard, the minimum tailwater depth will determine the elevation of the endsill. (See below.) The sidewall height J should be increased in amount equal to the difference between the maximum and minimum tailwater depths which may be expected for a discharge equal to the required capacity without freeboard. The SAF outlet will operate satisfactorily for greater tailwater depths than the d_2' provided the sidewall heights are sufficiently great to prevent re-entrance of the tailwater over the top of the sidewalls into the basin. The tailwater elevation at the endsill can be determined by computing the water-surface profile from a point sufficiently far downstream from the endsill for a discharge equal to the discharge Q_{fr}. (See Engineering Handbook, Section 5, Hydraulics.) The flow in this region is subcritical; therefore, these calculations are made in an upstream direction. The SAF outlet will not prevent erosion in the channel downstream from the SAF if the channel is scouring. When a scouring condition exists, it should be realized that the tailwater elevation will be lowered after a period of time because the channel bottom is lowered as a result of erosion. Scouring can be controlled by a gradient control structure downstream from the SAF outlet. The minimum required tailwater elevation in terms of depth d_2' above the SAF floor can be attained in one of two ways:

1. Proper determination of the elevation of the SAF outlet floor with respect to the nonerosive channel bottom.

2. Construction of a structure downstream from the SAF outlet to fix the tailwater elevation.

The criteria for chute and floor blocks and their placement are given on sheet 1 of ES-73. Pitting of concrete due to cavitation will occur at the floor and chute blocks when the entrance velocity v_1 is greater than 65 ft/sec.[1] When such a condition occurs, these blocks can be designed of a shape to eliminate cavitation. The purpose of these blocks is to remove energy from the water and help create turbulence to effectively cause energy dissipation.

The basin having diverging sidewalls appears to be slightly more effective than the basin with parallel sidewalls.

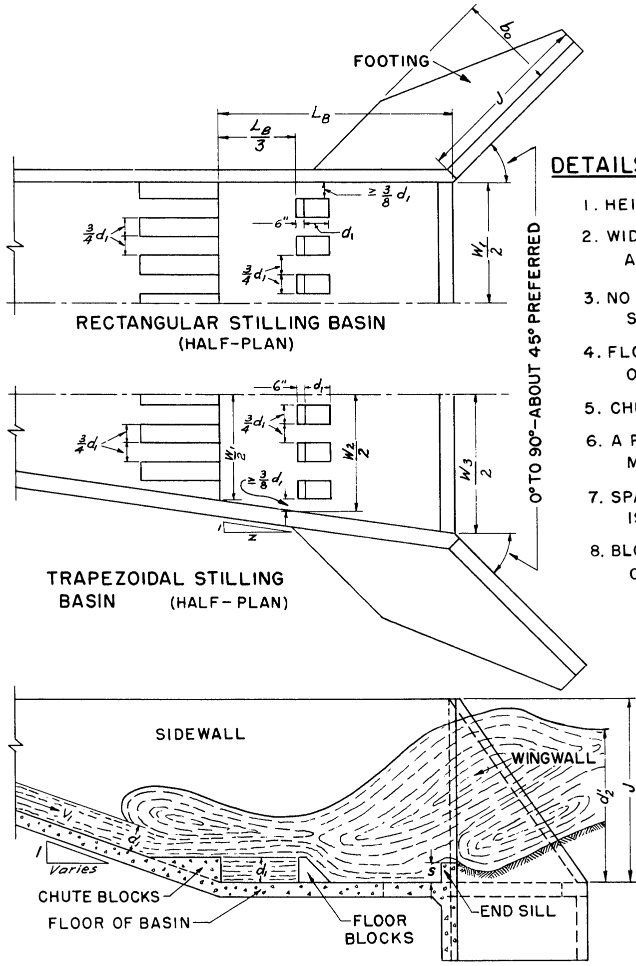
All odd dimensions read from ES-73 should be increased to the next even number to simplify construction.

---

[1]Thomas, H. A., and Hopkins, Cavitation on Baffle Piers, Proceedings of the Second Hydraulic Conference, Iowa, June 1942.

ES-86, page 2.202, gives the capacity without freeboard q_{mo} of SAF outlets for various values of d_1, J, and L_B. For a given required capacity without freeboard, a study of ES-78 and ES-86 will show an increase in the width of the chute will decrease q_{mo}, d_1, J, and L_B. The corresponding values for required tailwater depth d_2' and height of endsill s is given on page 2.203. These values are also listed in tabular form on pages 2.199 to 2.201.

HYDRAULIC DESIGN CRITERIA AND CHARTS FOR SAF STILLING BASIN



SECTION ALONG CENTER LINE

DETAILS OF LAYOUT FOR FLOOR AND CHUTE BLOCKS

1. HEIGHT OF FLOOR AND CHUTE BLOCKS IS d_1
2. WIDTH AND SPACING OF FLOOR AND CHUTE BLOCKS APPROXIMATELY $\frac{3d_1}{4}$
3. NO FLOOR BLOCK SHOULD BE PLACED CLOSER TO SIDEWALL THAN $\frac{3d_1}{8}$
4. FLOOR BLOCKS OCCUPY BETWEEN 40 AND 55 PERCENT OF STILLING BASIN WIDTH AT BLOCKS
5. CHUTE BLOCKS TO BE STAGGERED WITH FLOOR BLOCKS
6. A PORTION OF A CHUTE BLOCK OR A WHOLE CHUTE BLOCK MAY BE ADJACENT TO A SIDEWALL
7. SPACE BETWEEN SIDEWALL AND FIRST CHUTE BLOCK IS NOT TO BE GREATER THAN APPROXIMATELY $\frac{3d_1}{4}$
8. BLOCKS ARE TO BE SYMMETRICAL ABOUT STILLING BASIN CENTER LINE

DESIGN FORMULAS

$$3 \leq F_1 \leq 300$$

1. $F_1 = \frac{v_1^2}{g d_1}$
2. $d_2 = \frac{d_1}{2}(-1 + \sqrt{8 F_1 + 1})$
3. $d_2' = 1.4\, d_1 F_1^{0.45}$
4. $L_B = \frac{4.5\, d_2}{F_1^{0.38}}$
5. $J = \frac{d_2}{3} + d_2'$
6. $s = 0.07\, d_2$
7. $z \geq 3\sqrt{F_1}$

DEFINITION OF SYMBOLS

F_1 = FROUDE'S NUMBER $\equiv \frac{v_1^2}{g d_1}$ (DIMENSIONLESS NUMBER)

v_1 = ENTRANCE VELOCITY OF WATER TO SAF STILLING BASIN — FT./SEC.

d_1 = ENTRANCE DEPTH OF WATER TO SAF STILLING BASIN — FEET

L_B = LENGTH OF SAF STILLING BASIN — FEET

J = HEIGHT OF SIDEWALLS OF SAF STILLING BASIN — FEET

s = HEIGHT OF TRANSVERSE END SILL OF SAF STILLING BASIN — FEET

d_2' = REQUIRED HEIGHT OF TAILWATER OVER SAF STILLING BASIN — FEET

d_2 = SEQUENT DEPTH OF FLOW TO DEPTH d_1 — FEET

g = ACCELERATION DUE TO GRAVITY — 32.16 FT./SEC.^{2}

W_1 = WIDTH OF SAF STILLING BASIN AT DOWNSTREAM END OF CHUTE BLOCKS-FEET

W_2 = WIDTH OF SAF STILLING BASIN AT UPSTREAM END OF FLOOR BLOCKS-FEET

W_3 = WIDTH OF SAF STILLING BASIN AT DOWNSTREAM END — FEET

Z = DIVERGENCE OF SIDEWALL (RATIO)

REFERENCE

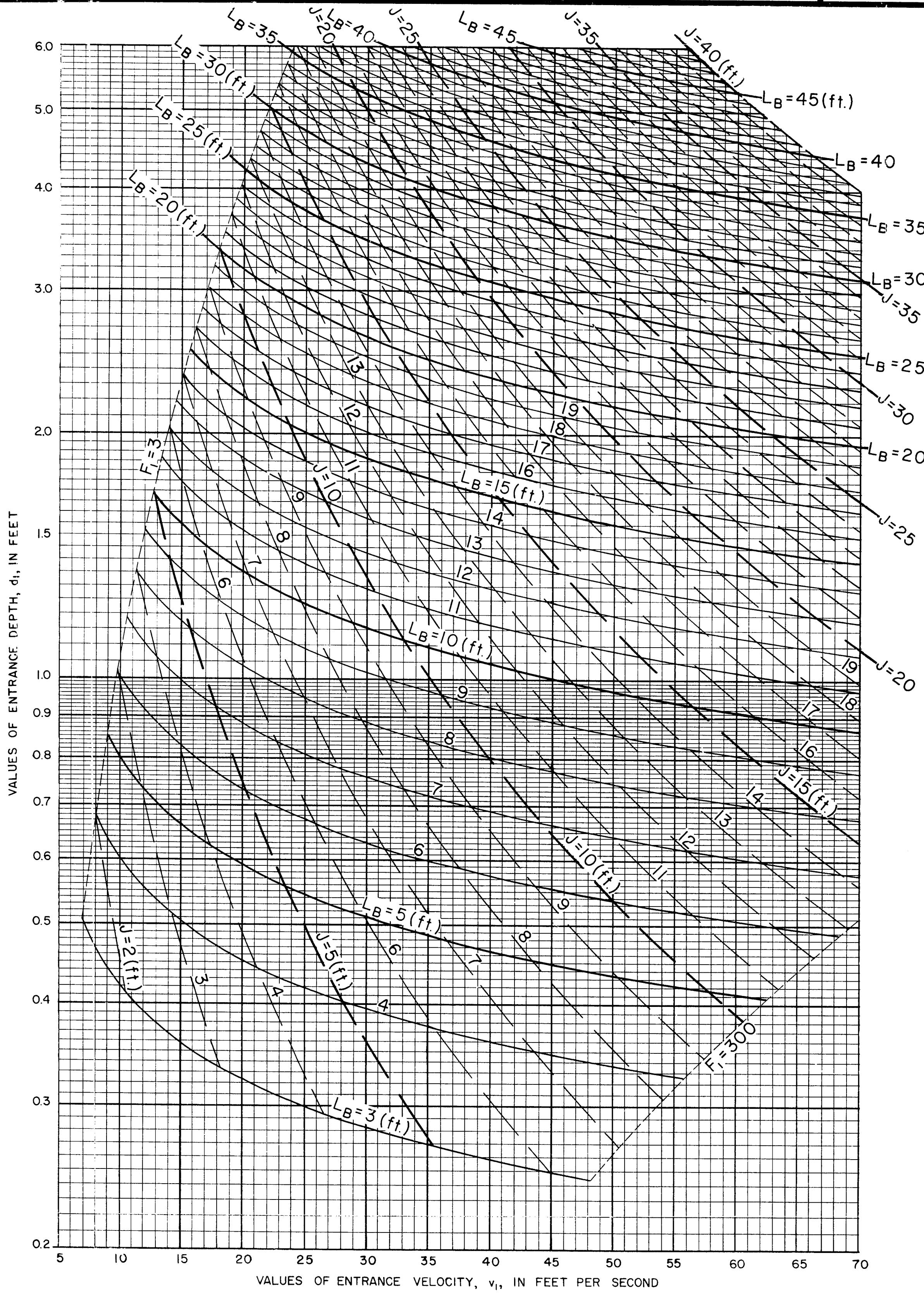
Blaisdell, F.W. "Development and Hydraulic Design, Saint Anthony Falls Stilling Basin". (SAF Stilling Basin) Trans. A S C E 113 P. 483-561; 1948

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

STANDARD DRAWING NO.
ES-73
SHEET 1 OF 3
DATE: 3-23-53
Revised 4-10-54

HYDRAULIC DESIGN CRITERIA AND CHARTS FOR SAF STILLING BASIN

L_B-Feet
J-Feet



REFERENCE
Blaisdell, F. W. "Development And Hydraulic Design, Saint Anthony Falls Stilling Basin." (SAF Stilling Basin)
Trans. A S C E 113 P. 483-561; 1948
This diagram was developed by Paul D. Doubt, Engineering Design Section.

