

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

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

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 .

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

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

$$\begin{aligned} x_1 &= 18 s_v \\ y_1 &= 9 s_v^2 \end{aligned} \quad 5.3$$

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 $s_o = 1/3$.

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

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

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 $s_o = 1/3$.

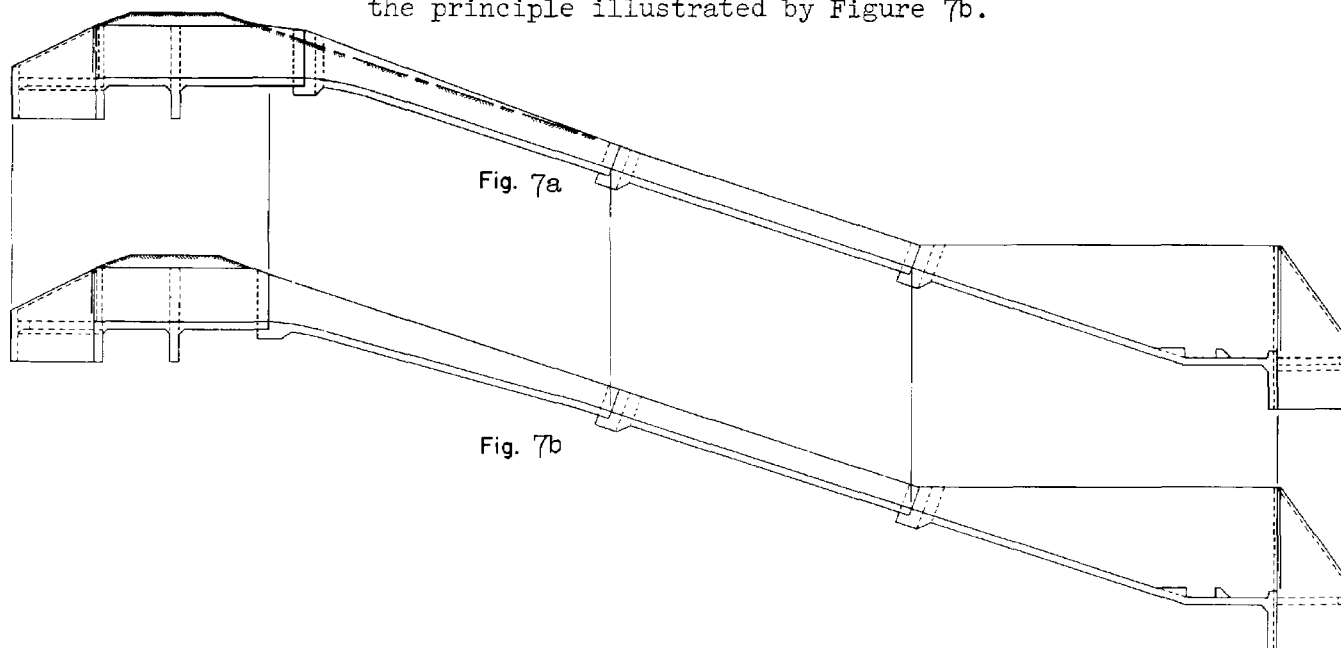
Values of x_2 and y_2 (see ES-88, page 2.125, for definition) are given by the equations

$$\begin{aligned} x_2 &= \frac{1}{s_o} \left[M + \mathcal{J} - N \sec (\tan^{-1} s_o) \right] - 50 s_o + 32 s_v \\ y_2 &= \mathcal{J} + 16 s_v^2 - 25 s_o^2 \end{aligned}$$

Values of x_2 and y_2 for channel bottoms having $\mathcal{J}$ 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_0 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.

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

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

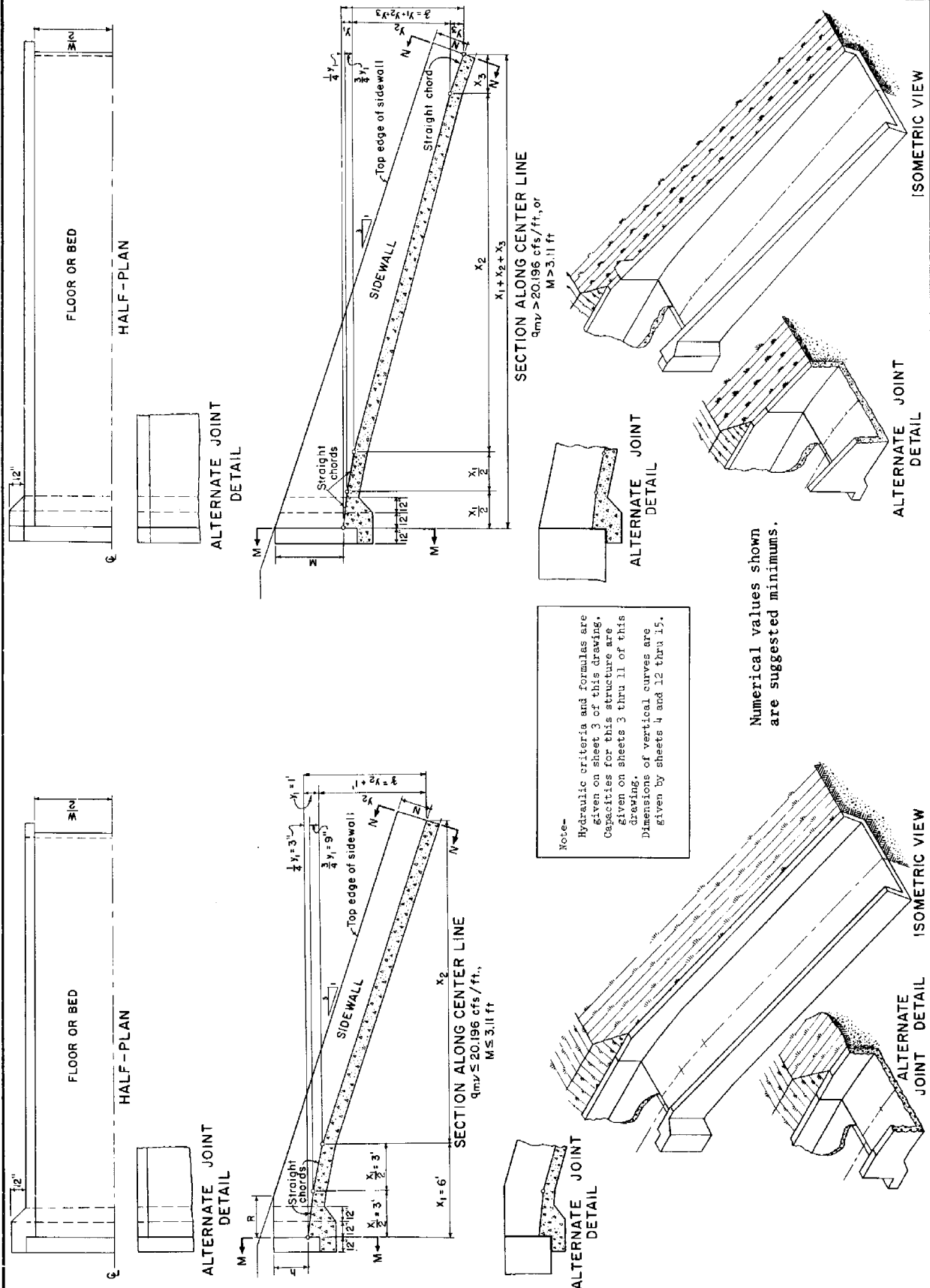
for vertical curve sections having various values of M , N , and z may be determined from Tables 3a and 3b, pages 2.125 and 2.126. The capacity without freeboard Q_{mv} for various widths W and drops z is given by ES-88, pages 2.127, 2.128, 2.129, 2.130, 2.131, 2.132, and 2.133.

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 WITH STRAIGHT CHORDS;

The general layout drawing

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



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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS; $s_0 = \frac{1}{3}$

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 β and N
Table gives Q_{mN}

N	Values of β					
	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 Sections¹

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

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

FORMULAS

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

$$Q_{mM} = \frac{27}{64} W^3$$

Q_{mN} = discharge having a depth of $\frac{3}{4}N$; when $W = 4$ and $y = \frac{3}{4}$ as shown by water surface profile without air entrainment for β 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_0 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
 β = vertical drop of vertical curve section in ft
 s_v = slope of floor of vertical curve section in ft/ft
 s_0 = slope of floor of channel in ft/ft
 $\theta = \tan^{-1} s_0$
 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 s_0 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

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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 Sections¹