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ENGINEERING DIVISION-DESIGN SECTION

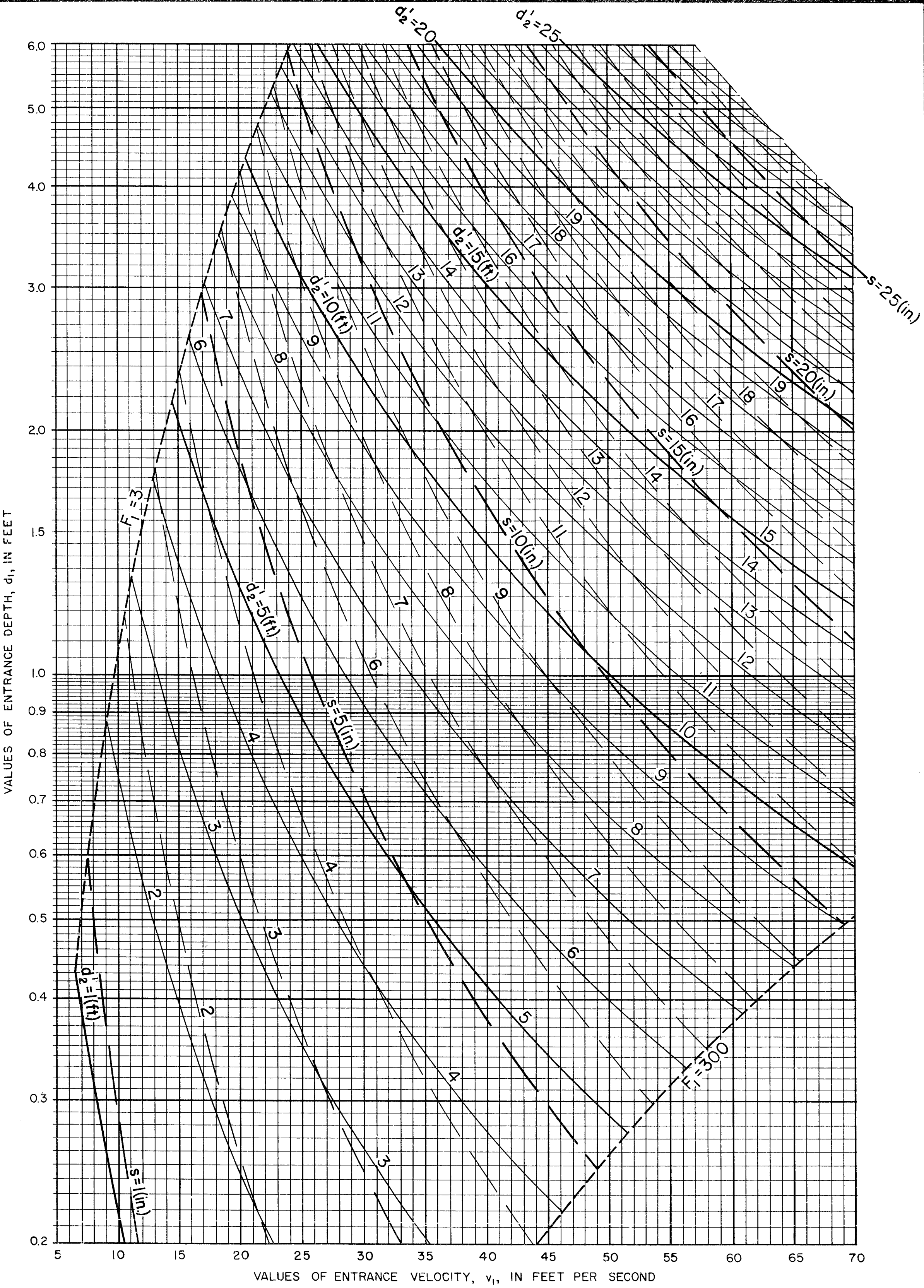
STANDARD DRAWING NO.
ES-73

SHEET 2 OF 3

DATE: 3-23-53
Revised 4-10-54

HYDRAULIC DESIGN CRITERIA AND CHARTS FOR SAF STILLING BASIN

s - Inches
d_2' - Feet



REFERENCE

Blaisdell, F. W. "Development And Hydraulic Design, Saint Anthony Falls Stilling Basin." (SAF Stilling Basin) Trans. A S C E 113 P. 483-561, 1948

This diagram was developed by Paul D. Doubt, Engineering Design Section.

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ENGINEERING DIVISION-DESIGN SECTION

STANDARD DRAWING NO.

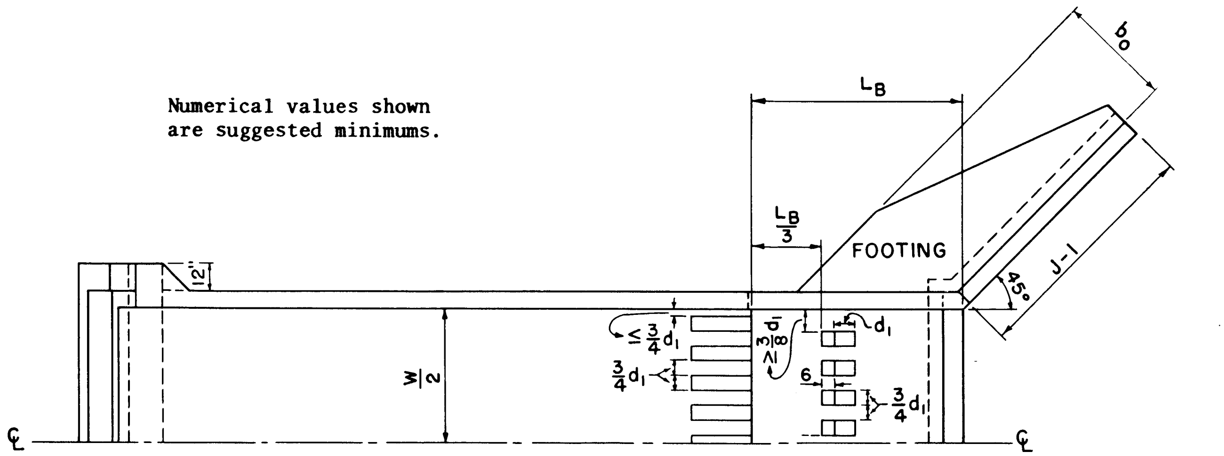
ES-73

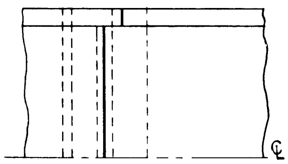
SHEET 3 OF 3

DATE: 3-23-53
Revised 4-10-54

CHUTE SPILLWAYS: SAF OUTLETS
The General Layout Drawing

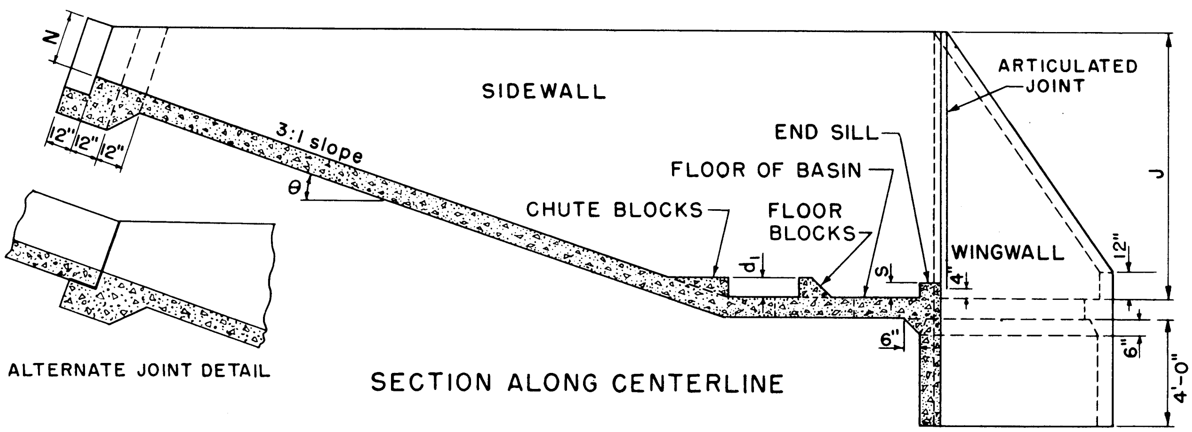
Numerical values shown are suggested minimums.





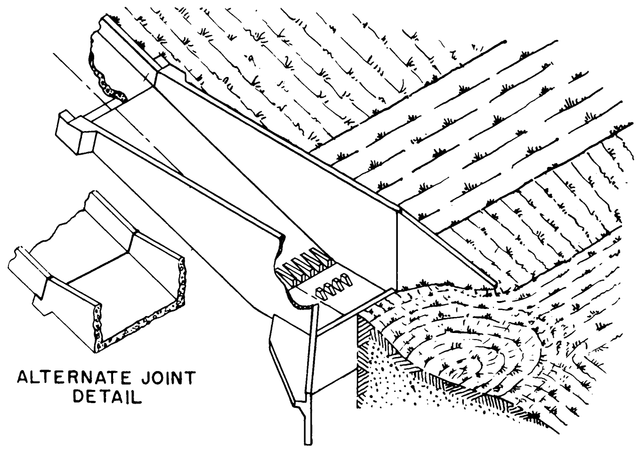
ALTERNATE JOINT DETAIL

HALF-PLAN



ALTERNATE JOINT DETAIL

SECTION ALONG CENTERLINE



ALTERNATE JOINT DETAIL

ISOMETRIC VIEW

NOTE—

Hydraulic Criteria and Formulas are given by ES-73, or by sheets 2, 6, and 7 of this drawing.

Capacities for this structure are given on sheets 2 through 7 of this drawing.

The backfill will be limited to one of the following heights, whichever is least:

1. Top of sidewall and wingwall.
2. $\frac{2}{3} d_2'$ above the floor of the basin.
3. 5 feet above the floor of the basin.

REFERENCE:	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION- DESIGN SECTION	STANDARD DWG. NO. ES-86 SHEET 1 OF 8 SHEETS DATE 3-30-54
Revised: 11-1-54		

Revised 10/77

CHUTE SPILLWAYS: SAF OUTLETS;

Definition of symbols and Formulas

DEFINITION OF SYMBOLS

F_1 = Froude's number $\equiv \frac{v_1^2}{gd_1}$ at entrance of SAF basin (dimensionless number)
J = Height of sidewalls of SAF above floor in ft
L_B = Length of SAF basin (including end sill) in ft
d_1 = Height of floor and chute blocks above floor of SAF basin in ft
d_1 = Entrance depth of water without air to SAF basin in ft
s = Height of transverse end sill above floor of SAF basin in inches
d_2' = Required height of tailwater above floor of SAF basin in ft
d_2 = Sequent depth of flow to depth d_1 in ft
v_1 = Entrance velocity of water to SAF basin in ft/sec
W = Width of SAF outlet in ft
Q_r = Design discharge in cfs
Q_{fr} = Recommended required capacity without freeboard of SAF outlet in cfs
Q_{mo} = Capacity without freeboard of SAF outlet in cfs
Q_{so} = Capacity of SAF outlet in cfs
q_r = Design discharge per foot width in cfs/ft
q_{mo} = Capacity without freeboard of SAF outlet per foot width in cfs/ft
s_o = Slope of bottom of channel in the SAF outlet ft/ft
N = Perpendicular height of sidewalls above channel floor at upstream end of SAF outlet in ft
g = Acceleration due to gravity--32.16 ft/sec^2

DESIGN FORMULAS

$3 \leq F_1 \leq 300$

1. $F_1 = \frac{v_1^2}{gd_1}$
2. $d_2 = \frac{d_1}{2}\left(-1 + \sqrt{8F_1 + 1}\right)$
3. $d_2' = 1.4\, d_1 F_1^{0.45}$
4. $L_B = \frac{4.5\, d_2}{F_1^{0.38}}$
5. $J = \frac{d_2}{3} + d_2'$
6. $s = 0.07\, d_2$

$Q_{fr} = (1.20 + 0.003\, Z)\, Q_r$

The backfill will be limited to one of the following heights, whichever is least:

1. Top of sidewall and wing-wall.
2. $\frac{2}{3}d_2'$ above the floor of the basin.
3. 5 feet above the floor of the basin.