M	N	X ₁	Y ₁	X ₂	Y ₂	X ₃	Y ₃	S _V	Q _{mv}
$\bar{g} = 8 \text{ ft.}$									
5.11	2.00	6.0000	1.0000	21.000	7.0000	0	0	0.3333	20.19
5.25	2.00	5.6802	0.9606	21.213	6.9299	0.3320	0.1095	0.3267	21.58
5.50	2.00	5.6777	0.8955	21.603	6.8145	0.8950	0.2900	0.3154	24.12
5.75	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	22.458	6.6113	1.9340	0.6075	0.2947	29.47
4.25	2.00	5.1511	0.7313	22.881	6.5224	2.4135	0.7465	0.2851	32.27
4.50	2.00	4.9675	0.6834	23.339	6.4407	2.8655	0.8739	0.2760	35.16
4.75	2.00	4.8115	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
5.25	2.25	4.8197	0.6454	23.787	6.3694	3.2780	0.9852	0.2678	41.18
5.50	2.25	4.6717	0.6065	24.274	6.3000	3.6895	1.0937	0.2575	44.32
5.75	2.25	4.5310	0.5703	24.773	6.2360	4.0805	1.1937	0.2517	46.60
5.90	2.50	4.6796	0.6083	24.247	6.3036	3.6675	1.0881	0.2600	47.51
5.75	2.50	4.5305	0.5722	24.746	6.2394	4.0595	1.1834	0.2521	50.78
6.00	2.50	4.4044	0.5336	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	25.250	6.1832	4.4125	1.2762	0.2451	57.56
6.50	2.75	4.2833	0.5097	25.752	6.1283	4.7680	1.3620	0.2380	58.65
6.50	3.00	4.4103	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	1.3522	0.2387	68.22
$\bar{g} = 6 \text{ ft.}$									
5.11	2.00	6.0000	1.0000	15.000	5.0000	0	0	0.3333	20.19
5.25	2.00	5.3331	0.9431	15.129	4.9024	0.4659	0.1525	0.3241	21.58
5.50	2.00	5.5532	0.8566	15.381	4.7450	1.2412	0.3984	0.3085	24.12
5.75	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	0.8151	0.2803	29.47
4.25	2.00	4.8112	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	3.8907	1.1430	0.2557	35.16
4.75	2.00	4.4032	0.5395	17.087	4.1796	4.4357	1.2819	0.2446	38.13
4.75	2.25	4.6145	0.5915	16.672	4.2737	3.8487	1.1348	0.2564	38.13
5.00	2.25	4.4267	0.5409	17.085	4.1838	4.4092	1.2755	0.2452	41.18
5.25	2.25	4.2820	0.4961	17.481	4.1042	4.9277	1.3997	0.2348	42.50
5.50	2.25	4.4240	0.5436	17.043	4.1888	4.3777	1.2676	0.2458	44.51
5.50	2.50	4.2558	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	1.3889	0.2359	50.78
6.00	2.75	4.0639	0.4599	17.871	4.0393	5.3640	1.5003	0.2261	52.90
6.00	3.00	4.2556	0.5051	17.442	4.1163	4.8457	1.3804	0.2364	54.14
6.25	3.00	4.0785	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	58.65
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	64.59
7.00	3.25	4.0963	0.4665	17.799	4.0510	5.2865	1.4827	0.2276	64.59
7.00	3.50	3.9239	0.4291	18.232	3.9849	5.7500	1.5860	0.2183	68.22
$\bar{g} = 4 \text{ ft.}$									
5.11	2.00	6.0000	1.0000	9.000	3.0000	0	0	0.3333	20.19
5.25	2.00	5.1213	0.9094	8.931	2.8390	0.7727	0.2516	0.3179	21.58
5.50	2.00	5.2992	0.7683	8.850	2.6881	2.0577	0.6436	0.2992	24.12
5.75	2.00	4.8316	0.6484	8.848	2.5750	3.2457	0.9766	0.2684	26.74
4.00	2.00	4.4597	0.5476	8.902	2.4936	4.3342	1.2568	0.2467	29.47
4.25	2.00	4.0331	0.4631	9.018	2.0456	5.3245	1.4913	0.2268	32.00
4.25	2.25	4.4630	0.5526	8.897	2.2045	4.2777	1.2429	0.2478	32.27
4.50	2.25	4.1015	0.4673	9.010	2.0929	5.2735	1.4798	0.2279	35.16
4.75	2.25	3.7769	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	6.1293	1.6675	0.2107	41.18
5.25	2.50	3.4988	0.3400	9.398	1.8263	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	1.9770	0.1812	51.10
6.25	3.25	3.5446	0.3490	9.357	1.8427	6.8205	1.8083	0.1969	54.14
6.25	3.50	3.2751	0.2980	9.628	1.7519	7.5690	1.9501	0.1820	56.15
6.50	3.50	3.5599	0.3521	9.344	1.8460	6.7780	1.7999	0.1978	57.56
6.50	3.75	3.2890	0.3004	9.612	1.7563	7.5305	1.9433	0.1827	61.08
6.75	3.75	3.0584	0.2597	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	0.2597	9.912	1.6841	8.1710	2.0560	0.1699	66.65
7.00	4.00	3.3169	0.3056	9.581	1.7696	7.4530	1.9288	0.1843	68.22
$\bar{g} = 3 \text{ ft.}$									
5.11	2.00	6.0000	1.0000	6.000	2.0000	0	0	0.3333	20.19
5.25	2.00	5.5782	0.8644	5.676	1.7598	1.7598	1.1117	0.3168	20.19
5.50	2.00	4.8546	0.6947	5.139	1.3860	3.1517	0.9993	0.2697	21.58
5.75	2.00	4.1849	0.4817	4.665	1.0787	3.0985	1.4356	0.2314	24.12
4.00	2.00	3.5188	0.3439	4.264	0.8357	6.8920	1.8224	0.1955	26.74
4.25	2.25	4.2007	0.4902	4.686	1.0936	4.9932	1.4162	0.2334	29.47
4.25	2.25	3.5225	0.3506	4.284	0.8454	6.7885	1.8204	0.1974	32.27
4.50	2.25	3.9615	0.4337	3.983	0.6954	8.4400	2.1009	0.1645	35.16
4.50	2.50	3.5868	0.3572	4.303	0.8573	6.7053	1.7835	0.2092	35.16
4.75	2.50	3.9918	0.4496	4.996	0.6643	8.3560	2.0871	0.1662	37.75
4.75	2.75	3.6202	0.3641	4.373	0.8694	6.6105	1.7665	0.2011	38.13
5.00	2.75	3.0220	0.2937	5.012	0.6732	8.2720	2.0721	0.1679	41.18
5.25	2.75	2.0407	0.1157	7.015	0.4277	9.968	2.4564	0.1154	42.20
5.25	3.00	3.0532	0.2930	4.624	0.6826	8.1895	2.0584	0.1696	43.31
5.50	3.00	2.5205	0.1765	5.897	0.5360	9.6600	2.2875	0.1400	46.80
5.50	3.25	3.0838	0.2642	4.053	0.6913	8.1009	2.0404	0.1713	47.51
5.75	3.25	2.5472	0.1803	5.894	0.5426	9.3010	2.2771	0.1415	50.78
6.00	3.25	2.0902	0.1214	7.772	0.4379	10.861	2.4407	0.1161	51.50
6.00	3.50	2.5744	0.1841	5.842	0.5495	9.3595	2.2664	0.1430	54.14
6.25	3.50	2.1127	0.1240	8.771	0.4426	10.798	2.4334	0.1174	56.05
6.25	3.75	2.6017	0.1880	5.850	0.5565	9.4395	2.2555	0.1445	57.56
6.50	3.75	2.1355	0.1267	9.771	0.4474	10.735	2.4299	0.1186	61.08
6.75	4.00	2.1586	0.1294	9.772	0.4523	10.671	2.4183	0.1199	64.59
7.00	4.00	1.7712	0.0871	9.853	0.3712	11.747	2.5357	0.0984	66.45
7.00	4.25	2.1018	0.1322	9.772	0.4573	10.606	2.4105	0.1212	68.22

¹See sheet 3, table 3a, for vertical curve sections with smaller dimensionsWhen M = 5.11 ft, the value of $x_2 = 5(\bar{g} - 1)$ and $y_2 = \bar{g} - 1$; $x_1 = 0$, $y_1 = 1.0$ are to be used.

REFERENCE

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STANDARD DWG. NO.

ES-88

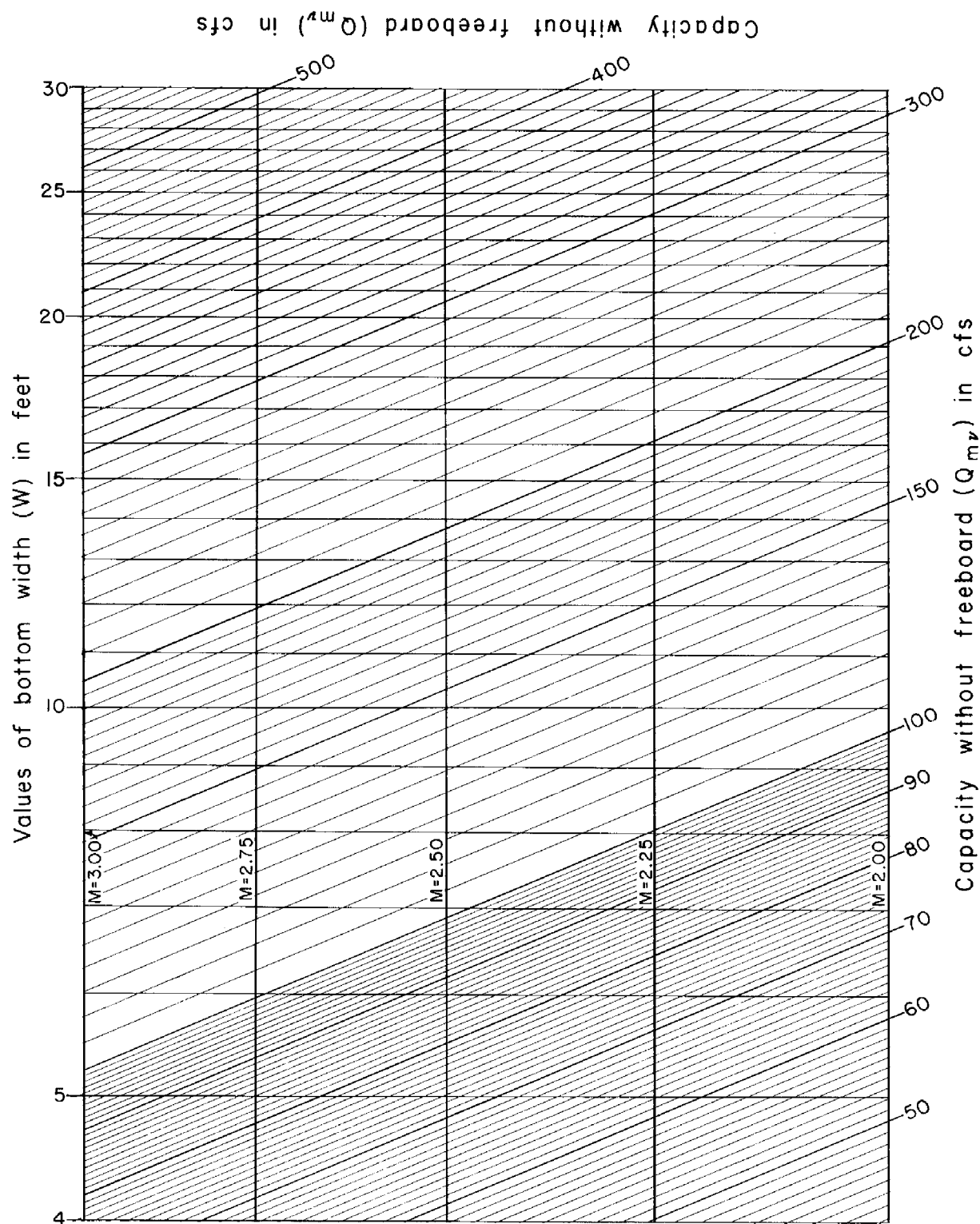
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DATE February 1954

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv} .



REFERENCE:

U. S. DEPARTMENT OF AGRICULTURE
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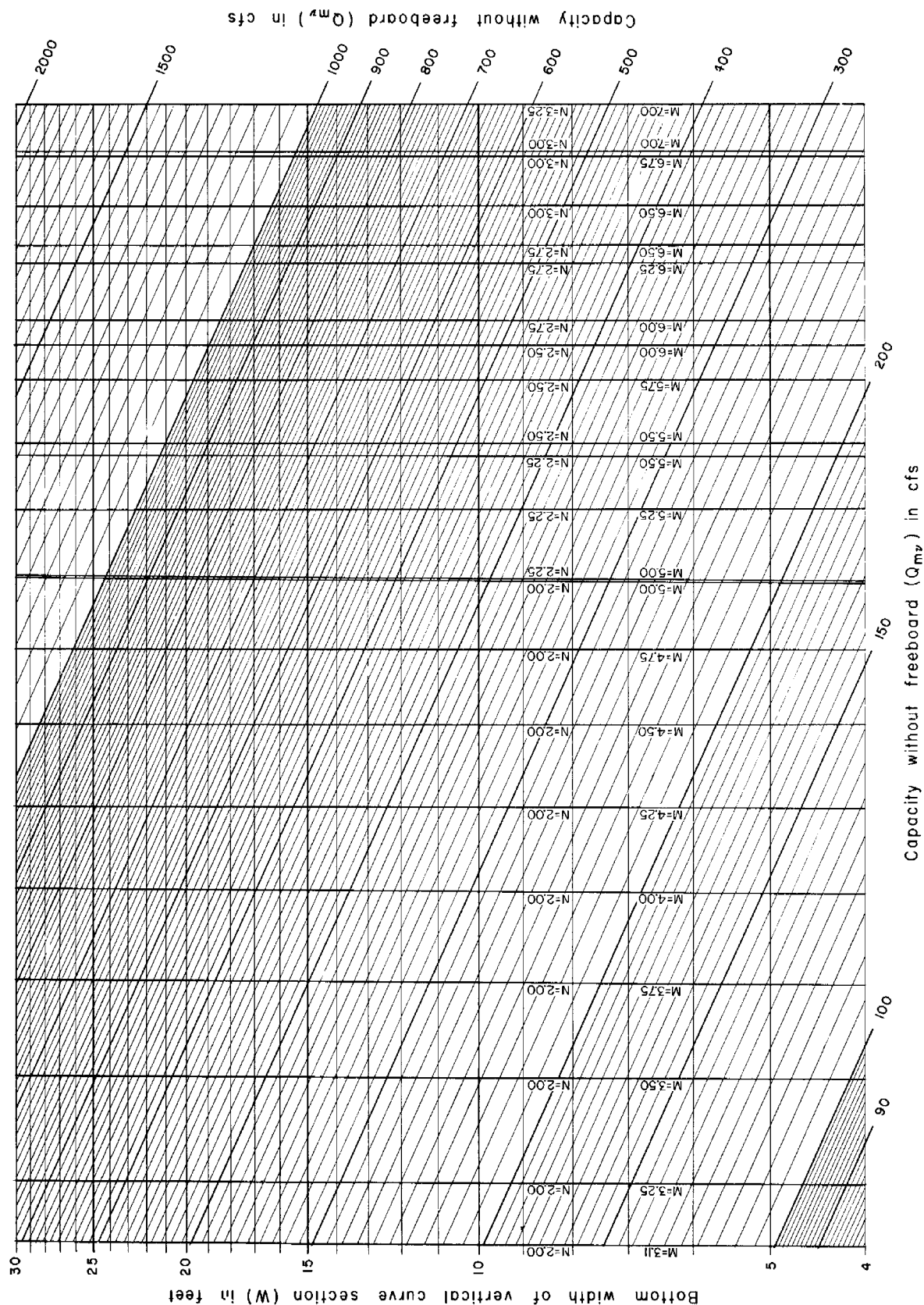
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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv} $z = 8$ feet

REFERENCE

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

STANDARD DWG. NO.