REFERENCE	U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-86 SHEET 2 OF 8 DATE February 1954

Revised 10/77

CHUTE SPILLWAYS: SAF OUTLETS

Dimensions and Capacities

$S_o = \frac{1}{3}$

J = 3.0 to 10.5

J	L_B	N	b_o	d_1	q_{mo}
3.0	3.0	2.00	2.75	0.3330	6.061
3.5	3.0	2.00	3.00	0.3100	6.913
3.5	3.5	2.00	3.00	0.3800	7.638
3.5	4.0	2.00	3.00	0.4720	8.354
4.0	3.5	2.00	3.50	0.3640	8.518
4.0	4.0	2.00	3.50	0.4410	9.305
4.5	3.5	2.00	4.00	0.3470	9.490
4.5	4.0	2.00	4.00	0.4205	10.323
5.0	3.5	2.00	4.25	0.3315	10.409
5.0	4.0	2.00	4.25	0.4015	11.322
5.0	4.5	2.00	4.25	0.4750	12.160
5.0	5.0	2.00	4.25	0.5550	13.043
5.5	3.5	2.00	4.25	0.3185	11.291
5.5	4.0	2.00	4.25	0.3860	12.273
5.5	4.5	2.00	4.25	0.4560	13.201
5.5	5.0	2.00	4.25	0.5300	14.098
5.5	5.5	2.00	4.25	0.6100	15.036
6.0	3.5	2.00	4.25	0.3085	12.216
6.0	4.0	2.00	4.25	0.3725	13.261
6.0	4.5	2.00	4.25	0.4400	14.256
6.0	5.0	2.00	4.25	0.5100	15.198
6.0	5.5	2.00	4.25	0.5870	16.172
6.0	6.0	2.00	4.25	0.6660	17.116
6.5	3.5	2.00	4.25	0.3000	13.155
6.5	4.0	2.00	4.25	0.3595	14.218
6.5	4.5	2.00	4.25	0.4250	15.300
6.5	5.0	2.00	4.25	0.4925	16.302
6.5	5.5	2.00	4.25	0.5650	17.317
6.5	6.0	2.00	4.25	0.6410	18.333
6.5	6.5	2.00	4.25	0.7240	19.331
6.5	7.0	2.00	4.25	0.8040	20.261
7.0	4.0	2.00	4.25	0.3490	15.120
7.0	4.5	2.00	4.25	0.4125	16.335
7.0	5.0	2.00	4.25	0.4780	17.424
7.0	5.5	2.00	4.25	0.5455	18.438
7.0	6.0	2.00	4.25	0.6200	19.530
7.0	6.5	2.00	4.25	0.6990	20.551
7.0	7.0	2.00	4.25	0.7780	21.551
7.0	7.5	2.00	4.25	0.8615	22.550
7.0	8.0	2.00	4.25	0.9480	23.558
7.5	4.0	2.00	4.25	0.3395	16.177
7.5	4.5	2.00	4.25	0.4000	17.340
7.5	5.0	2.00	4.25	0.4645	18.487
7.5	5.5	2.00	4.25	0.5290	19.626
7.5	6.0	2.00	4.25	0.6013	20.740
7.5	6.5	2.00	4.25	0.6760	21.835
7.5	7.0	2.00	4.25	0.7520	22.898
7.5	7.5	2.00	4.25	0.8350	23.965
7.5	8.0	2.00	4.25	0.9150	24.888
7.5	8.5	2.00	4.25	1.0000	25.970
7.5	8.5	2.25	4.25	1.0000	25.970
7.5	8.5	2.50	4.25	1.0000	25.970
8.0	4.5	2.00	4.25	0.3900	18.408
8.0	5.0	2.00	4.25	0.4525	19.639
8.0	5.5	2.00	4.25	0.5145	20.760
8.0	6.0	2.00	4.25	0.5850	21.967
8.0	6.5	2.00	4.25	0.6570	23.126
8.0	7.0	2.00	4.25	0.7310	24.196
8.0	7.5	2.00	4.25	0.8080	25.250
8.0	8.0	2.00	4.25	0.8850	26.285
8.0	8.5	2.00	4.25	0.9700	27.354
8.0	9.0	2.00	4.25	1.0580	28.460
8.0	9.0	2.25	4.25	1.0580	28.460
8.0	9.0	2.50	4.25	1.0580	28.460
8.0	9.5	2.25	4.25	1.1450	29.541
8.0	9.5	2.50	4.25	1.1450	29.541
8.0	9.5	2.75	4.25	1.1450	29.541
8.0	9.5	3.00	4.25	1.1450	29.541
8.5	5.0	2.00	4.25	0.4410	20.683
8.5	5.5	2.00	4.25	0.5015	21.865
8.5	6.0	2.00	4.25	0.5700	23.142
8.5	6.5	2.00	4.25	0.6390	24.346
8.5	7.0	2.00	4.25	0.7110	25.418
8.5	7.5	2.00	4.25	0.7860	26.567
8.5	8.0	2.00	4.25	0.8620	27.756
8.5	8.5	2.00	4.25	0.9400	28.856
8.5	9.0	2.00	4.25	1.0270	29.937
8.5	9.0	2.25	4.25	1.0270	29.937
8.5	9.5	2.00	4.25	1.1150	30.997
8.5	9.5	2.25	4.25	1.1150	30.997
8.5	9.5	2.50	4.25	1.1150	30.997
8.5	9.5	2.75	4.25	1.1150	30.997
8.5	10.0	2.50	4.25	1.2030	32.060

J	L_B	N	b_o	d_1	q_{mo}
8.5	10.0	2.75	4.23	1.2030	32.060
8.5	10.0	3.00	4.25	1.2030	32.060
9.0	5.0	2.00	4.25	0.4300	21.737
9.0	5.5	2.00	4.25	0.4910	23.028
9.0	6.0	2.00	4.25	0.5570	24.369
9.0	6.5	2.00	4.25	0.6220	25.595
9.0	7.0	2.00	4.25	0.6930	26.784
9.0	7.5	2.00	4.25	0.7650	27.961
9.0	8.0	2.00	4.25	0.8410	29.099
9.0	8.5	2.00	4.25	0.9170	30.261
9.0	9.0	2.00	4.25	1.0000	31.400
9.0	9.0	2.25	4.25	1.0000	31.400
9.0	9.5	2.00	4.25	1.0840	32.520
9.0	9.5	2.25	4.25	1.0840	32.520
9.0	9.5	2.50	4.25	1.0840	32.520
9.0	10.0	2.25	4.25	1.1700	33.638
9.0	10.0	2.50	4.25	1.1700	33.638
9.0	10.0	2.75	4.25	1.1700	33.638
9.0	10.5	2.50	4.25	1.2600	34.776
9.0	10.5	2.75	4.25	1.2600	34.776
9.0	10.5	3.00	4.25	1.2600	34.776
9.0	11.0	2.75	4.25	1.3500	35.892
9.0	11.0	3.00	4.25	1.3500	35.892
9.0	11.0	3.25	4.25	1.3500	35.892
9.0	11.0	3.50	4.25	1.3500	35.892
9.0	11.0	3.75	4.25	1.3500	35.892
9.5	5.5	2.00	4.25	0.4800	24.240
9.5	6.0	2.00	4.25	0.5450	25.533
9.5	6.5	2.00	4.25	0.6100	26.901
9.5	7.0	2.00	4.25	0.6775	28.116
9.5	7.5	2.00	4.25	0.7470	29.320
9.5	8.0	2.00	4.25	0.8200	30.545
9.5	8.5	2.00	4.25	0.8940	31.692
9.5	9.0	2.00	4.25	0.9760	32.940
9.5	9.5	2.00	4.25	1.0540	34.097
9.5	9.5	2.25	4.25	1.0540	34.097
9.5	10.0	2.00	4.25	1.1390	35.252
9.5	10.0	2.25	4.25	1.1390	35.252
9.5	10.0	2.50	4.25	1.1390	35.252
9.5	10.5	2.25	4.25	1.2220	36.355
9.5	10.5	2.50	4.25	1.2220	36.355
9.5	10.5	2.75	4.25	1.2220	36.355
9.5	11.0	2.50	4.25	1.3100	37.466
9.5	11.0	2.75	4.25	1.3100	37.466
9.5	11.0	3.00	4.25	1.3100	37.466
9.5	11.0	3.25	4.25	1.3100	37.466
9.5	11.5	3.00	4.25	1.4040	38.680
9.5	11.5	3.25	4.25	1.4040	38.680
9.5	11.5	3.50	4.25	1.4040	38.680
9.5	11.5	3.75	4.25	1.4040	38.680
9.5	12.0	3.00	4.25	1.4940	39.815
9.5	12.0	3.25	4.25	1.4940	39.815
9.5	12.0	3.50	4.25	1.4940	39.815
9.5	12.0	3.75	4.25	1.4940	39.815
9.5	12.0	4.00	4.25	1.4940	39.815
10.0	5.5	2.00	4.25	0.4720	25.323
10.0	6.0	2.00	4.25	0.5335	26.782
10.0	6.5	2.00	4.25	0.5970	28.059
10.0	7.0	2.00	4.25	0.6625	29.349
10.0	7.5	2.00	4.25	0.7300	30.660
10.0	8.0	2.00	4.25	0.8010	31.880
10.0	8.5	2.00	4.25	0.8740	33.168
10.0	9.0	2.00	4.25	0.9530	34.451
10.0	9.5	2.00	4.25	1.0300	35.638
10.0	10.0	2.00	4.25	1.1100	36.797
10.0	10.0	2.25	4.25	1.1100	36.797
10.0	10.5	2.00	4.25	1.1930	37.937
10.0	10.5	2.25	4.25	1.1930	37.937
10.0	10.5	2.50	4.25	1.1930	37.937
10.0	11.0	2.50	4.25	1.2750	39.079
10.0	11.0	2.75	4.25	1.2750	39.079
10.0	11.0	3.00	4.25	1.2750	39.079
10.0	11.5	2.75	4.25	1.3650	40.268
10.0	11.5	3.00	4.25	1.3650	40.268
10.0	12.0	3.00	4.25	1.4550	41.540
10.0	12.0	3.25	4.25	1.4550	41.540
10.0	12.0	3.50	4.25	1.4550	41.540
10.0	12.5	3.50	4.25	1.5500	42.703
10.0	12.5	3.75	4.25	1.5500	42.703
10.0	12.5	4.00	4.25	1.5500	42.703
10.5	6.0	2.00	4.25	0.5230	27.902
10.5	6.5	2.00	4.25	0.5850	29.367
10.5	7.0	2.00	4.25	0.6500	30.745
10.5	7.5	2.00	4.25	0.7160	32.041
10.5	8.0	2.00	4.25	0.7870	33.369
10.5	8.5	2.00	4.25	0.8570	34.580
10.5	9.0	2.00	4.25	0.9310	35.882
10.5	9.5	2.00	4.25	1.0050	37.135
10.5	10.0	2.00	4.25	1.0850	38.355
10.5	10.0	2.25	4.25	1.0850	38.355

REFERENCE:

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

STANDARD DWG. NO.
ES- 86
SHEET 3 OF 8
DATE 9-8-54

Revised 10/77

CHUTE SPILLWAYS: SAF OUTLETS

Dimensions and Capacities

$S_O = \frac{1}{3}$

J = 10.5 to 13.0

J	L_B	N	b_o	d_1	q_{mo}
10.5	10.5	2.00	4.25	1.1650	39.610
10.5	10.5	2.25	4.25	1.1650	39.610
10.5	10.5	2.50	4.25	1.1650	39.610
10.5	11.0	2.25	4.25	1.2460	40.744
10.5	11.0	2.50	4.25	1.2460	40.744
10.5	11.0	2.75	4.25	1.2460	40.744
10.5	11.5	2.50	4.25	1.3300	41.962
10.5	11.5	2.75	4.25	1.3300	41.962
10.5	11.5	3.00	4.25	1.3300	41.962
10.5	12.0	2.75	4.25	1.4160	43.188
10.5	12.0	3.00	4.25	1.4160	43.188
10.5	12.0	3.25	4.25	1.4160	43.188
10.5	12.0	3.50	4.50	1.4160	43.188
10.5	12.5	3.00	4.50	1.5120	44.528
10.5	12.5	3.25	4.50	1.5120	44.528
10.5	12.5	3.50	4.50	1.5120	44.528
10.5	13.0	3.25	4.50	1.6080	45.828
10.5	13.0	3.50	4.50	1.6080	45.828
10.5	13.0	3.75	4.50	1.6080	45.828
10.5	13.5	3.25	4.50	1.7000	46.886
10.5	13.5	3.50	4.50	1.7000	46.886
10.5	13.5	3.75	4.50	1.7000	46.886
10.5	13.5	4.00	4.50	1.7000	46.886
10.5	13.5	4.25	4.50	1.7000	46.886
11.0	6.0	2.00	4.50	0.5140	29.118
11.0	6.5	2.00	4.50	0.5745	30.621
11.0	7.0	2.00	4.50	0.6375	32.003
11.0	7.5	2.00	4.50	0.7010	33.298
11.0	8.0	2.00	4.50	0.7710	34.695
11.0	8.5	2.00	4.50	0.8400	36.036
11.0	9.0	2.00	4.50	0.9110	37.260
11.0	9.5	2.00	4.50	0.9860	38.651
11.0	10.0	2.00	4.50	1.0620	39.878
11.0	10.5	2.00	4.50	1.1400	41.154
11.0	10.5	2.25	4.50	1.1400	41.154
11.0	11.0	2.00	4.50	1.2200	42.456
11.0	11.0	2.25	4.50	1.2200	42.456
11.0	11.0	2.25	4.50	1.2200	42.456
11.0	11.5	2.50	4.75	1.3050	43.783
11.0	11.5	2.75	4.75	1.3050	43.783
11.0	11.5	3.00	4.75	1.3050	43.783
11.0	12.0	2.50	4.75	1.3880	45.041
11.0	12.0	2.75	4.75	1.3880	45.041
11.0	12.0	3.00	4.75	1.3880	45.041
11.0	12.5	3.00	4.75	1.4750	46.168
11.0	12.5	3.25	4.75	1.4750	46.168
11.0	13.0	3.00	4.75	1.5650	47.420
11.0	13.0	3.25	4.75	1.5650	47.420
11.0	13.0	3.50	4.75	1.5650	47.420
11.0	13.0	3.75	4.75	1.5650	47.420
11.0	13.5	3.50	4.75	1.6600	48.638
11.0	13.5	3.75	4.75	1.6600	48.638
11.0	13.5	4.00	4.75	1.6600	48.638
11.0	14.0	4.00	4.75	1.7500	49.700
11.0	14.0	4.25	4.75	1.7500	49.700
11.5	6.5	2.00	4.75	0.5640	31.725
11.5	7.0	2.00	4.75	0.6270	33.231
11.5	7.5	2.00	4.75	0.6900	34.673
11.5	8.0	2.00	4.75	0.7570	36.109
11.5	8.5	2.00	4.75	0.8270	37.587
11.5	9.0	2.00	4.75	0.8930	38.801
11.5	9.5	2.00	4.75	0.9670	40.179
11.5	10.0	2.00	4.75	1.0420	41.522
11.5	10.0	2.25	4.75	1.0402	41.522
11.5	10.5	2.00	4.75	1.1200	42.896
11.5	10.5	2.25	4.75	1.1200	42.896
11.5	11.0	2.25	4.75	1.1920	44.104
11.5	11.0	2.50	4.75	1.1920	44.104
11.5	11.5	2.25	4.75	1.2720	45.347
11.5	11.5	2.50	4.75	1.2720	45.347
11.5	11.5	2.75	4.75	1.2720	45.347
11.5	12.0	2.25	4.75	1.3550	46.613
11.5	12.0	2.50	4.75	1.3550	46.613
11.5	12.0	2.75	4.75	1.3550	46.613
11.5	12.0	3.00	4.75	1.3550	46.613
11.5	12.5	2.75	5.00	1.4400	47.880
11.5	12.5	3.00	5.00	1.4400	47.880
11.5	12.5	3.25	5.00	1.4400	47.880
11.5	13.0	3.00	5.00	1.5280	49.278
11.5	13.0	3.25	5.00	1.5280	49.278
11.5	13.0	3.50	5.00	1.5280	49.278
11.5	13.5	3.25	5.00	1.6180	50.482
11.5	13.5	3.50	5.00	1.6180	50.482
11.5	13.5	3.75	5.00	1.6180	50.482
11.5	13.5	4.00	5.00	1.6180	50.482
11.5	14.0	3.75	5.00	1.7030	51.686
11.5	14.0	4.00	5.00	1.7030	51.686
11.5	14.5	3.75	5.00	1.8120	52.942
11.5	14.5	4.00	5.00	1.8120	52.942
11.5	14.5	4.25	5.00	1.8120	52.942
11.5	14.5	4.50	5.00	1.8120	52.942

J	L_B	N	b_o	d_1	q_{mo}
12.0	6.5	2.00	4.75	0.5500	32.835
12.0	7.0	2.00	5.00	0.6170	34.552
12.0	7.5	2.00	5.00	0.6785	35.995
12.0	8.0	2.00	5.00	0.7440	37.498
12.0	8.5	2.00	5.00	0.8120	38.935
12.0	9.0	2.00	5.00	0.8770	40.254
12.0	9.5	2.00	5.00	0.9475	41.595
12.0	9.5	2.25	5.00	0.9475	41.595
12.0	10.0	2.00	5.00	1.0200	42.993
12.0	10.0	2.25	5.00	1.0200	42.993
12.0	10.5	2.25	5.00	1.0960	44.388
12.0	11.0	2.25	5.00	1.1680	45.668
12.0	11.5	2.25	5.00	1.2500	47.063
12.0	11.5	2.50	5.00	1.2500	47.063
12.0	12.0	2.25	5.00	1.3300	48.412
12.0	12.0	2.50	5.00	1.3300	48.412
12.0	12.0	2.75	5.00	1.3300	48.412
12.0	12.5	2.25	5.00	1.4120	49.702
12.0	12.5	2.50	5.00	1.4120	49.702
12.0	12.5	2.75	5.00	1.4120	49.702
12.0	12.5	3.00	5.00	1.4120	49.702
12.0	12.5	3.25	5.00	1.4120	49.702
12.0	13.0	2.50	5.00	1.5000	51.075
12.0	13.0	2.75	5.00	1.5000	51.075
12.0	13.0	3.00	5.00	1.5000	51.075
12.0	13.0	3.25	5.00	1.5000	51.075
12.0	13.5	3.00	5.00	1.5850	52.305
12.0	13.5	3.25	5.00	1.5850	52.305
12.0	13.5	3.50	5.00	1.5850	52.305
12.0	13.5	3.75	5.00	1.5850	52.305
12.0	14.0	3.50	5.00	1.6700	53.523
12.0	14.0	3.75	5.00	1.6700	53.523
12.0	14.5	3.50	5.00	1.7630	54.829
12.0	14.5	3.75	5.00	1.7630	54.829
12.0	14.5	4.00	5.00	1.7630	54.829
12.0	14.5	4.25	5.00	1.7630	54.829
12.0	15.0	4.00	5.25	1.8600	56.172
12.0	15.0	4.25	5.25	1.8600	56.172
12.0	15.0	4.50	5.25	1.8600	56.172
12.0	15.0	4.75	5.25	1.8600	56.172
12.5	7.0	2.00	5.00	0.6070	35.813
12.5	7.5	2.00	5.00	0.6670	37.252
12.5	8.0	2.00	5.00	0.7300	38.836
12.5	8.5	2.00	5.00	0.7990	40.389
12.5	9.0	2.00	5.00	0.8610	41.715
12.5	9.0	2.25	5.00	0.8610	41.715
12.5	9.5	2.00	5.25	0.9300	43.152
12.5	9.5	2.25	5.25	0.9300	43.152
12.5	10.0	2.25	5.25	1.0010	44.594
12.5	10.5	2.25	5.25	1.0760	46.000
12.5	11.0	2.25	5.25	1.1480	47.355
12.5	11.0	2.50	5.25	1.1480	47.355
12.5	11.5	2.25	5.25	1.2250	48.692
12.5	11.5	2.50	5.25	1.2250	48.692
12.5	12.0	2.50	5.25	1.3030	50.035
12.5	12.0	2.75	5.25	1.3030	50.035
12.5	12.5	2.50	5.25	1.3830	51.378
12.5	12.5	2.75	5.25	1.3830	51.378
12.5	12.5	3.00	5.25	1.3830	51.378
12.5	13.0	2.50	5.25	1.4650	52.740
12.5	13.0	2.75	5.25	1.4650	52.740
12.5	13.0	3.00	5.25	1.4650	52.740
12.5	13.5	3.00	5.25	1.5550	54.114
12.5	13.5	3.25	5.25	1.5550	54.114
12.5	13.5	3.50	5.25	1.5550	54.114
12.5	14.0	3.00	5.25	1.6370	55.412
12.5	14.0	3.25	5.25	1.6370	55.412
12.5	14.0	3.50	5.25	1.6370	55.412
12.5	14.0	3.75	5.25	1.6370	55.412
12.5	14.5	3.50	5.25	1.7300	56.744
12.5	14.5	3.75	5.25	1.7300	56.744
12.5	14.5	4.00	5.25	1.7300	56.744
12.5	15.0	3.75	5.25	1.8180	57.994
12.5	15.0	4.00	5.25	1.8180	57.994
12.5	15.0	4.25	5.25	1.8180	57.994
12.5	15.0	4.50	5.25	1.8180	57.994
12.5	15.5	4.00	5.50	1.9200	59.328
12.5	15.5	4.25	5.50	1.9200	59.328
12.5	15.5	4.50	5.50	1.9200	59.328
12.5	15.5	4.75	5.50	1.9200	59.328
13.0	7.0	2.00	5.25	0.6000	37.320
13.0	7.5	2.00	5.50	0.6560	38.682
13.0	8.0	2.00	5.50	0.7185	40.236
13.0	8.5	2.00	5.50	0.7850	41.762
13.0	8.5	2.25	5.50	0.7850	41.762
13.0	9.0	2.00	5.50	0.8480	43.248
13.0	9.0	2.25	5.50	0.8480	43.248
13.0	9.5	2.25	5.50	0.9170	44.704
13.0	10.0	2.25	5.50	0.9860	46.145
13.0	10.5	2.25	5.50	1.0570	47.565
13.0	10.5	2.50	5.50	1.0570	47.565
13.0	11.0	2.25	5.50	1.1300	48.986
13.0	11.0	2.50	5.50	1.1300	48.986

REFERENCE:

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

STANDARD DWG. NO.
ES- 86
SHEET 4 OF 8
DATE 9-8-54

Revised 10/77

CHUTE SPILLWAYS: SAF OUTLETS

Dimensions and Capacities

$S_0 = \frac{1}{3}$

J = 13.0 to 15.0

J	L_B	N	b_o	d_1	q_{mo}
13.0	11.5	2.50	5.50	1.2040	50.327
13.0	12.0	2.50	5.50	1.2850	51.729
13.0	12.5	2.50	5.50	1.3600	53.176
13.0	12.5	2.75	5.50	1.3600	53.176
13.0	13.0	2.50	5.50	1.4380	54.500
13.0	13.0	2.75	5.50	1.4380	54.500
13.0	13.0	3.00	5.50	1.4380	54.500
13.0	13.5	2.75	5.50	1.5230	55.818
13.0	13.5	3.00	5.50	1.5230	55.818
13.0	13.5	3.25	5.50	1.5230	55.818
13.0	14.0	2.75	5.50	1.6080	57.164
13.0	14.0	3.00	5.50	1.6080	57.164
13.0	14.0	3.25	5.50	1.6080	57.164
13.0	14.0	3.50	5.50	1.6080	57.164
13.0	14.5	3.25	5.50	1.6980	58.581
13.0	14.5	3.50	5.50	1.6980	58.581
13.0	14.5	3.75	5.50	1.6980	58.581
13.0	15.0	3.75	5.50	1.7800	59.897
13.0	15.0	4.00	5.50	1.7800	59.897
13.0	15.5	3.75	5.50	1.8800	61.288
13.0	15.5	4.00	5.50	1.8800	61.288
13.0	15.5	4.25	5.50	1.8800	61.288
13.0	15.5	4.50	5.50	1.8800	61.288
13.0	15.5	4.75	5.50	1.8800	61.288
13.0	16.0	3.75	5.50	1.9700	62.548
13.0	16.0	4.00	5.50	1.9700	62.548
13.0	16.0	4.25	5.50	1.9700	62.548
13.0	16.0	4.50	5.50	1.9700	62.548
13.0	16.0	4.75	5.50	1.9700	62.548
13.5	7.5	2.00	5.50	0.6450	39.990
13.5	8.0	2.00	5.50	0.7070	41.572
13.5	8.0	2.25	5.50	0.7070	41.572
13.5	8.5	2.00	5.50	0.7710	43.137
13.5	8.5	2.25	5.50	0.7710	43.137
13.5	9.0	2.25	5.50	0.8350	44.673
13.5	9.5	2.25	5.50	0.9010	46.267
13.5	10.0	2.25	5.50	0.9700	47.724
13.5	10.0	2.50	5.50	0.9700	47.724
13.5	10.5	2.25	5.50	1.0400	49.140
13.5	10.5	2.50	5.50	1.0400	49.140
13.5	11.0	2.50	5.50	1.1120	50.596
13.5	11.5	2.50	5.50	1.1850	52.140
13.5	12.0	2.50	5.50	1.2600	53.550
13.5	12.0	2.75	5.50	1.2600	53.550
13.5	12.5	2.50	5.50	1.3350	54.935
13.5	12.5	2.75	5.50	1.3350	54.935
13.5	13.0	2.75	5.50	1.4130	56.308
13.5	13.0	3.00	5.50	1.4130	56.308
13.5	13.5	2.75	5.75	1.4970	57.784
13.5	13.5	3.00	5.75	1.4970	57.784
13.5	13.5	3.25	5.75	1.4970	57.784
13.5	14.0	2.75	5.75	1.5800	59.250
13.5	14.0	3.00	5.75	1.5800	59.250
13.5	14.0	3.25	5.75	1.5800	59.250
13.5	14.0	3.50	5.75	1.5800	59.250
13.5	14.5	2.75	5.75	1.6650	60.606
13.5	14.5	3.00	5.75	1.6650	60.606
13.5	14.5	3.25	5.75	1.6650	60.606
13.5	14.5	3.50	5.75	1.6650	60.606
13.5	14.5	3.75	5.75	1.6650	60.606
13.5	15.0	2.75	5.75	1.7500	61.950
13.5	15.0	3.00	5.75	1.7500	61.950
13.5	15.0	3.25	5.75	1.7500	61.950
13.5	15.0	3.50	5.75	1.7500	61.950
13.5	15.0	3.75	5.75	1.7500	61.950
13.5	15.5	3.75	5.75	1.8380	63.227
13.5	15.5	4.00	5.75	1.8380	63.227
13.5	16.0	4.25	5.75	1.9280	64.588
13.5	16.0	4.50	5.75	1.9280	64.588
13.5	16.0	4.75	5.75	1.9280	64.588
14.0	8.0	2.00	5.75	0.6960	42.943
14.0	8.0	2.25	5.75	0.6960	42.943
14.0	8.5	2.25	5.75	0.7600	44.536
14.0	9.0	2.25	5.75	0.8210	46.181
14.0	9.5	2.25	5.75	0.8890	47.828
14.0	9.5	2.50	5.75	0.8890	47.828
14.0	10.0	2.25	5.75	0.9540	49.274
14.0	10.0	2.50	5.75	0.9540	49.274
14.0	10.5	2.50	5.75	1.0240	50.739
14.0	11.0	2.50	5.75	1.0930	52.191
14.0	11.5	2.50	5.75	1.1640	53.660
14.0	11.5	2.75	5.75	1.1640	53.660
14.0	12.0	2.50	5.75	1.2380	55.153
14.0	12.0	2.75	5.75	1.2380	55.153
14.0	12.5	2.75	5.75	1.3130	56.630
14.0	13.0	2.75	5.75	1.3880	58.087
14.0	13.5	2.75	5.75	1.4680	59.527
14.0	13.5	3.00	5.75	1.4680	59.527
14.0	14.0	2.75	5.75	1.5500	61.039
14.0	14.0	3.00	5.75	1.5500	61.039
14.0	14.0	3.25	5.75	1.5500	61.039
14.0	14.5	3.00	5.75	1.6320	62.506
14.0	14.5	3.25	5.75	1.6320	62.506
14.0	14.5	3.50	5.75	1.6320	62.506
14.0	15.0	3.00	5.75	1.7150	63.884
14.0	15.0	3.25	5.75	1.7150	63.884
14.0	15.0	3.50	5.75	1.7150	63.884
14.0	15.0	3.75	5.75	1.7150	63.884
14.0	15.5	3.00	5.75	1.8020	65.279
14.0	15.5	3.25	5.75	1.8020	65.279
14.0	15.5	3.50	5.75	1.8020	65.279
14.0	15.5	3.75	5.75	1.8020	65.279
14.0	15.5	4.00	5.75	1.8020	65.279
14.0	16.0	3.00	6.00	1.8900	66.623
14.0	16.0	3.25	6.00	1.8900	66.623
14.0	16.0	3.50	6.00	1.8900	66.623
14.0	16.0	3.75	6.00	1.8900	66.623
14.0	16.0	4.00	6.00	1.8900	66.623
14.0	16.0	4.25	6.00	1.8900	66.623
14.0	16.0	4.50	6.00	1.8900	66.623
14.0	16.5	3.25	6.00	1.9820	67.982
14.0	16.5	3.75	6.00	1.9820	67.982
14.0	16.5	4.00	6.00	1.9820	67.982
14.0	16.5	4.25	6.00	1.9820	67.982
14.0	16.5	4.50	6.00	1.9820	67.982
14.0	16.5	4.75	6.00	1.9820	67.982
14.0	16.5	5.00	6.00	1.9820	67.982
14.0	16.5	5.25	6.00	1.9820	67.982
14.5	8.0	2.25	6.00	0.6900	44.367
14.5	8.5	2.25	5.75	0.7490	46.064
14.5	9.0	2.25	6.00	0.8100	47.628
14.5	9.0	2.50	6.00	0.8100	47.628
14.5	9.5	2.25	6.00	0.8760	49.275
14.5	9.5	2.50	6.00	0.8760	49.275
14.5	10.0	2.50	6.00	0.9400	50.901
14.5	10.5	2.50	6.00	1.0080	52.416
14.5	11.0	2.50	6.00	1.0750	53.858
14.5	11.0	2.75	6.00	1.0750	53.858
14.5	11.5	2.50	6.00	1.1460	55.409
14.5	11.5	2.75	6.00	1.1460	55.409
14.5	12.0	2.75	6.00	1.2200	56.974
14.5	12.5	2.75	6.00	1.2940	58.424
14.5	13.0	2.75	6.00	1.3700	60.006
14.5	13.0	3.00	6.00	1.3700	60.006
14.5	13.5	3.00	6.00	1.4500	61.553
14.5	14.0	3.00	6.00	1.5300	63.036
14.5	14.5	3.00	6.00	1.6100	64.480
14.5	14.5	3.25	6.00	1.6100	64.480
14.5	15.0	3.00	6.00	1.6900	65.741
14.5	15.0	3.25	6.00	1.6900	65.741
14.5	15.0	3.50	6.00	1.6900	65.741
14.5	15.5	3.00	6.00	1.7720	67.159
14.5	15.5	3.25	6.00	1.7720	67.159
14.5	15.5	3.50	6.00	1.7720	67.159
14.5	15.5	3.75	6.00	1.7720	67.159
14.5	16.0	3.25	6.00	1.8560	68.579
14.5	16.0	3.50	6.00	1.8560	68.579
14.5	16.0	3.75	6.00	1.8560	68.579
14.5	16.0	4.25	6.00	1.8560	68.579
14.5	16.5	3.25	6.00	1.9500	70.020
14.5	16.5	3.75	6.00	1.9500	70.020
14.5	16.5	4.00	6.00	1.9500	70.020
15.0	8.5	2.25	6.00	0.7375	47.348
15.0	8.5	2.50	6.00	0.7375	47.348
15.0	9.0	2.25	6.00	0.7990	49.099
15.0	9.0	2.50	6.00	0.7990	49.099
15.0	9.5	2.50	6.00	0.8640	50.760
15.0	10.0	2.50	6.00	0.9280	52.432
15.0	10.5	2.50	6.25	0.9940	53.974
15.0	10.5	2.75	6.25	0.9940	53.974
15.0	11.0	2.50	6.25	1.0600	55.491
15.0	11.0	2.75	6.25	1.0600	55.491
15.0	11.5	2.75	6.25	1.1350	57.147
15.0	12.0	2.75	6.25	1.2030	58.646
15.0	12.5	2.75	6.25	1.2750	60.116
15.0	12.5	3.00	6.25	1.2750	60.116
15.0	13.0	2.75	6.25	1.3500	61.628
15.0	13.0	3.00	6.25	1.3500	61.628
15.0	13.5	3.00	6.25	1.4250	63.128
15.0	14.0	3.00	6.25	1.5050	64.640
15.0	14.0	3.25	6.25	1.5050	64.640
15.0	14.5	3.00	6.25	1.5860	66.136
15.0	14.5	3.25	6.25	1.5860	66.136
15.0	15.0	3.00	6.25	1.6640	67.558
15.0	15.0	3.25	6.25	1.6640	67.558
15.0	15.0	3.50	6.25	1.6640	67.558
15.0	15.5	3.25	6.25	1.7470	69.007
15.0	15.5	3.50	6.25	1.7470	69.007
15.0	15.5	3.75	6.25	1.7470	69.007
15.0	16.0	3.25	6.25	1.8250	70.445
15.0	16.0	3.50	6.25	1.8250	70.445
15.0	16.0	3.75	6.25	1.8250	70.445
15.0	16.5	3.25	6.25	1.9170	71.983
15.0	16.5	3.50	6.25	1.9170	71.983
15.0	16.5	3.75	6.25	1.9170	71.983
15.0	16.5	4.00	6.25	1.9170	71.983

REFERENCE:

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

STANDARD DWG. NO.
ES- 86
SHEET 5 OF 8
DATE 9-8-54

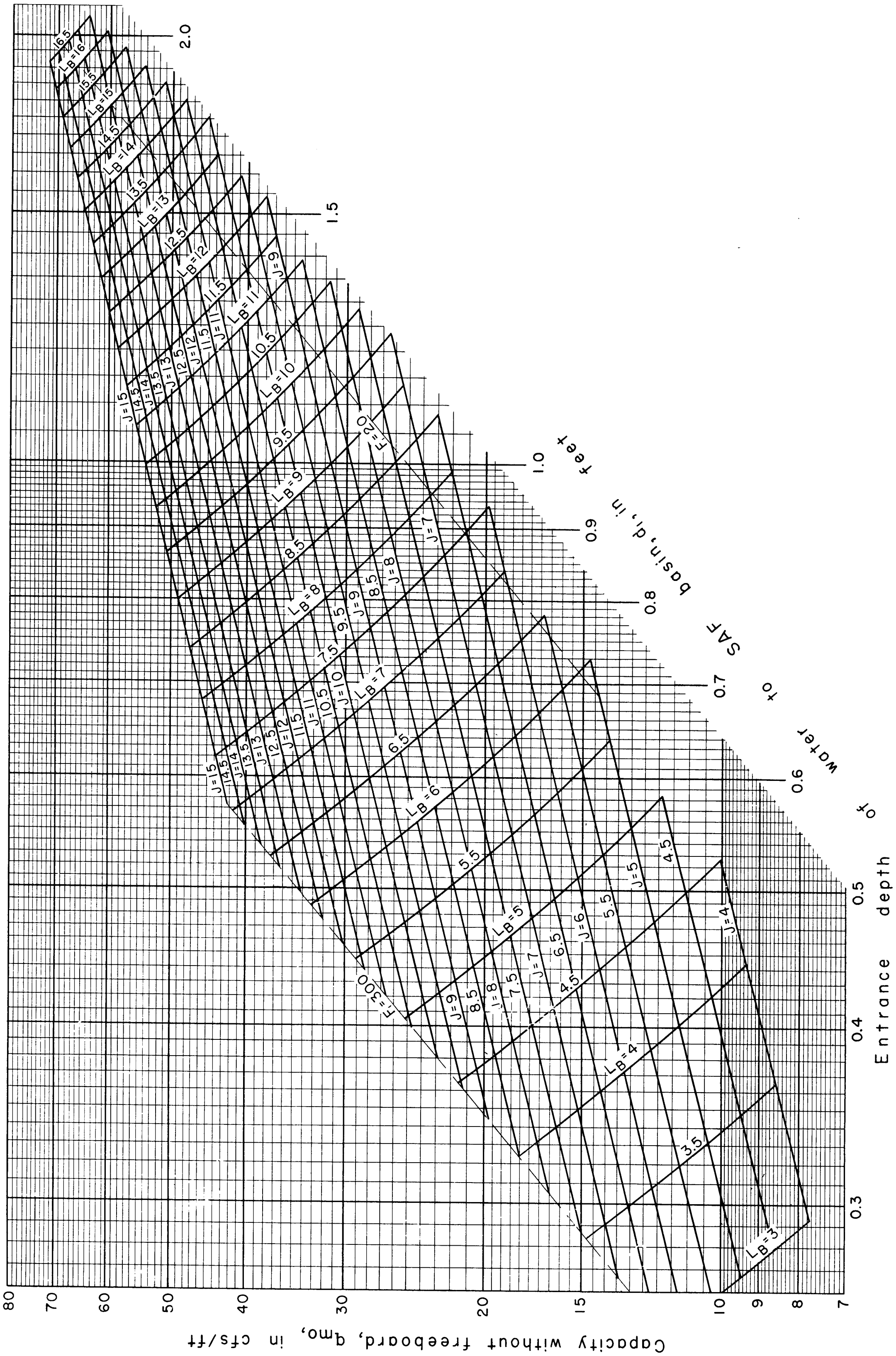
Revised 10/77

CHUTE SPILLWAYS: SAF OUTLETS

Capacities without freeboard for various dimensions

J in feet

L_B in feet



REFERENCE
Blaisdell, F. W. "Development And Hydraulic Design, Saint Anthony Falls Stilling Basin." (SAF Stilling Basin) Trans. A S C E 113P, 483-561, 1948
This diagram was developed by Paul D. Doubt, Engineering Design Section.

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ES-86
SHEET 6 OF
DATE 3-2-54

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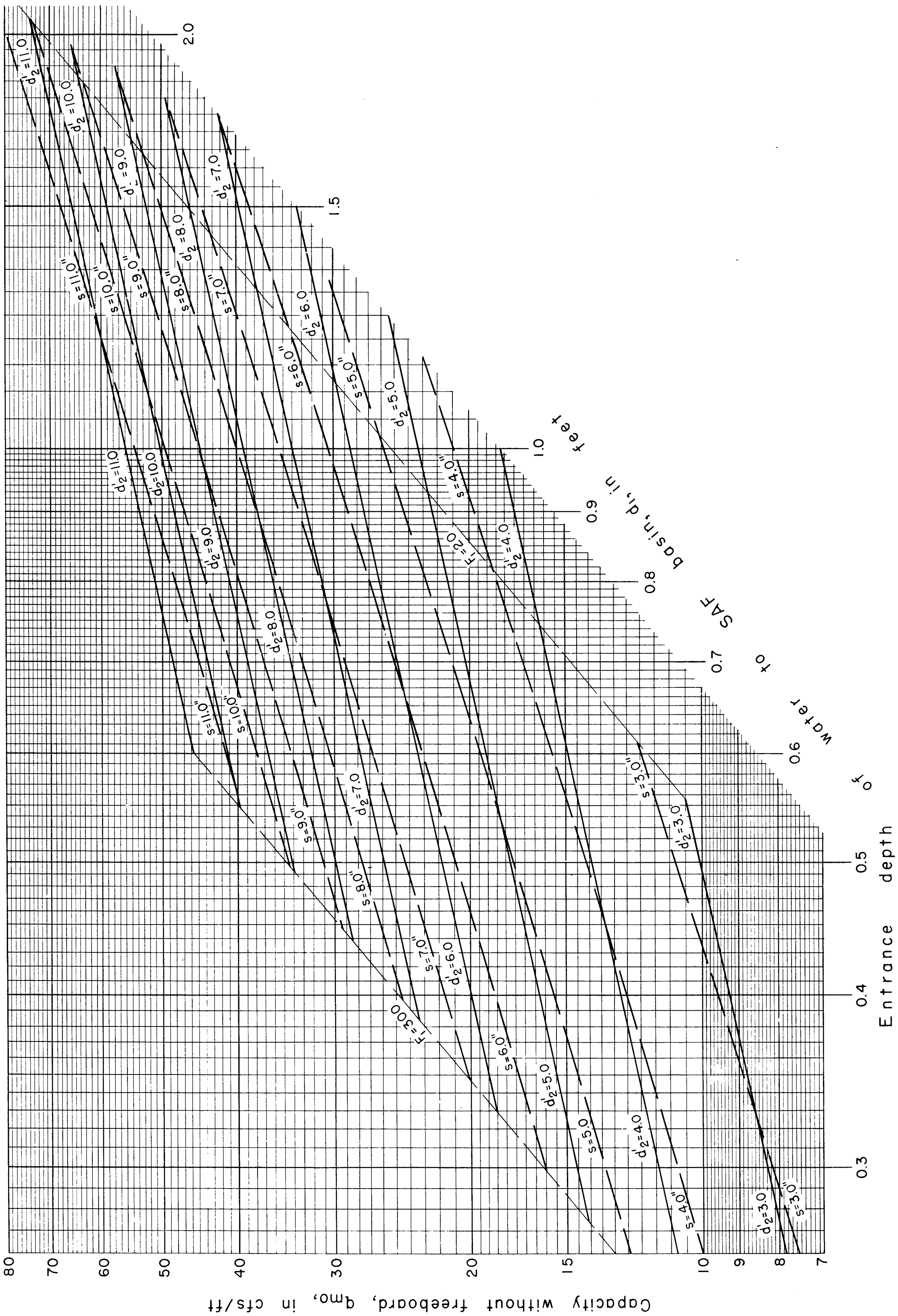
CHUTE SPILLWAYS: SAF OUTLETS

Tailwater requirment and end sill height.

d_2' in feet
s in inches



REFERENCE
Blaisdell, F. W. "Development And Hydraulic Design, Saint Anthony Falls Stilling Basin." (SAF Stilling Basin)
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SHEET 7 OF 8
DATE 2-25-54

CHUTE SPILLWAYS: SAF OUTLETS; Example

EXAMPLE

Given: A chute having a straight inlet, a bottom slope of 3 to 1 and a vertical drop of Z = 50 ft from the crest of inlet to the floor of the outlet. The design discharge is 200 cfs W = 8 ft $\mathfrak{Z}$ = 8 ft

Determine:
1. Required capacity without freeboard.
2. The height of the channel sidewalls, N, and entrance depth, d_1, of flow to SAF outlet without air entrainment.
3. Dimensions of SAF outlet.
4. Required depth of tailwater.

Solution:
1. The required capacity without freeboard, Q_{fr}, is

$$Q_{fr} = (1.20 + 0.003\ Z)\ Q_r$$

$$Q_{fr} = [1.20 + (0.003)(50)]\ 200 = 270 \text{ cfs}$$

$$q_{fr} = \frac{Q_{fr}}{W} = \frac{270}{8} = 33.75 \text{ cfs/ft}$$

2. The required height of channel sidewalls, N, is read from table 3b of ES-88 as

$$N = 2.00 \text{ ft}$$

The entrance depth of flow without air entrainment, d_1, is obtained from ES-78. Interpolation for this depth between W = 6 and W = 10 from sheets 9 and 11 obtain

$$d_1 = 0.659 \text{ ft}$$

3. The dimensions of the SAF may be read from ES-73 or ES-86.

a. The dimensions of the SAF as given on sheet 6 of ES-86 when $q = 33.75$ cfs/ft and $d_1 = 0.659$ ft is

$$J = 11.5 \text{ ft};\ L_B = 7.5 \text{ ft}$$

The height of the end sill as given on sheet 7 of ES-86 when $q = 33.75$ cfs/ft and $d_1 = 0.659$ ft is

$$s = 8 \text{ inches}$$

Since the value of d_1 is known, the size and spacing of floor and chute blocks can be determined from sheet 1 of ES-73.

b. The dimensions of the SAF outlet may also be determined by ES-73. The entrance velocity to the SAF outlet is determined by the formula

$$v_1 = \frac{q}{d_1} = \frac{33.75}{0.659} = 51.2 \text{ ft/sec}$$

From sheet 2 of ES-73 when $v_1 = 51.2$ ft/sec and $d_1 = 0.659$ ft read the dimensions

$$J = 11.5 \text{ ft};\ L_B = 7.5 \text{ ft}$$

The height of the end sill is read from sheet 3 of ES-73 as s = 8 inches

4. The SAF outlet will not cause dissipation of the kinetic energy unless it has sufficient tailwater height. Serious erosion will occur in the erodible channel downstream from the SAF outlet whenever sufficient tailwater depth is not present. The required tailwater depth d_2' may be read from sheet 7 of ES-86 or sheet 3 of ES-73.

$$d_2' = 8.1 \text{ ft}$$

3. DIMENSIONS OF CHUTE SPILLWAYS

Introduction

One of the original intents in the organization of the material for the Chute Spillway Section was to furnish information and data concerning chutes in a form which would make them readily usable for the design of systems of flood prevention, gradient control, water storage, and sediment collecting structures. This requires that material, quantities, and capacities of this structural type be given for a preselected range of sizes in order that a minimum cost may be determined with ease and at a nominal cost. Within limits of administrative decisions, this has been accomplished. The chute section is incomplete in this original intent, as well as others, because it was felt that much of the information now assembled should be disseminated to the field as quickly as possible. Without data of this kind for each type of structure available for use, the time and cost required to make the determination of minimum cost for a system of structures would be high.

The method of determining the dimensions of a chute spillway is dependent on one of two broad situations. The first and simpler situation is that in which the chute spillway is not a part of a system of proposed structures. This situation will be discussed in detail and illustrated by examples. The second situation arises when the chute spillway is a part of a system of structures in which the most economical system is being determined. Examples for this situation are to be given in the Engineering Handbook, Section 10, Gradient and Flood Control Systems. An understanding of the first situation is essential to the determination of the dimensions for the most economical system of structures.

Nine factors (listed next page) are used to determine the dimensions of the chute spillways. Most of these factors have values as defined by the relationship of certain parameters.[1] Many of the parameters used in evaluating

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[1]To understand the definition of a parameter, the definition of a function must be understood.

DEFINITION OF A FUNCTION: A function is a quantity whose value depends upon the value of other quantities. The "other quantities" are frequently known as "arguments" and "independent variables of the function."

Example: $$y = \frac{x^2}{4}$$

Here y is a function of x. When the value of x is fixed, the value of y is known. x is known as the independent variable of the function y.

DEFINITION OF A PARAMETER: When the function and its arguments are functions of a third quantity, the third quantity is known as a parameter.

Example: $$y = \frac{x^2}{4} \qquad (1)$$

$$y = \alpha^2 \qquad x = 2\,\alpha \qquad (2)$$

Here y is a function of its argument x, and the function y is a function of α. The argument or the independent variable x of the function y is also a function of α. The quantity α is known as a parameter and equations 2 are known as parametric equations of the dependent variable y and of the independent variable x.

a factor are also used in evaluating other factors. For instance, in hydraulic design the height h of the sidewalls above the crest of the inlet is a parameter used in a relationship involving the capacity of the inlet without freeboard. It is also a parameter used in structural design to determine the thickness of the sidewalls. All of the factors, in the most general situation, are interrelated.