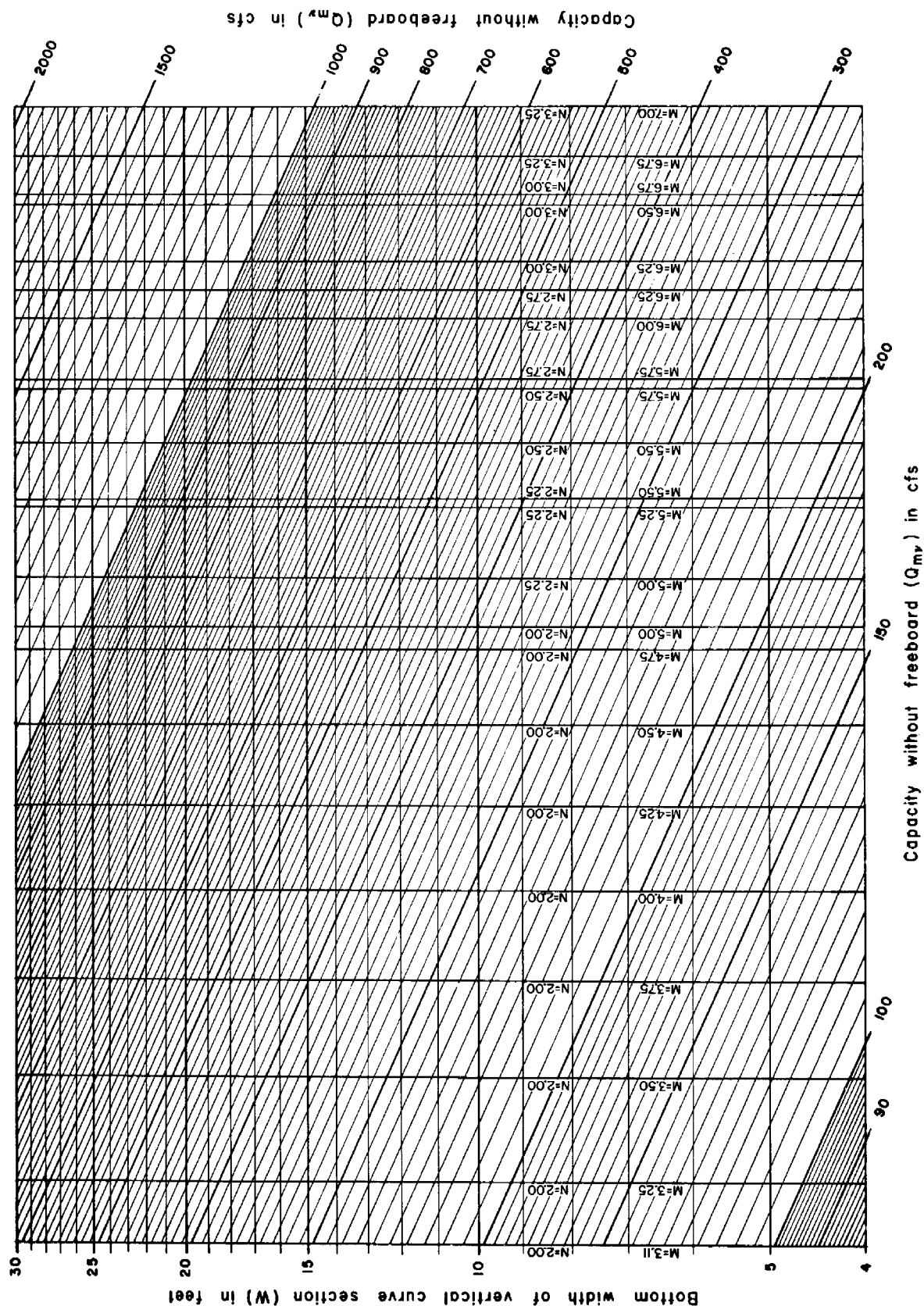
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DATE 3-29-54

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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv} $z = 7$ feet

REFERENCE

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SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.

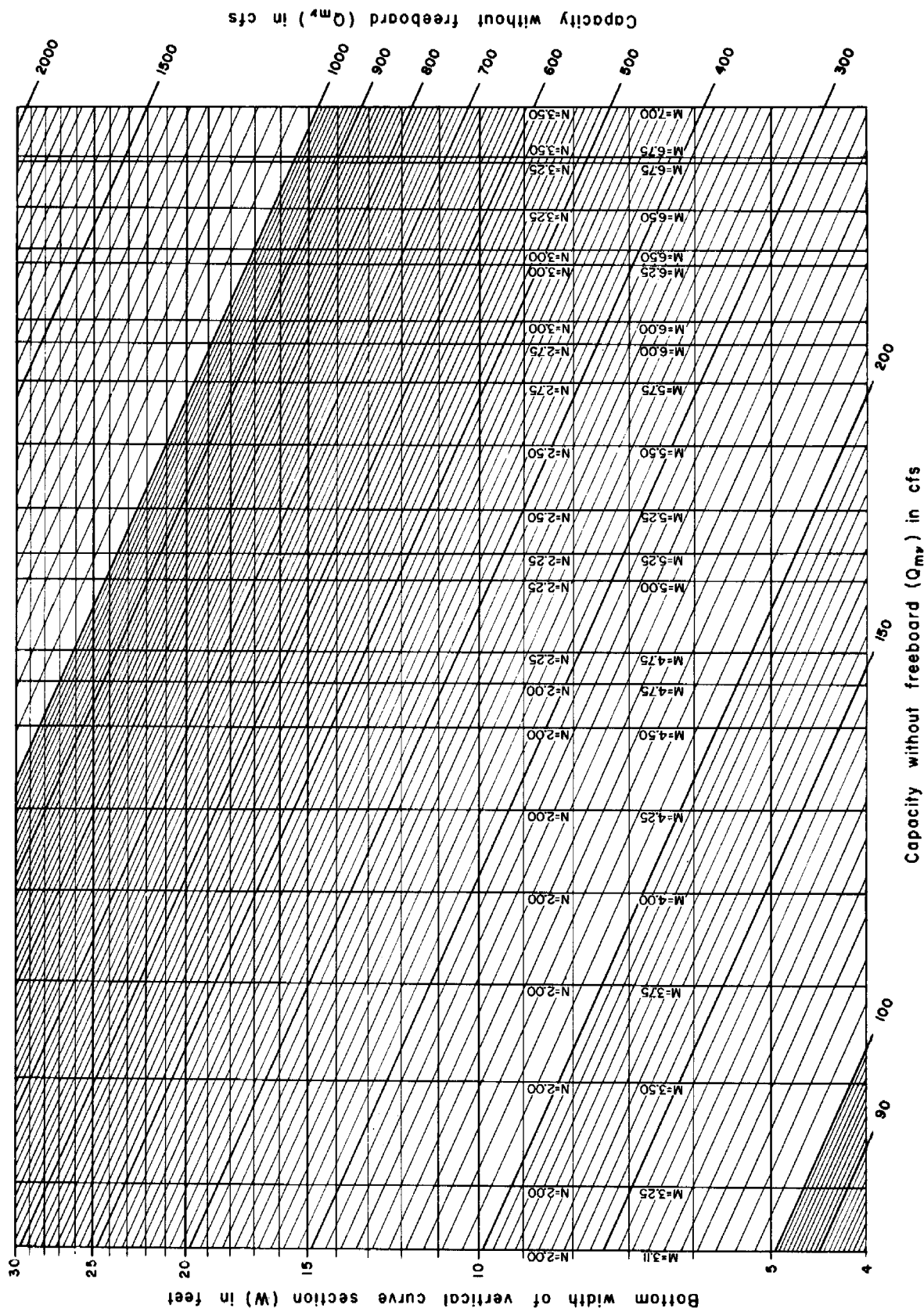
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DATE 3-29-54

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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv} $z = 6$ feet

REFERENCE

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SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.

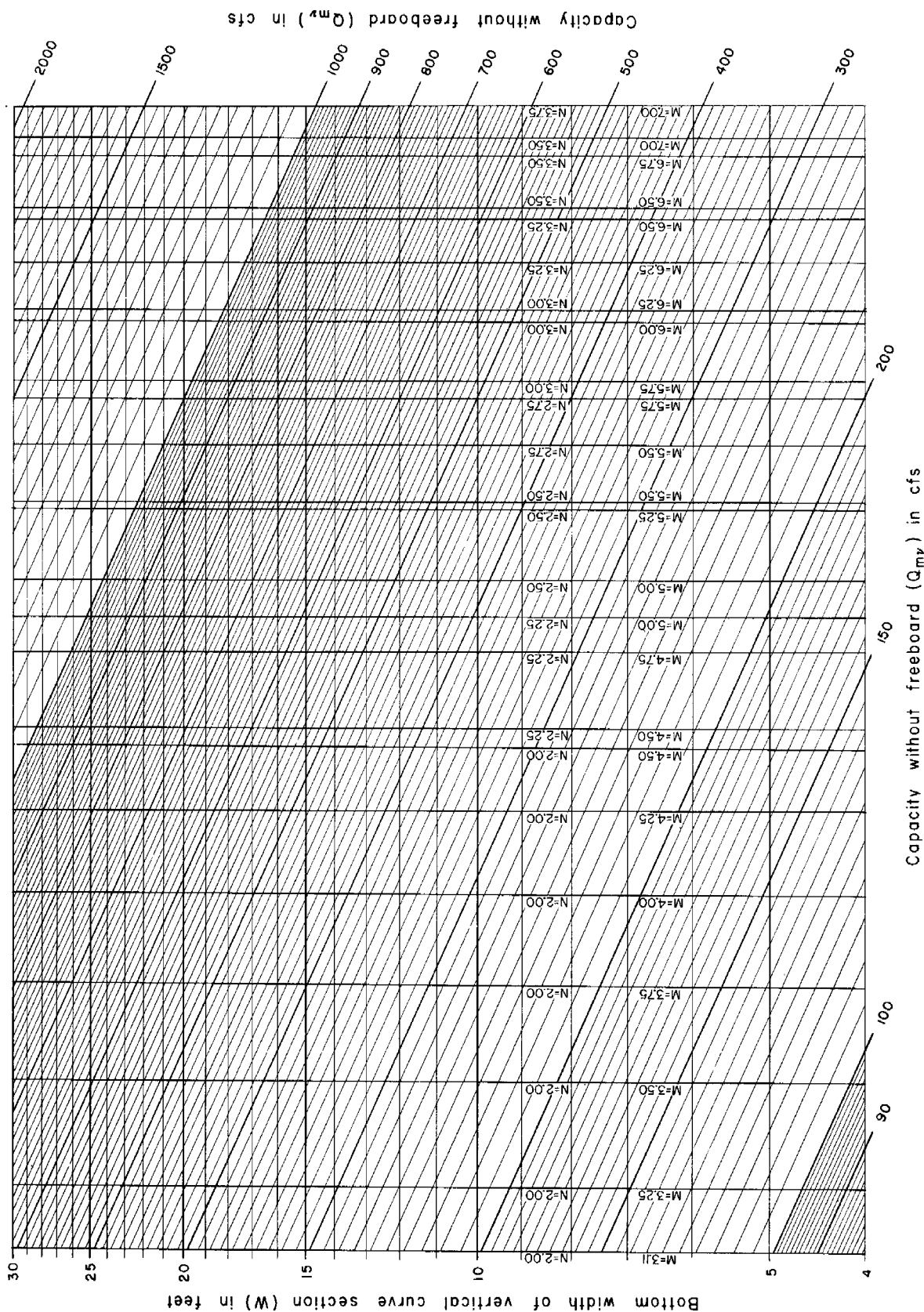
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Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv} $z = 5$ feet