The factors are

1. Purpose of chute
2. Spillway storage
3. Design discharge Q_r
4. Vertical drop Z
5. Site location
6. Hydraulic design relationship
7. Structural design relationship
8. Economic relationship
9. Systems of Structures

These nine factors are exhibited separately from other parameters because of the relationships that exist between them. The four factors, spillway storage, design discharge Q_r, vertical drop Z, and site location, are often interrelated. For example, the design discharge Q_r is decreased by increasing the value of Z if the spillway storage is increased significantly.

The hydraulic design relationship and the structural design relationship are written in terms of the factors Q_r and Z and all the other dimensions of the chute. When the factor spillway storage of the chute spillway is significant, it is related to the dimension h of the chute spillway. Thus, in the general case all the factors are interrelated. A more nearly complete discussion of these relationships for the first situation will be given after describing a few of the parameters related to each factor.

I. FIRST SITUATION--Introduction

To prevent a misunderstanding, a fuller explanation is made of the first situation. Chute spillways are often associated with an embankment and other appurtenances to form an integral structure. When a number of integral structures are located within a drainage area and are designed to be interdependent, the totality of such interdependent integral structures is known as a system of structures. Under the first situation will be discussed the methods of determining the dimensions of the chute spillway when the chute is not a part of a system of structures in which the most economical system is being determined. The first situation includes those situations in which the chute spillway is to become a part of an existing system of structures. Since the first situation is not of a system of structures, the ninth factor is eliminated. A general discussion of the first eight listed factors and their interrelationship in the first situation follows.

1. Purposes of chute. The purposes for which chute spillways are usually used by the Soil Conservation Service are

a. Spillways for gradient control structures or as a gradient control structure.

b. Spillways for flood prevention reservoirs (retarding reservoirs). The degree of flood prevention is often used as a parameter.

c. Spillways for water conservation reservoirs (irrigation, livestock, recreational, and wildlife).

d. Spillways for sediment collecting reservoirs.

Reservoirs are often constructed for more than one purpose.

2. Spillway storage. The spillway storage and the purpose of the chute spillway are usually related in the following manner.

a. Chute spillways when used as gradient control structures generally have insignificant spillway storage. The spillway storage is insignificant if the ratio of spillway storage to the total volume of runoff is sufficiently small to cause no significant difference between the peak inflow to the reservoir and peak outflow from the reservoir when the inflow hydrograph is routed through the reservoir.

b. Flood prevention reservoirs are dependent on the availability of significant retarding spillway storage. Spillway storage is always significant when a chute is associated with a retarding reservoir.

c. Water conservation structures and sediment collecting reservoirs having chute spillways usually have significant spillway storage.

When reservoirs are constructed for more than one purpose, the associated chute spillways will usually have significant spillway storage.

3. The design discharge Q_r. (See Engineering Handbook, Section 4, Hydrology.) When the spillway storage is insignificant, the design discharge Q_r is the peak rate of inflow as determined by hydrological principles and the three parameters listed at the top of page 1.3.

If the chute spillway is associated with a significant spillway storage, the discharge Q_r is dependent on the design inflow hydrograph, the spillway storage, and the rate of outflow, i.e., the dimensions h and W of the chute spillway. The dimensions h and W are dimensions which are to be determined. (See Engineering Handbook, Section 5, Hydraulics, Reservoir Routing.)

4. The vertical drop Z from the crest of the inlet to the floor of the outlet. (See Engineering Handbook, Section 3, Sedimentation.) This factor is a dimension of the spillway and its value is dependent, along with other parameters, on the purpose of the chute.

a. When the chute is a gradient control structure, the vertical drop Z is dependent on the vertical gradient control required, including the aggradation or degradation downstream from the chute spillway. Tailwater requirements are a parameter in determining the bottom elevation of the SAF outlet.

b. The factor Z of the inlet is dependent on the parameters which express the degree of flood prevention, the design discharge Q_r, spillway storage, site location, and the dimensions h and W of the inlet of the chute spillways associated with retarding reservoirs.

c. When the chute spillway is associated with water conservation systems, the value of Z will be dependent on water yields and needs.

d. Sediment yield and trap efficiency, along with types of sediment, become important parameters in evaluating Z for chute spillways associated with sediment collecting pools.

5. Site location. (See Engineering Handbook, Section 7, Soil Mechanics, and Section 8, Engineering Geology.) The values of parameters used in the determination of site locations are obtained from an evaluation of the pertinent site data of surface and foundation investigations. The topography of the reservoir area is included in this factor. The location of the site with respect to the rest of the drainage area however is not one of the parameters. Such parameters are included in the factors Q_r, Purpose and Economics. The geographic location of the site is not a parameter in site location; it is a parameter in the design discharge Q_r.

6. Hydraulic design. (See part 2, Hydraulic Design, Chute Spillway Section.) The general relationship of parameters used in the determination of a proper hydraulic proportioning of a chute are given in part 2.

7. Structural design. (See Engineering Handbook, Section 6, Structural Design.) The general relationship of parameters used in the determination of required structural dimensions are given in Section 6. At this time administrative decision has resulted in the abandonment of writing these relationships as they pertain to chutes in the Chute Spillway Section.

8. Economics. The dimensions of the chute spillway are to be taken as those dimensions which will give the minimum combined estimated costs of the spillway and its associated appurtenances consistent with the first seven listed factors. This requires that quantities of materials and unit costs of the materials be known or closely estimated. Combined costs of the structure throughout this section is used to mean the total estimated cost of the integral structure including the estimated cost of all spillways, embankment, excavation, toe drainage, land clearing, right-of-ways, and other estimated costs associated with the structure.

RELATIONSHIP OF hydraulic design, structural design, and economics. Observe that the last three factors are relationships of parameters which are to be satisfied. Examining the relationships involved in the hydraulic design when only Q_r, Z, and s_o are given, the dimensions of the chute spillway cannot be uniquely determined. For purposes of illustration, assume the values of Q_r, Z, and s_o are fixed and are not interrelated. The interdependence of the three factors, hydraulic design, structural design, and economics, is to be examined.

Assume the chute has a straight inlet. Part 2 does not give the dimensions of the chute for a given capacity; it gives the capacity for a given set of dimensions. Any number of sets of dimensions can be found with the same capacity. Arbitrarily choosing a width W for the chute with a straight inlet, all other dimensions of the chute are determined by hydraulic and structural design. For every width, there is a set of dimensions associated with each width. Since any number of widths could arbitrarily be chosen for the chute, there exists any number of sets of dimensions of the chute which satisfy the hydraulic and structural design criteria. For example; if the width W is arbitrarily chosen, the dimensions h, M, N, L_B, J, etc., are determined since the design discharge Q_r, vertical drop Z, and s_o are known. The dimensions W, h, M, N, L_B, J, etc., are a set of dimensions in which each has a value dependent on the value of W. The hydraulic relationship for chutes with a straight inlet has one degree of freedom because by choosing one dimension (the width W) all other dimensions of the chute are fixed.

For a particular set of site conditions, each arbitrary choice of W has an associated volume of concrete in the chute spillway; but there is one particular width which has the least volume of concrete.

Assume the chute has a box inlet instead of a straight inlet. If the inlet of the chute is changed to a box inlet, two degrees of freedom are present in the hydraulic criteria of Part 2. If only Q_r, Z, and s_o are given, the hydraulic relationship does not uniquely determine the dimensions of the chute if W is arbitrarily chosen. By arbitrarily choosing both W and h for the chute with a box inlet, all other dimensions of the chute are determined by hydraulic and structural design relationships. When a set of dimensions is selected which satisfy the hydraulic relationship, all other dimensions can be uniquely determined by the relationships involved in structural design.

Economics dictates which set of dimensions, satisfying the hydraulic and structural design relationships, is to be taken for the dimensions of the chute. It is that set of dimensions which results in the lowest combined cost of the chute spillway and its associated appurtenances.

RELATIONSHIP OF spillway storage, design discharge Q_r, vertical drop Z, and site location. The hydraulic and structural design relationships have as parameters the factors Q_r and Z. Before the dimensions of a chute spillway at a given site location and for a stated purpose can be determined, the relationship between Q_r and Z is required. In some situations the values of Q_r and Z are known before the dimensions of the chute are known; while in other situations the values of these factors are determined simultaneously with the dimensions of the chute. The relationship of Q_r and Z are dependent on the site location since the spillway storage along with certain dimensions of the inlet and the design hydrograph are parameters used to express this relationship.

When the spillway storage is insignificant, the factors Q_r and Z are independent. The manner of determining the values of these factors has been given. In this situation the factors Q_r and Z are known prior to the dimensions of the chute spillway.

When the spillway storage is significant, the four factors, spillway storage, Q_r, Z, and site location, are interrelated. Reservoir routing is required to determine the relationship of Q_r and Z. The data required to determine this relationship by reservoir routing are

(1) volume of storage vs elevation curve which is dependent on the site location

(2) the design inflow hydrograph

(3) the rate of outflow which is dependent on the type and dimensions of spillways. When the chute spillway is the only type of spillway associated with the integral structure, the type and dimensions of the inlet will determine the rate of outflow.

Since the type and the dimensions of the inlet are parameters to be determined, the factors Q_r, Z, hydraulic and structural design, and economics will need to be solved simultaneously to obtain the dimensions of the chute and the values of Q_r and Z.

Straight Inlets. When the only spillway for the integral structure is a chute spillway with a straight inlet, the relationship of Q_r and Z can be ascertained as an independent determination. The relationship can be expressed in terms of the parameter W or in terms of the parameter h. It is desirable to have this relationship in both forms. The relationship of Q_r, Z, and W is obtained by determining the value of Q_r by reservoir routing for various selected values of Z and W. The relationship of Q_r, W, and h is given by the weir formula $Q_{fr} = 3.1\ W\ h^{3/2}$. The relationships of Q_{fr}, Z, W, and h can be represented graphically. The graphical representation has a family of W-lines and a family of h-lines when the values of Z are plotted as ordinates and the values of Q_{fr} as abscissas.

Straight inlet associated with a drop inlet. When the integral structure has other spillways besides the chute spillway with a straight inlet, a graphical relationship of Q_{fr}, Z, W, and h can be determined by recognizing the elevations of the crest and the sizes of the other spillways. This plot is determined in a manner similar to that given in the preceding paragraph.

Box Inlets. When the only spillway of the integral structure is a chute spillway with a box inlet, a graphical relationship of Q_{fr}, Z, h, and (2 B + W) can be determined in a manner similar to that used for a straight inlet. The relationship can be expressed in terms of these parameters for any of the four classifications of box inlets listed on page 2.19 if entrance conditions to the inlet are known. Usually the approach channel to box inlets having significant spillway storage is wide.

OUTLINE OF THE METHODS FOR DETERMINING THE DIMENSIONS OF A CHUTE--Introduction

Because Q_r and Z are independent factors when the spillway storage is insignificant and are interrelated when the spillway storage is significant, the first situation will be divided according to whether the spillway storage is significant or insignificant. For each of these divisions, a discussion will be made of chutes having any known general slope s_o. The situation in which the bottom slope s_o is one of the parameters to be determined is considered in the outline. The discussion pertaining to the bottom slope of the channel is subdivided according to whether the associated appurtenance costs of the chute are significantly or insignificantly dependent on the parameters W and h for a given value of the factor Z. Usually the appurtenance costs will not be significantly dependent on the parameters W and h for a given value of Z if the associated embankment and excavation of the chute are insignificant. Only inlets having no functions other than those listed on page 2.1 and requiring no freeboard are considered in the outline. This limits the types of inlets for consideration in the outline to the straight inlet and the box inlet. Additional comments of other types of inlets having other functions or inlets requiring wave freeboard are made after the outline.

Concrete volumes of chutes with straight inlets and box inlets. A chute with a straight inlet of proper dimensions for a given set of values of Z, Q_r, and s_o will always contain less volume of concrete than a chute with a box inlet for the same given set of values of Z, Q_r, and s_o. Chutes with box inlets are only used to serve other functions or to decrease the cost of appurtenances. The decreased cost of appurtenances is accomplished by an increased cost of the chute.