REFERENCE

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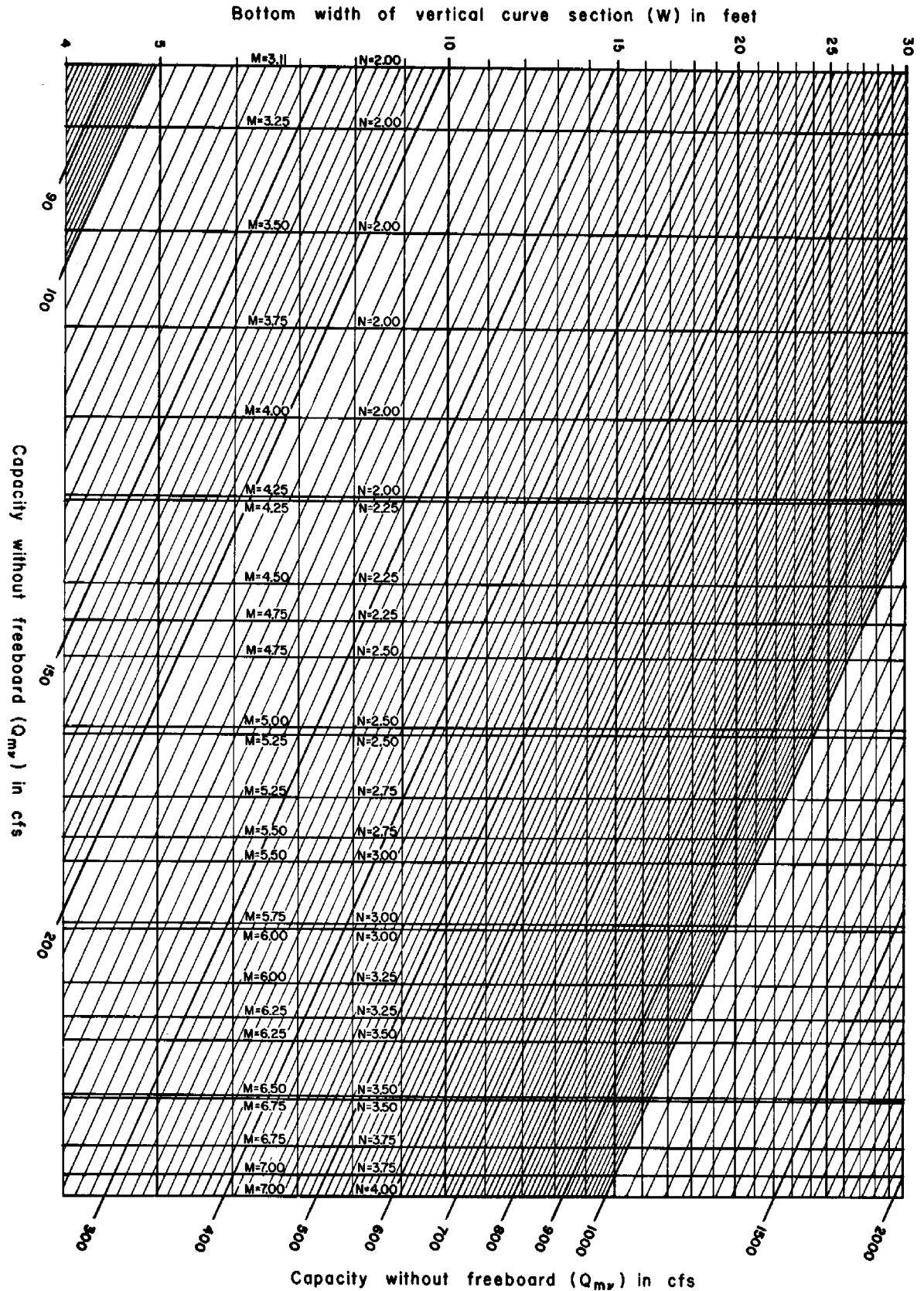
DATE 3-29-54

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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv}

$z = 4$ feet



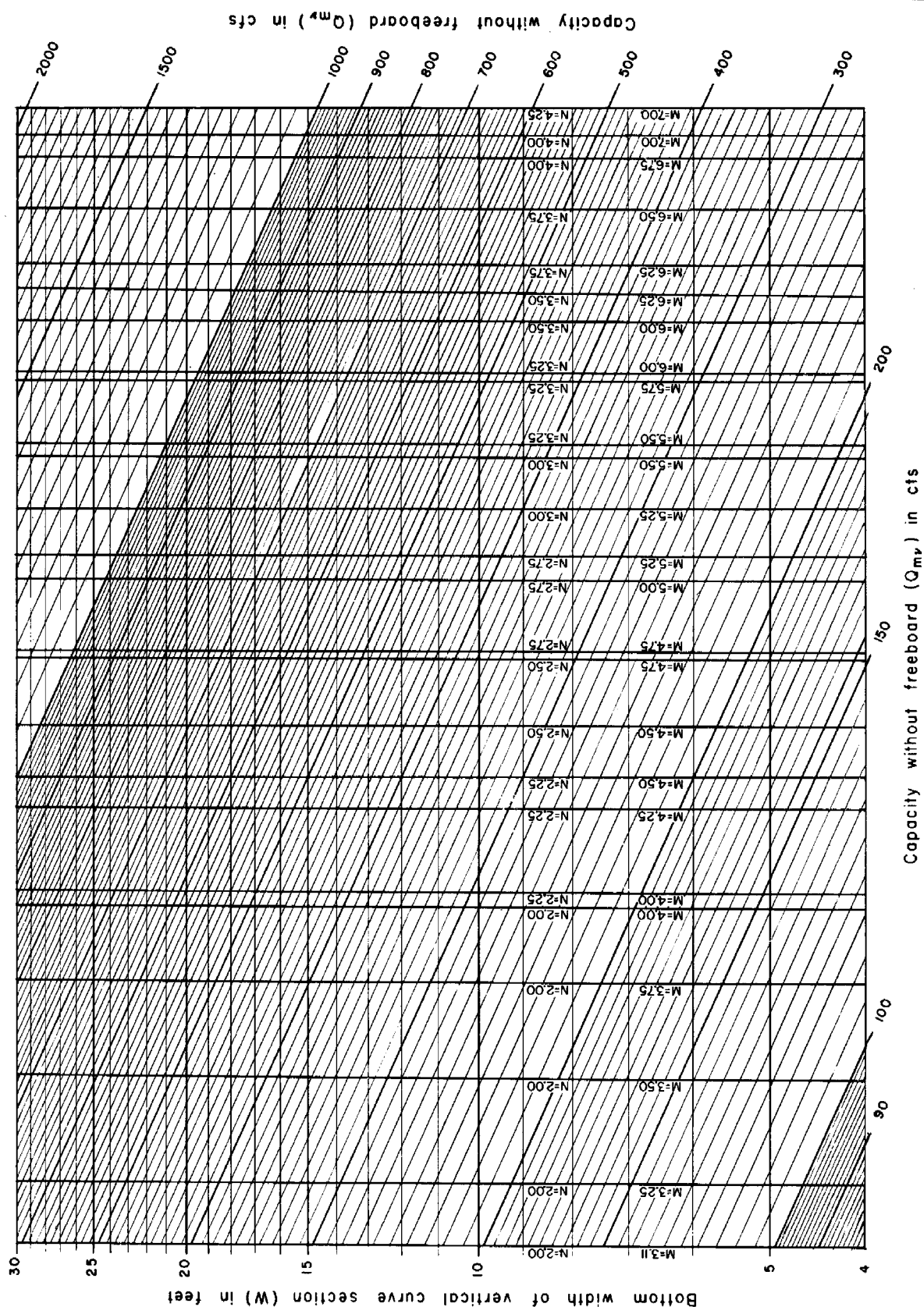
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SHEET 10 OF 16
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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Capacities without freeboard, Q_{mv} $z = 3$ feet

REFERENCE

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SHEET 11 OF 16

DATE 3-29-54

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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_0 can be obtained by the solution of the quadratic equation:

$$16s_0 s_v^2 + [M + \beta - N \sec(\tan^{-1}s_0) - 50s_0^2] s_v + s_0(25s_0^2 - \beta) = 0$$

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.

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_0 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.

SOLVING FOR COORDINATES OF UPPER VERTICAL CURVE

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

$$x_1 = 4.9673 \quad 0.6854 = y_1$$

SOLVING FOR VALUES OF x_2 AND y_2

Values of x_2 and y_2 for any channel slope s_0 are given by the equations:

$$x_2 = \frac{1}{s_0} [M + \beta - N \sec(\tan^{-1}s_0)] - 50s_0 + 32s_v$$

$$y_2 = \beta + 16s_v^2 - 25s_0^2$$

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

SOLVING FOR COORDINATES OF LOWER VERTICAL CURVE

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

$$x_3 = 2.8685 \quad 0.8739 = y_3$$

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:

$$x_3 = 50(s_0 - s_v)$$

$$y_3 = 25(s_0^2 - s_v^2)$$

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

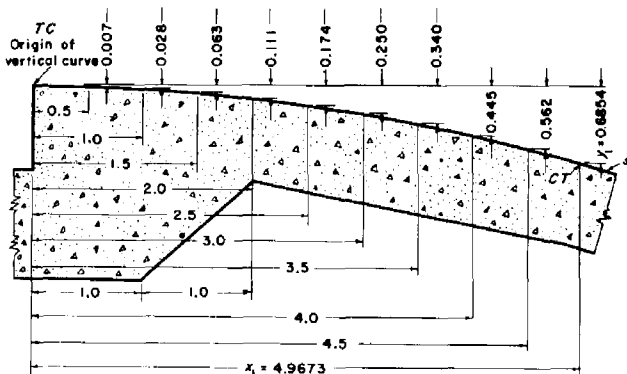
EXAMPLE

Given: Vertical curve section as shown by drawing on sheet 1 with the following dimensions: $M = 4.5$, $N = 2.0$, $\beta = 8.0$, $s_0 = 1/3$.

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 $s_0 = 1/3$ 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.

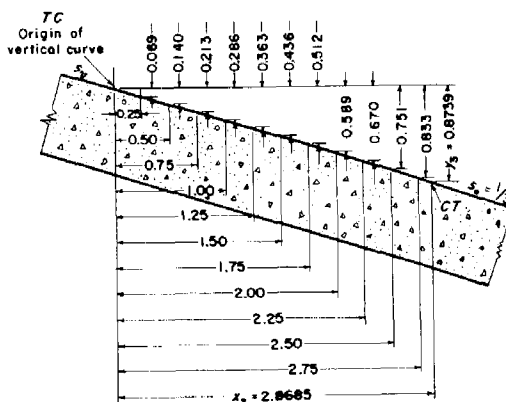


All dimensions are in feet. Values of x_1 and y_1 may be read from Table 3b, sheet 4.

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

$$x_2 = 23.339 \text{ ft}$$

$$y_2 = 6.4407 \text{ ft}$$



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

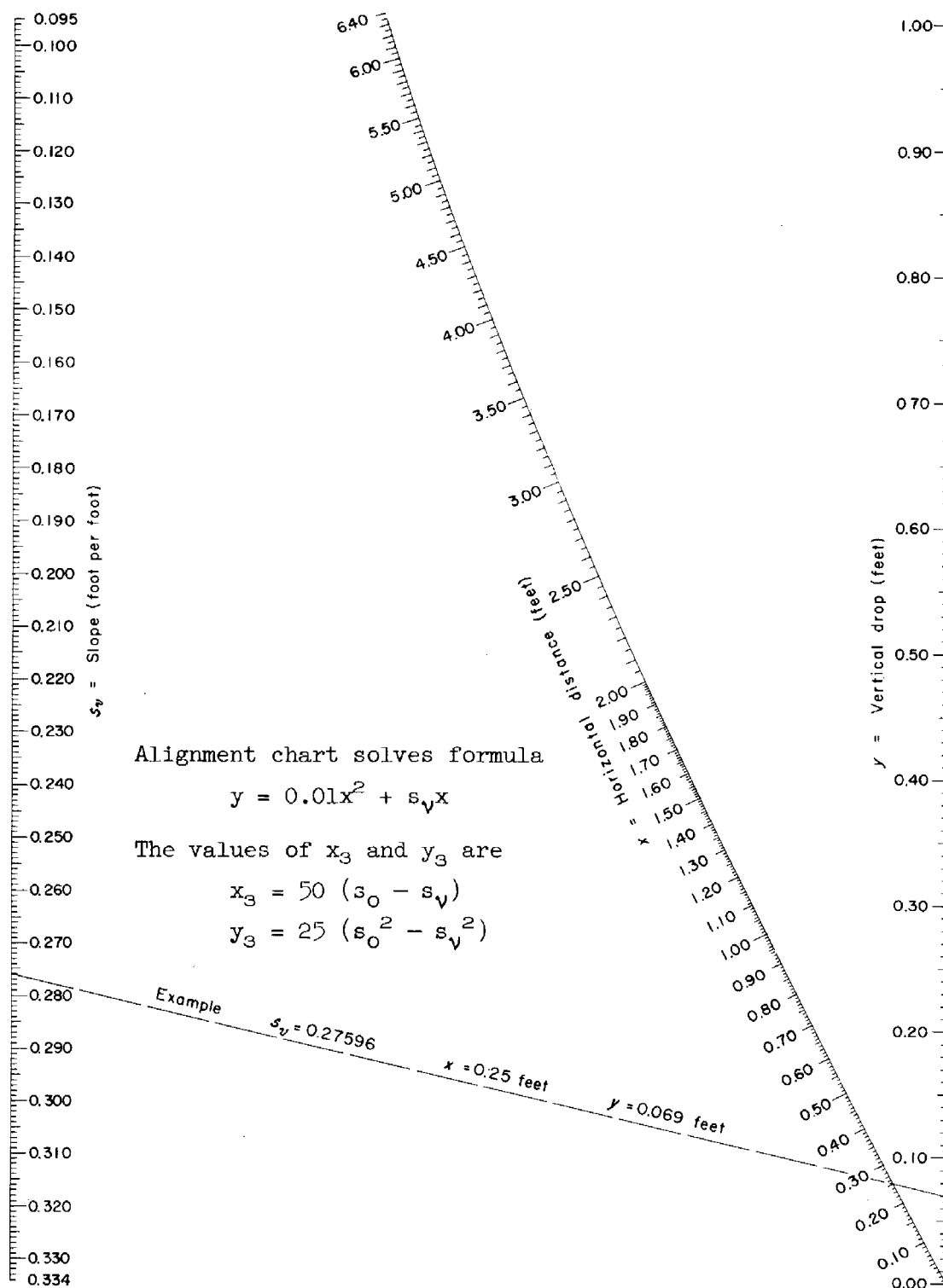
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CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Lower Vertical Curves and Value of s_v 

REFERENCE:

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

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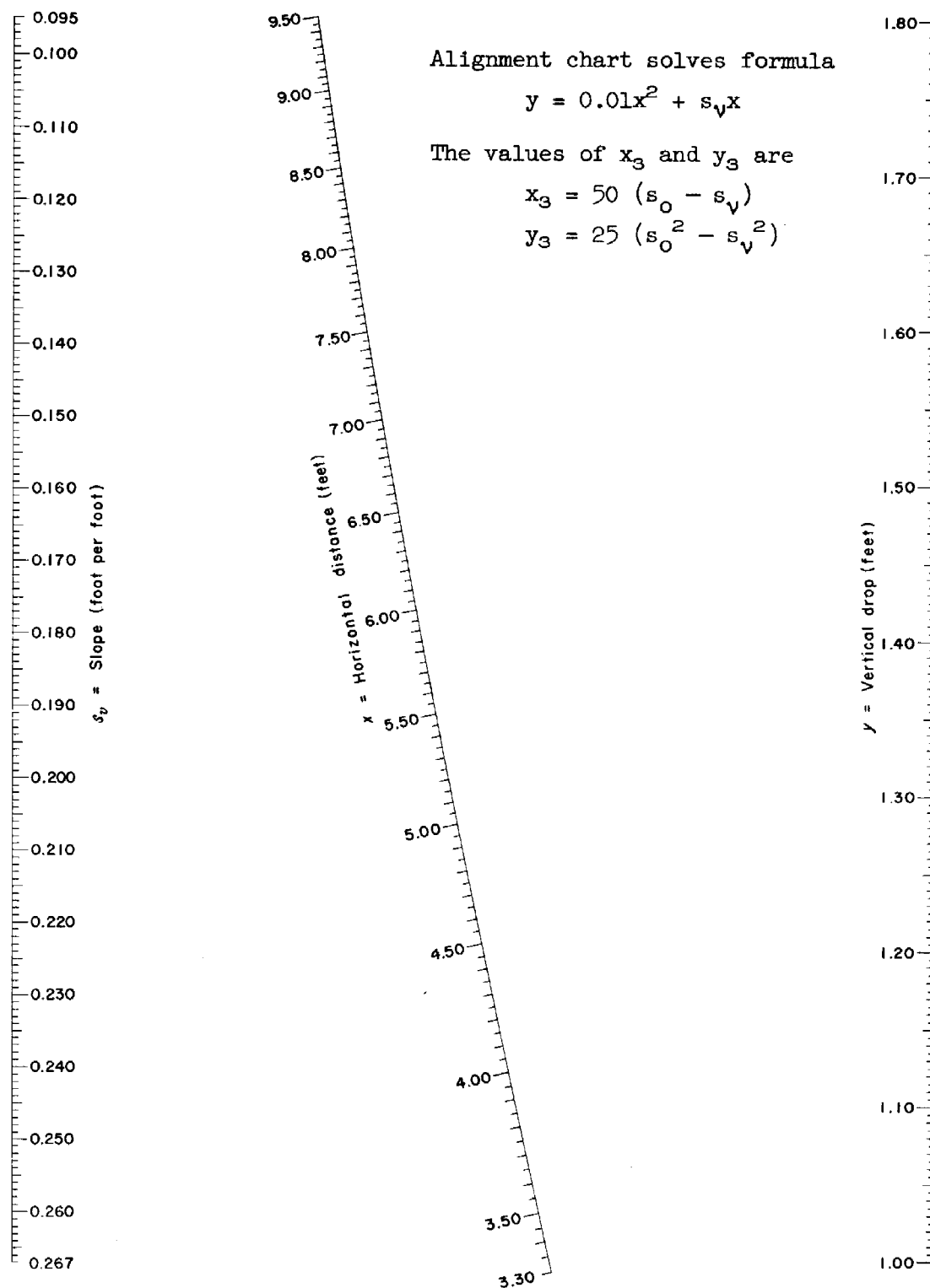
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Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Lower Vertical Curves and Value of s_v



REFERENCE:

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

STANDARD DWG. NO.

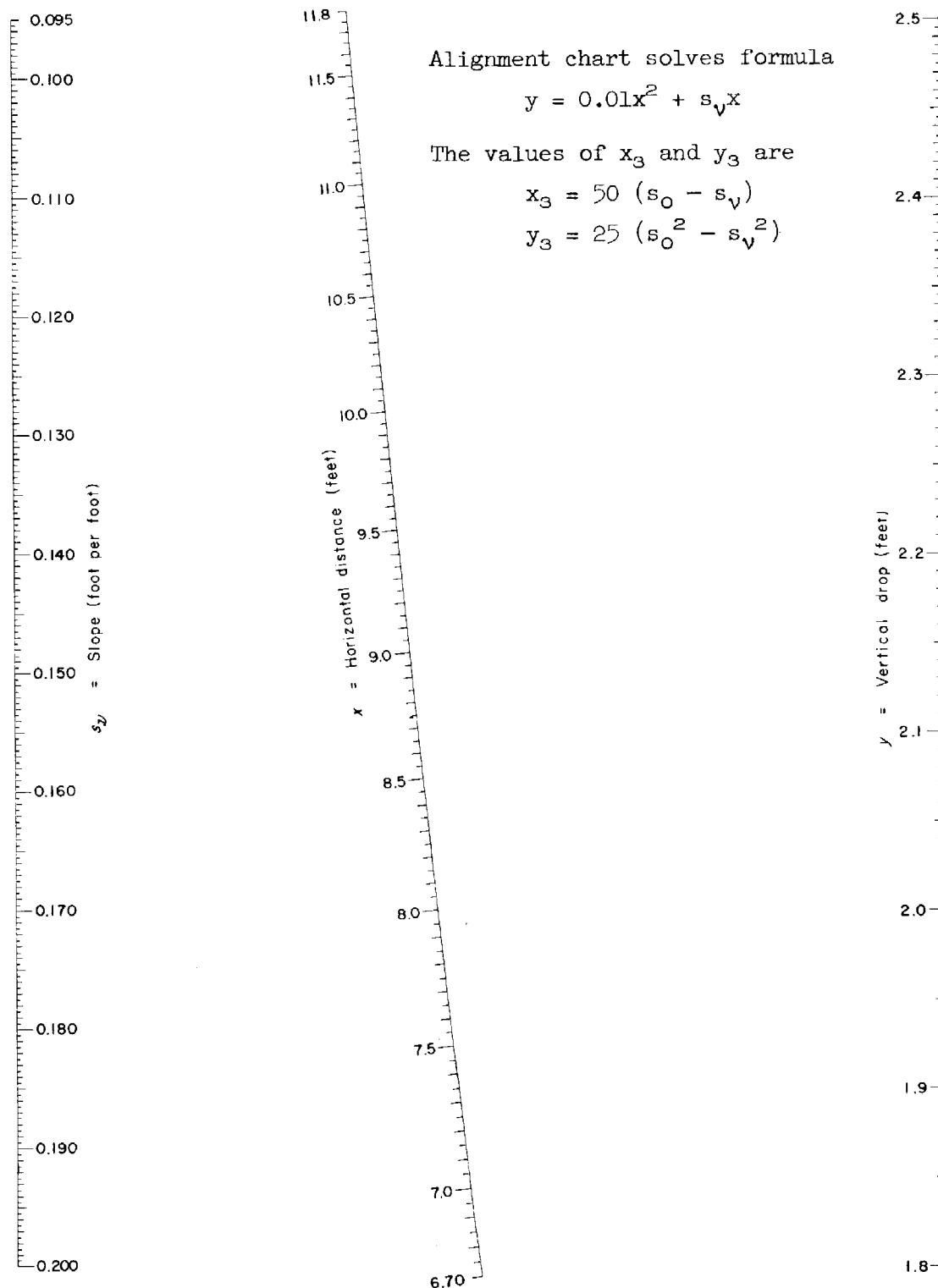
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DATE January 1954

Revised 10/77

CHUTE SPILLWAYS: VERTICAL CURVE SECTIONS

Coordinates of Lower Vertical Curves and Value of s_v 

REFERENCE:

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

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

STANDARD DWG. NO.

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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 $3 = 8$ 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

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

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

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

2. (a) Read on sheet 6, for $3 = 8$ ft, at $W = 12$ ft and $Q_{fr} = 415.68$ cfs the required dimensions

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

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 $3 = 8$ 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

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

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

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

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

$$(W = 10) \quad d = 1.283 \text{ ft}$$

$$(W = 15) \quad d = 1.280 \text{ ft}$$

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

$$(W = 10) \quad d = 1.029 \text{ ft}$$

$$(W = 15) \quad d = 1.023 \text{ ft}$$

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

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

REFERENCE

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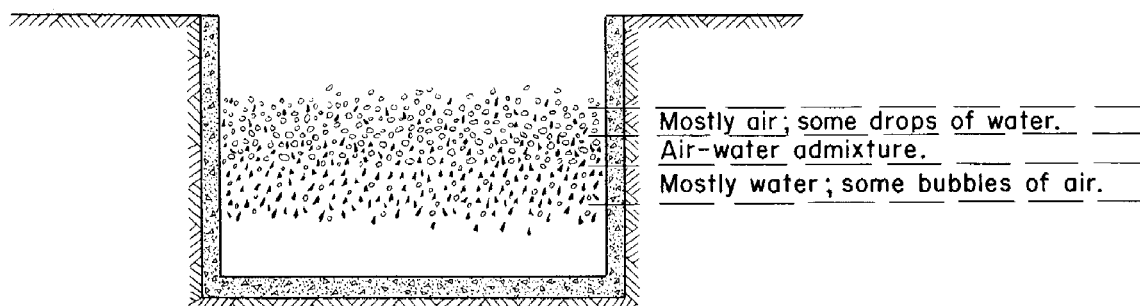
Revised 10/77

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. Gumensky¹ 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

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

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

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

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/sec²

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

$$d_a = \rho d \quad 6.3$$

where ρ = volume of air-water admixture per cubic foot of water in ft³

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:

¹Gumensky, 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.