OUTLINE

I. The associated spillway storage is insignificant. Structures involving chute spillways which have insignificant spillway storage are usually gradient control structures, and it is unlikely that any wave freeboard is required. The design discharge Q_r is not dependent upon any of the other seven factors listed except the amount of damage to the chute spillway by a higher runoff discharge. (See related item b, top of page 1.3.) The factor Z and site location in this situation are independent of the factor Q_r. Some site locations of this situation need to be examined for the possibilities of decreasing combined costs by increasing the value of Z to attain significant spillway storage and reduce the design discharge Q_r.

A. Bottom slope of the spillway is known. The bottom slopes of chutes are usually known only when they are located on a moisture-controlled compacted embankment. The bottom slope of such spillways will usually have the same slope as the embankment. The volume of concrete in a chute spillway decreases as the bottom slope of the chute spillway increases. The maximum bottom slope of a chute is limited by the stability of its foundation, anticipated water-table levels, type of materials in its foundation and the construction difficulties to be encountered on steep slopes.

1. Chute spillways having associated appurtenance costs which are not significantly dependent on the dimensions of the chute will always have straight inlets unless the inlet has additional functions besides those listed on page 2.1 or a large wave freeboard is required. (As already stipulated in the superheading of this outline the values of Z, Q_r, and s_o are fixed here.) When the cost of the embankment and excavation is insignificant, a change in the dimensions of the chute will not materially change the cost of embankment and excavation. If the combined costs less the cost of the concrete in the chute spillway do not change appreciably with the dimensions of the chute, then that set of dimensions which gives the minimum volume of concrete in the chute is the desired set.

In this situation one degree of freedom occurs; i.e., one dimension (the width W) is determined to find all other dimensions of the chute spillway.

2. Chute spillways having associated appurtenance costs which are dependent on the dimensions of the chute. In this situation it will usually be necessary to compare the combined cost of the chute with a straight inlet and box inlet.

Straight Inlets. When the associated embankment of a chute is significant, a saving in embankment cost may be made by increasing the width of the chute having a straight inlet. The value of the dimension h of the straight inlet decreases as the width of the chute increases. Decreasing the value of h is accompanied by an equal lowering of the top elevation of the embankment. Similarly when the excavation associated with the chute is significant, a saving in excavation cost may be obtained by changing the width of the chute.

This situation has one degree of freedom; i.e., one dimension (the width W) is determined to find all other dimensions of the chute spillway. A graphical representation of the relationship of the cost of concrete and the width W is obtained by plotting the cost of concrete in the chute spillway as ordinates and the width W as the abscissas. In a similar manner, on plotting the cost of embankment as ordinates and the widths W as abscissas, the relationship of the cost of embankment and the width W of the chute is obtained. After making similar additional plots of excavation, toe drainage, and other costs associated with the structure, it will be possible to sum the ordinates of each plot for a particular width W to obtain the combined cost of the structure having a chute of width W. A graphical representation of the relationship of combined cost and width of the chute spillway is obtained by repeating this summation for various values of W. This is a plot of combined cost plotted as ordinates and widths as abscissas. The value of the width W which gives the minimum combined cost may be read from this graph and all other dimensions of the chute can be readily found.

Since this situation has one degree of freedom the relationship of combined cost vs width W is given by a single curve. The minimum combined cost of the chute with a straight inlet should be compared to the minimum combined cost of the chute with a box inlet.

Box Inlets. For a given width W the head over the crest of a box inlet may be reduced by increasing the dimension B. Since the value of h for a given width W may be further reduced by using box inlets instead of the straight inlet, the minimum combined cost of a chute with a box inlet needs to be compared with the minimum combined cost of a chute with a straight inlet. Two degrees of freedom exist in this situation. A graphical representation of the cost of a chute with a box inlet and its width W can be made. This graphical relationship has a family of h-lines in a plot of cost of the chute for various widths as ordinates and the corresponding widths W as abscissas. After plotting the lower envelope of the h-lines on this graphical representation, other graphs consisting of cost of embankment, excavation, and other costs vs width of chute can be prepared. Summing the ordinates of these graphs, the minimum combined cost of the integral structure for various widths W may be found.

B. Bottom slope of the spillway is unknown. In this situation the bottom slope of the chute is one of the parameters to be determined. Chute spillways having unknown bottom slopes usually are placed in excavations. The slope which results in a minimum combined cost is to be determined. Of course it is understood such slopes are not to exceed a maximum limit as previously stated.

When the associated excavation is not significantly dependent on the dimensions of the chute, then the bottom slope of the chute is known.

1. Chute spillways having associated appurtenance costs which are dependent on the dimension of the chute. The excavation cost is significant for this situation.

Straight inlets will always be used for this situation if the combined cost less the concrete and excavation costs is not significantly dependent on the value of h. Two degrees of freedom exist in this situation. Two dimensions, namely the width W and the bottom slope s_o, are required to find all other dimensions of the chute spillway. A graphical representation of the relationship of the cost of concrete and width W for a given bottom slope s_o is obtained by plotting the cost of concrete in the chute as ordinates and the width W as abscissas. By plotting these values for various values of s_o, a graphical relationship is obtained consisting of s_o-curves with coordinates of cost of concrete in the chute vs width W. Similar graphs of embankment, excavation, and other costs as ordinates and widths as abscissas can be plotted for various values of s_o. The summation of the ordinates of these graphs for a particular set of W and s_o values will give the combined cost corresponding to that particular set of values of W and s_o. The value of W and s_o which gives the minimum combined cost may be read from this graph and all other dimensions of the chute can be readily found. This result should be compared with the minimum combined cost of chute spillways with a box inlet if the embankment cost is significant to determine the type of inlet. Since this situation has two degrees of freedom the relationship of combined cost vs width W is given by a family of s_o-curves.

Box inlets will usually be used when the associated embankment cost is significant. Three degrees of freedom exist in this situation. The determination of the three dimensions W, h, and s_o are required to find all other dimensions of the chute spillway. A graphical representation of the relationship of the combined cost of chutes as given in the outline heading IA2 (Box Inlets) can be found for various selected bottom slopes. The minimum combined cost for each selected slope can be plotted as ordinates and bottom slopes as abscissas. This type of analysis will give the minimum combined cost and the values of the three parameters, namely W, h, and s_o. Knowing these values permits the evaluation of all other parameters. This determination of minimum combined cost should be compared with the minimum combined cost of chutes with straight inlets. Since this situation has three degrees of freedom the relationship is determined by the two graphs.

a. Combined cost vs width W and a family of h-curves.

b. Minimum combined cost of chutes with box inlets of selected bottom slopes s_o as determined by the first graph vs bottom slope s_o.

II. The associated spillway storage is significant. The design discharge Q_r is dependent on the value of Z at any site location as well as certain dimensions of the inlet when the associated spillway storage is significant. The relationship of Q_r and Z and the method of obtaining this relationship have been discussed on pages 3.5 and 3.6. In some site locations the minimum combined cost of integral structures will decrease as the value of Z is increased from a low value to a higher value until a value of $Z = Z_l$ is reached. As Z is further increased above the value of Z_l, the minimum combined cost will increase. When the required value of Z, in accordance with the purpose of the chute and other factors is less than Z_l, the combined cost of the integral structure can be decreased by increasing the value of Z to Z_l. This situation requires that the value of Z_l be determined. When the required value of Z in accordance to the purpose of the chute and other factors is greater than Z_l, the combined cost of the integral structure is greater than that for a structure having a $Z = Z_l$. This situation requires that the minimum combined cost for the structure be determined when Z has the required value. The remainder of this outline pertains to the determination of the minimum combined cost of the integral structure for a given value of Z. A graphical solution may be made to obtain the value of Z_l. The graphical solution consists of the plot of minimum combined costs for selected values of Q_{fr} as ordinates and the corresponding value of Z as abscissas.

A. Bottom slope of the spillway is known.

1. Chute spillways having associated appurtenance costs which are not dependent on the dimensions of the chute will rarely be encountered. The value of Q_r will for a fixed Z increase as the value of W is increased because the spillway storage is reduced. Since the chute spillway will have a straight inlet in this situation, the chute is being sought which has the least volume of concrete. The value of W associated with the set of dimensions of this chute can be found by a graphical solution. The graphical solution consists of a plot of chute costs for various widths plotted as ordinates and the corresponding width plotted as abscissas. The capacity of the chutes for the various widths would need to reflect the design discharge Q_r corresponding to those widths.

This situation has one degree of freedom; i.e., one dimension (the width W) is determined to find all other dimensions of the chute spillway.

2. Chute spillways having associated appurtenance costs which are dependent on the dimensions of the chute.

Straight inlets. This situation has one degree of freedom. The width W is determined to find all the other dimensions of the chute. Associated with each width is a design discharge Q_r and as the width W is increased, the associated value of Q_r is increased. A graphical representation of the cost of the relationship of the cost of concrete and the width W is obtained by plotting the cost of concrete in the chute spillways as ordinates and the width W as abscissas. In a similar manner, on plotting the cost of the embankment as ordinates and the width W as abscissas, the relationship of the cost of embankment and the width W of the chute is obtained. After making similar additional plots of excavation, toe drainage, and other costs associated with the structure, it will be possible to sum the ordinates of each plot for a particular width to obtain a plot of combined cost of the integral structure vs width of the chute. The value of the width W which gives the minimum combined cost can be read from this graph. The minimum combined cost of the chute with a straight inlet should be compared to the minimum combined cost of the chute with a box inlet.

Box Inlets. For a given width W the head over the crest of a box inlet may be reduced by increasing the dimension B, but the spillway storage is reduced and the required values of Q_r and (2 B + W) according to the relationship of Q_r, Z, h, and (2 B + W) are both increased. Two degrees of freedom exist for this situation. A graphical representation of the relationship of the cost of a chute with a box inlet and the chute width can be made. This graphical relationship has a family of h-lines in a plot of cost of the chute for various widths as ordinates and the corresponding width W. The plot of h-lines will necessarily need to reflect the design discharge Q_r corresponding to the values determined by routing (see page 3.6, Box Inlets). After plotting the envelope of the h-lines on this graphical representation, the combined cost of the integral structure for various widths can be determined in a similar manner as previously illustrated.

B. Bottom slope is unknown. It is impossible to have the bottom slope unknown and the associated appurtenance costs independent of the dimension of the chute. The excavation cost for a chute is considered as a part of the associated appurtenance costs.

1. Chute spillways having associated appurtenance costs which are dependent on the dimensions of the chute.

Straight inlets used in this situation have two degrees of freedom. The two dimensions W and s_o are required to find all other dimensions of the chute spillway. A graphical representation of the relationship of the cost of concrete and width W for a given bottom slope s_o is obtained by plotting the cost of concrete in the chute as ordinates and the width W as abscissas. The change in the value of Q_r for various widths W as obtained by routing the design hydrograph should be reflected in the preparation of this graph. The set of dimensions for the chute with a fixed Z is obtained in a manner similar to that given by the situation under the outline heading IB1, Straight Inlets, page 3.9.

Box Inlets. Three degrees of freedom exist in this situation. The method of determining the set of dimensions is similar to that given in IB1, Box Inlets, page 3.9.

TYPES OF INLETS FOR OTHER FUNCTIONS OR WHEN THE WAVE FREEBOARD IS SUFFICIENTLY LARGE

Type of inlet when the wave freeboard is large. When the wave freeboard is large, the cost of other types of inlets should be investigated. Frequently culvert and box-culvert inlets can be used advantageously instead of a straight or box inlet. The use of culverts and box-culvert inlets permits the use of earth embankment and riprap over their top slab to withhold waves from overtopping the chute.

Type of inlet when other functions are required. Vehicle crossings of spillway will generally require that culvert or box-culvert inlets be used.

When the maximum elevation of the reservoir is limited and the value of Z is sufficiently large to prevent the use of the set of dimensions which corresponds to the minimum combined cost of the integral structure, other types of inlets may be required. In some situations the width of the straight inlet which would normally be used if the limitation were not present will be wider. In other situations the straight inlet would be changed to a box inlet. The decision of whether a straight inlet or a box inlet is to be used is made by comparative costs. The analysis of such situations would be simpler than that given in the outline because one degree of freedom is removed by such a limitation.