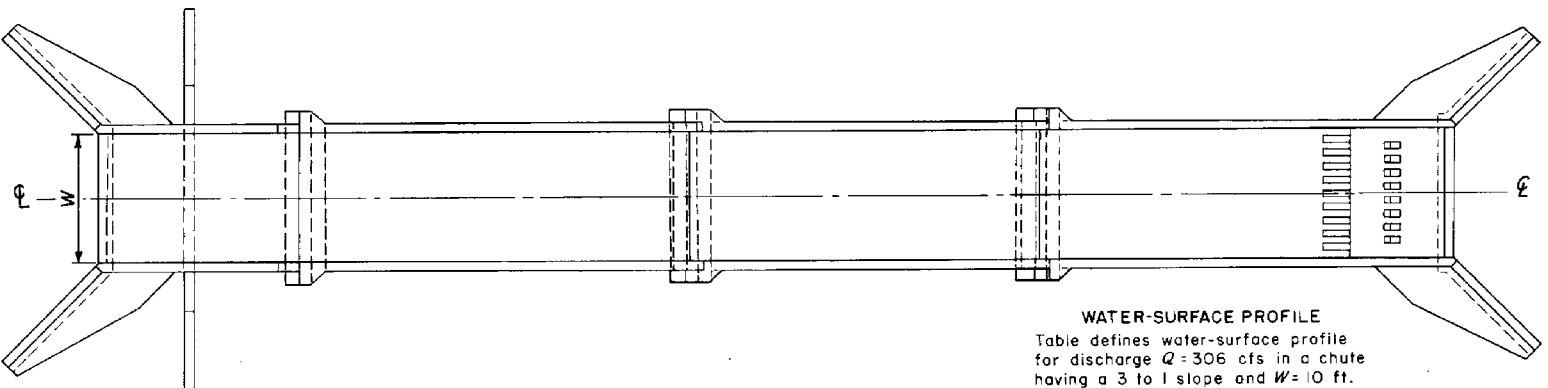
ES-147 gives water-surface profiles for 100 foot wide rectangular channels with slopes of 3 to 1, 4 to 1, and 10 to 1, pages 2.178 through 2.183. Since the influence of sidewall friction decreases with width, these drawings may be used with sufficient accuracy for all widths greater than about 50 feet.

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

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

2.143

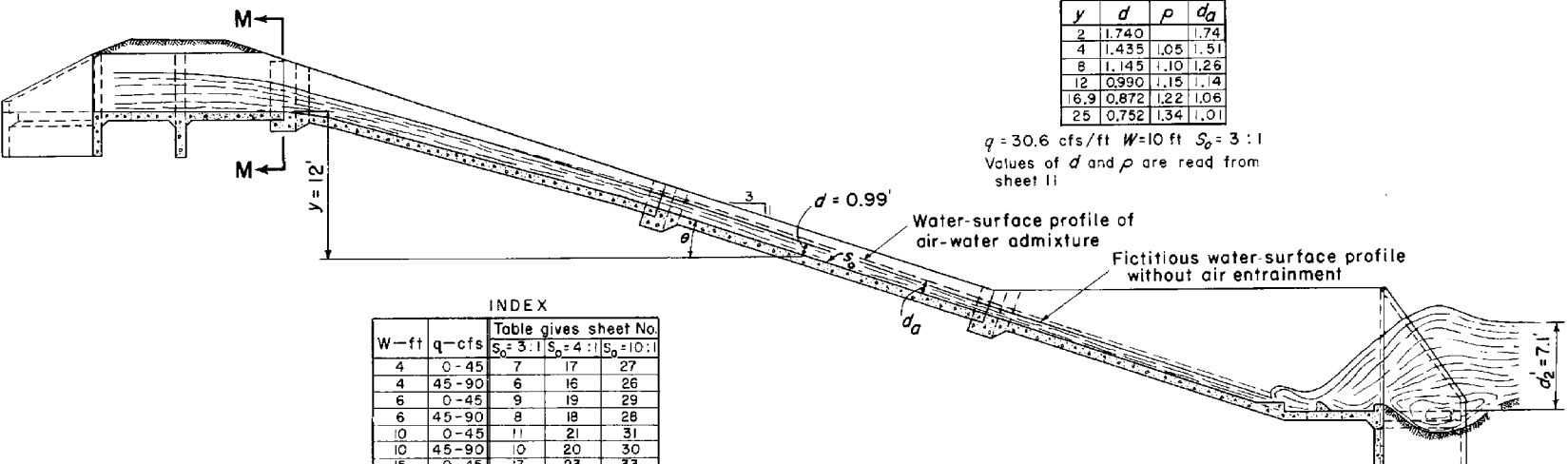


WATER-SURFACE PROFILE

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	p	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 p 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
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.
ES - 78
SHEET 1 OF 35
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 ft³
 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/sec²
 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 ft²
 r = Hydraulic radius corresponding to the depth d in ft

REFERENCE

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

STANDARD DWG. NO.

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SHEET 2 OF 35DATE 1-20-55

CHUTE SPILLWAYS: WATER-SURFACE PROFILES; Formulas.

FORMULAS AND VALUES

Differential equation of varied flow for flow on steep slopes

$$\frac{s_0}{\cos \theta} \frac{dx}{dd} = \frac{\left[\frac{Q}{W \sqrt{\cos \theta}} \right]^2 - 1}{\left[\frac{Q}{W \sqrt{\cos \theta}} \right]^2 - 1}$$

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_0 is in the interval $0.333 < s_0 \leq 0.5$.

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

REFERENCE:

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

STANDARD DWG. NO.

ES-78

SHEET 3 OF 35

DATE 1-20-55

Revised 10/77

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 has 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_0 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_0 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 $s_0 = 0.2857$.

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 $s_0 = 0.333$ 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)

REFERENCE:

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ES-78

SHEET 4 OF 35

DATE 1-20-55

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

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

REFERENCE:

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

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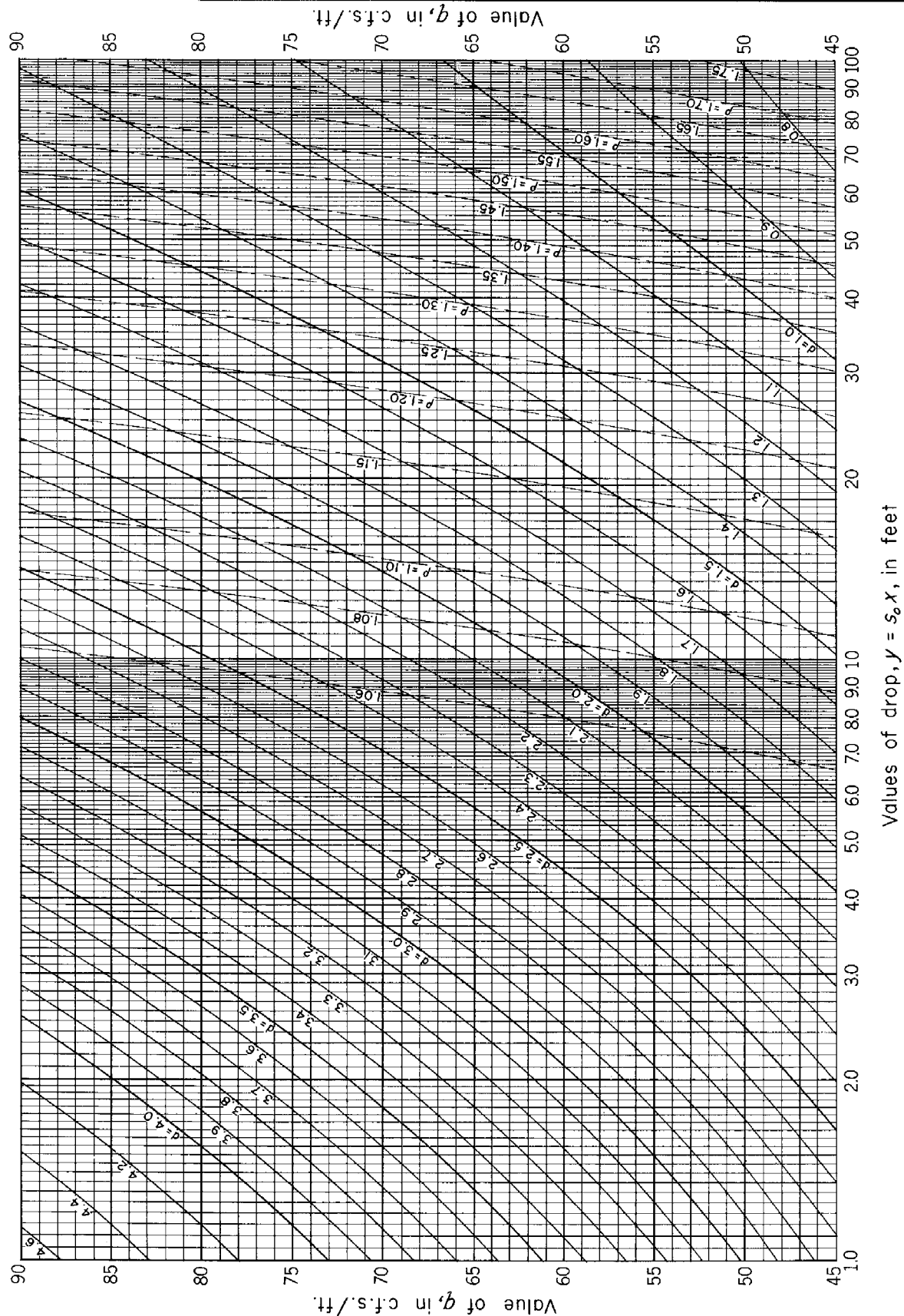
ES- 78

SHEET 5 OF 35

DATE 1-20-55

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

W = 4 feet
q = 45 to 90
s₀ = 3:1



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.

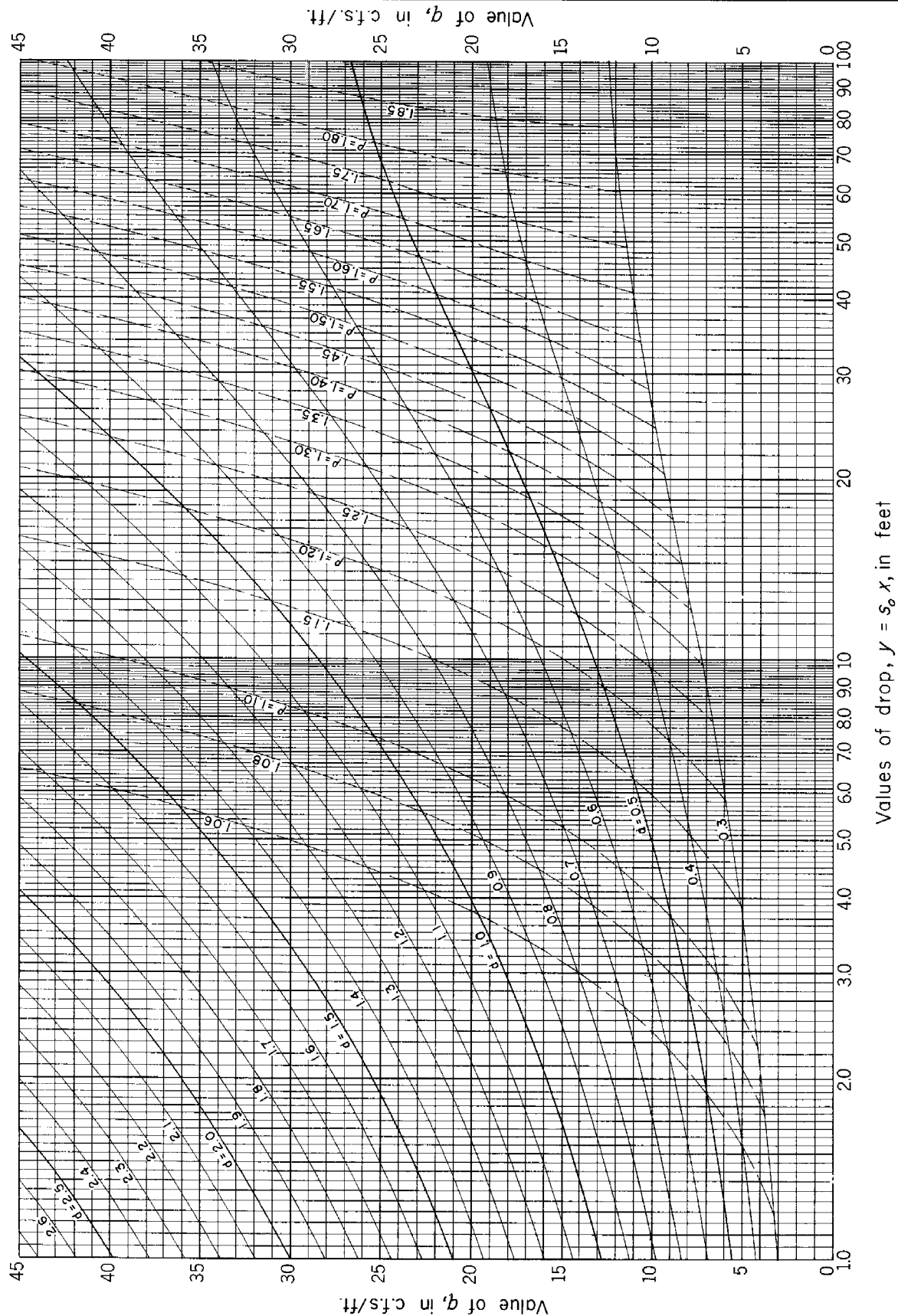
ES-78

SHEET 6 OF 35

DATE 1-14-68

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

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



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.

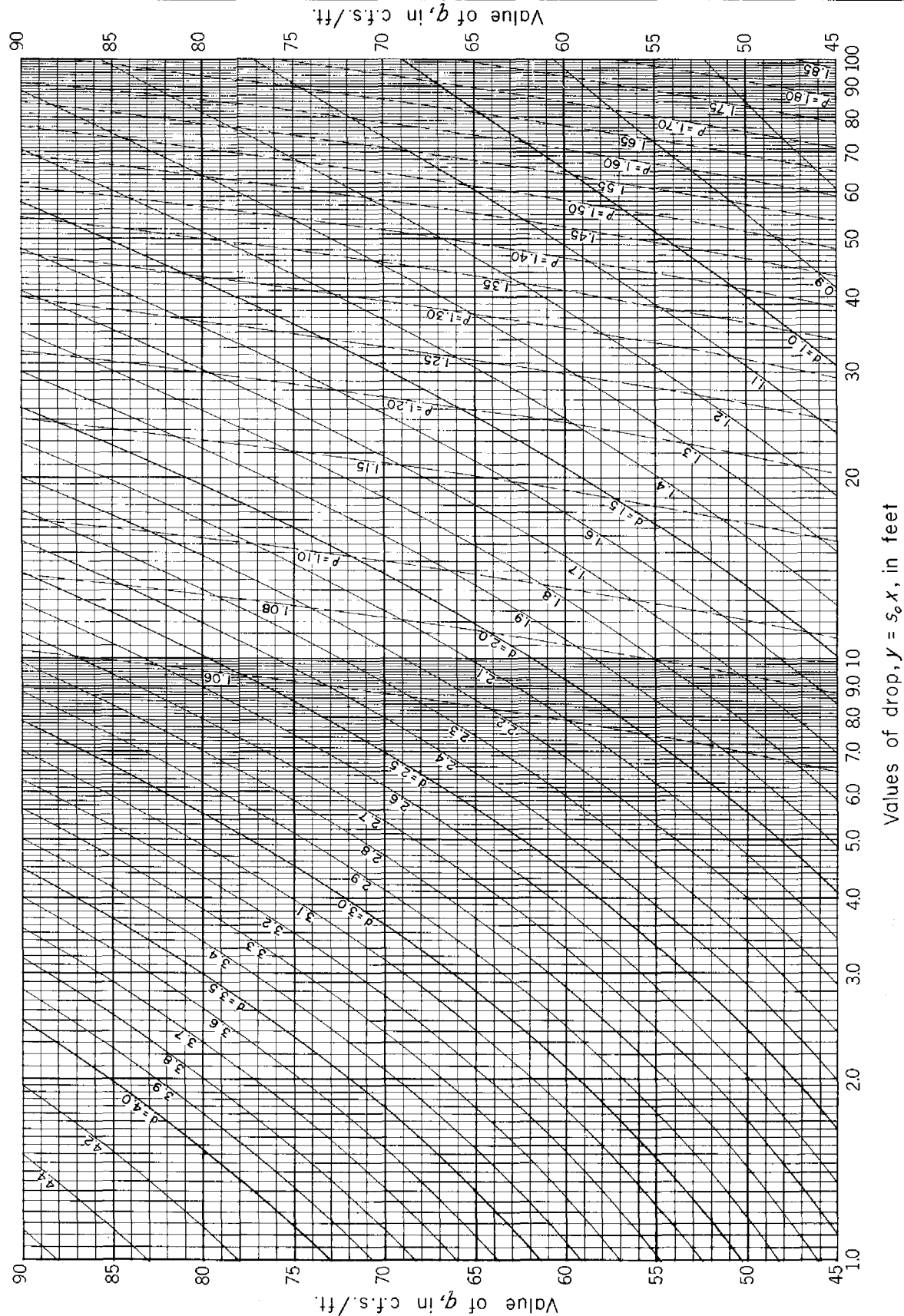
ES - 78

SHEET 7 OF 35

DATE 1-14-35

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

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



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.

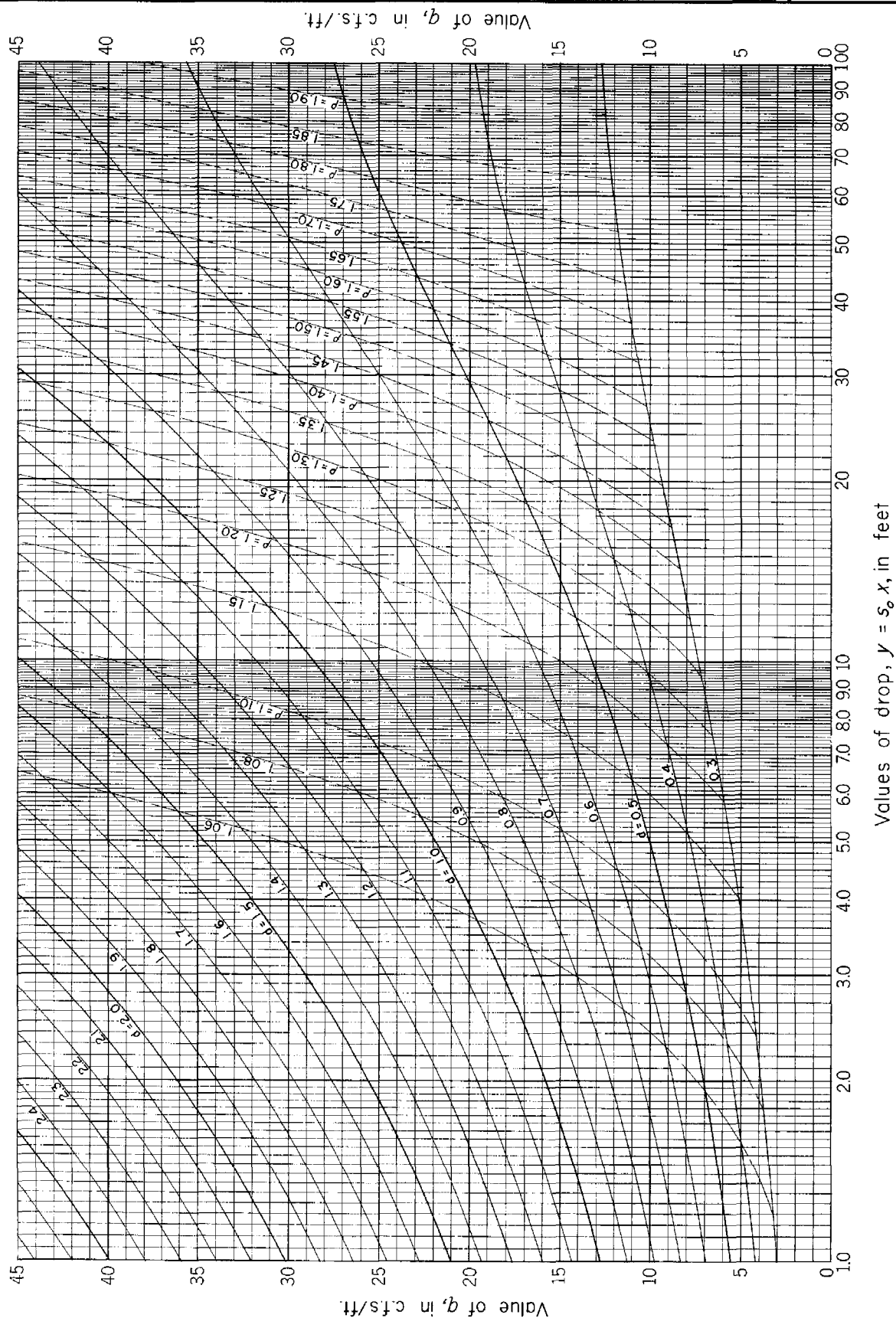
ES - 78

SHEET 8 OF 35

DATE 1-14-55

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

W = 6 feet
q = 0 to 45
S₀ = 3:1



REFERENCE

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

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STANDARD DWG. NO.

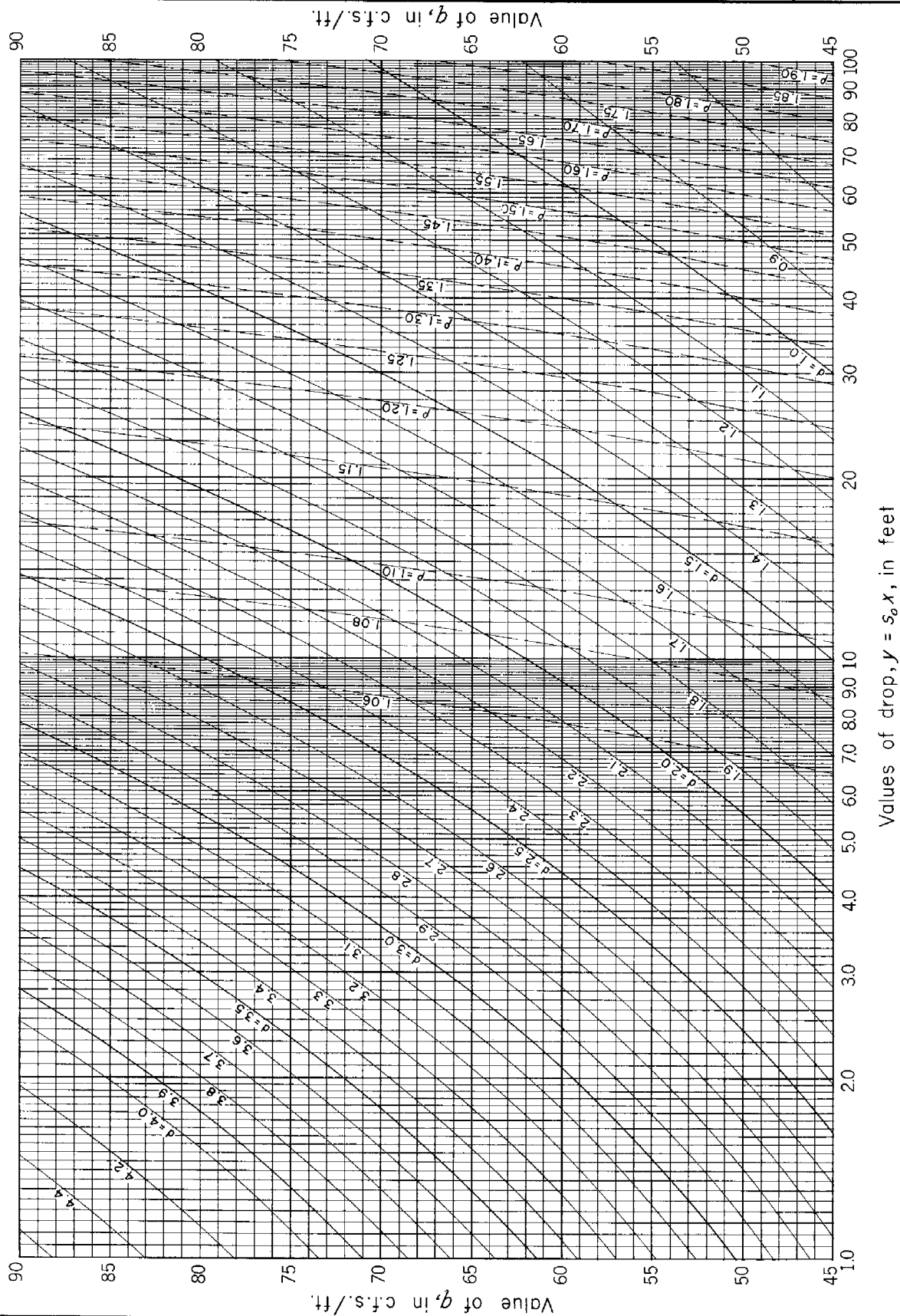
ES - 78

SHEET 9 OF 35

DATE 1-14-55

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

W = 10 feet
 q = 45 to 90
 $s_0 = 3:1$



REFERENCE

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

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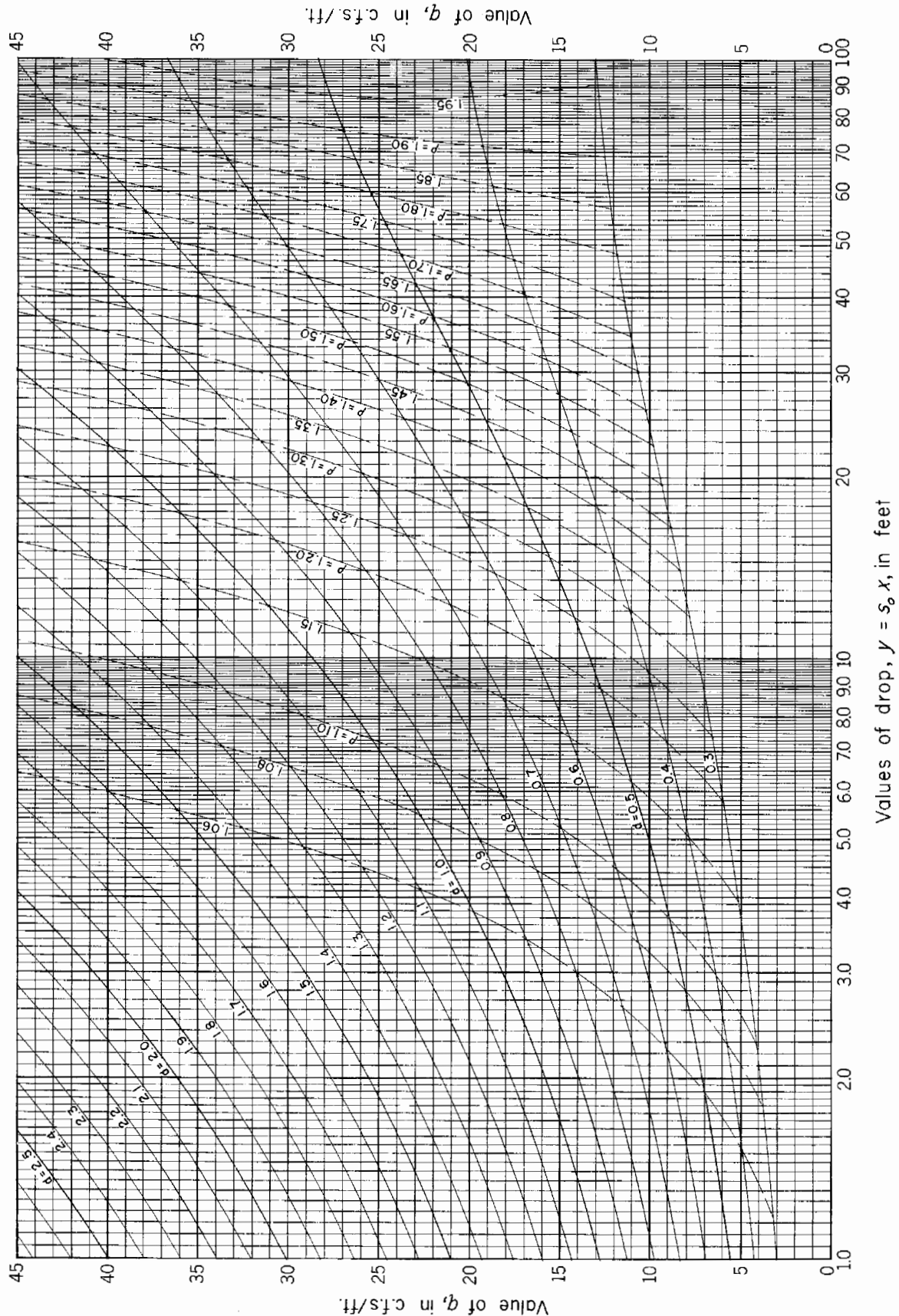
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SHEET 10 OF 35

DATE 1-14-55

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

W = 10 feet
 $q = 0$ to 45
 $S_0 = 3:1$



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

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STANDARD DWG. NO.

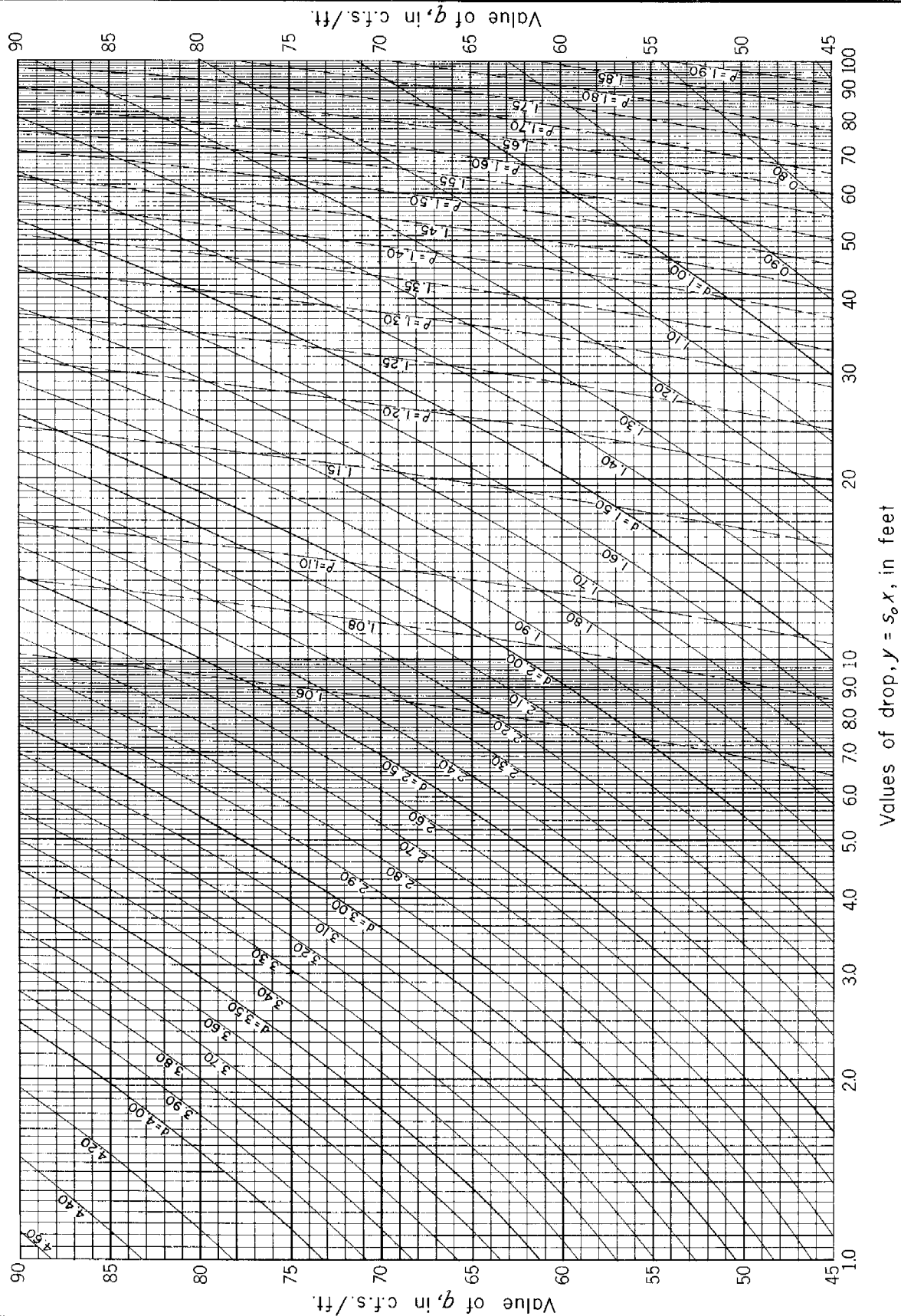
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SHEET 11 OF 35

DATE _____

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

W = 15 feet
q = 45 to 90
s₀ = 3:1



REFERENCE

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

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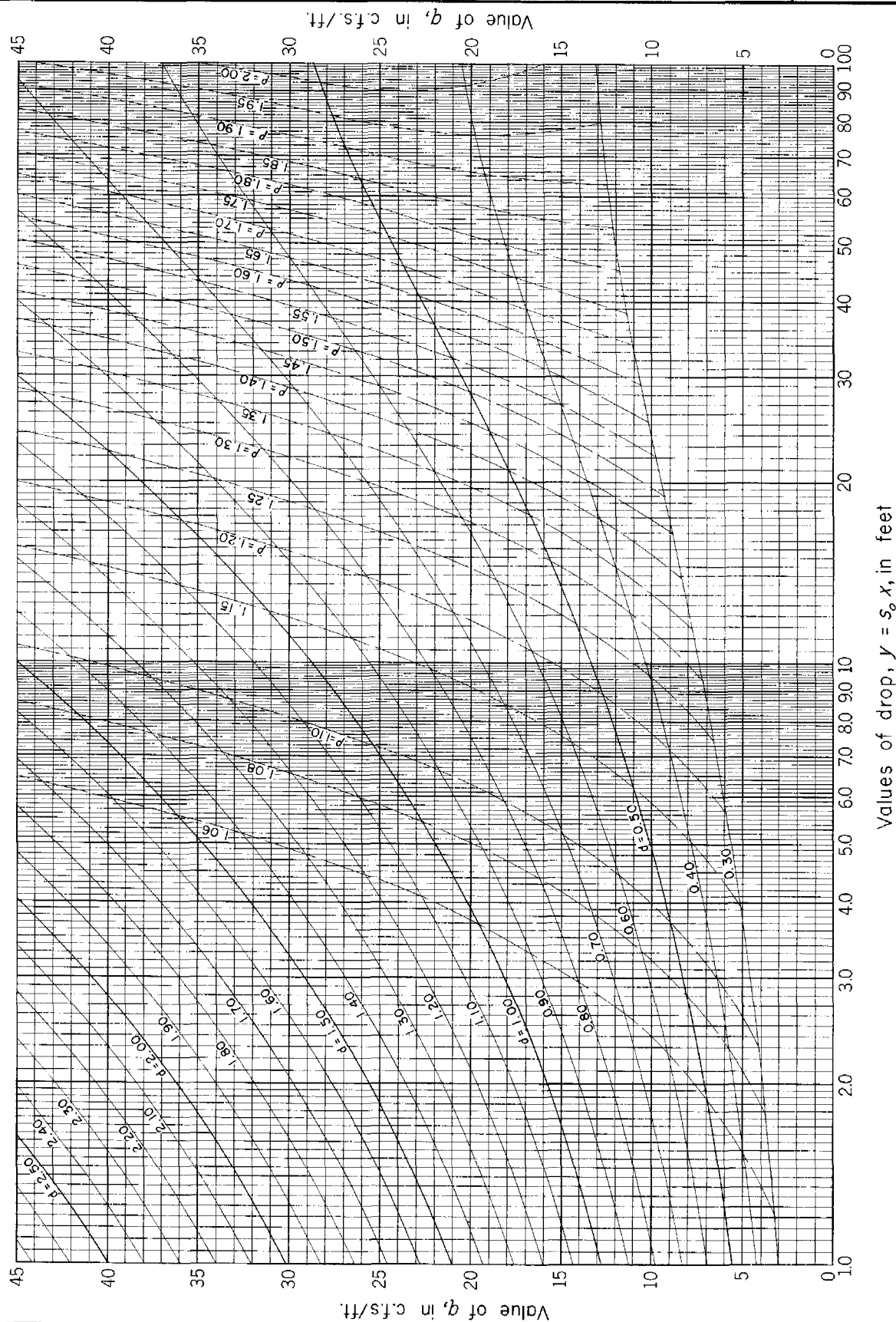
ES-78

SHEET 12 OF 35

DATE 1-14-58

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

W = 15 feet
 q = 0 to 45
 S₀ = 3:1



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

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STANDARD DWG. NO.

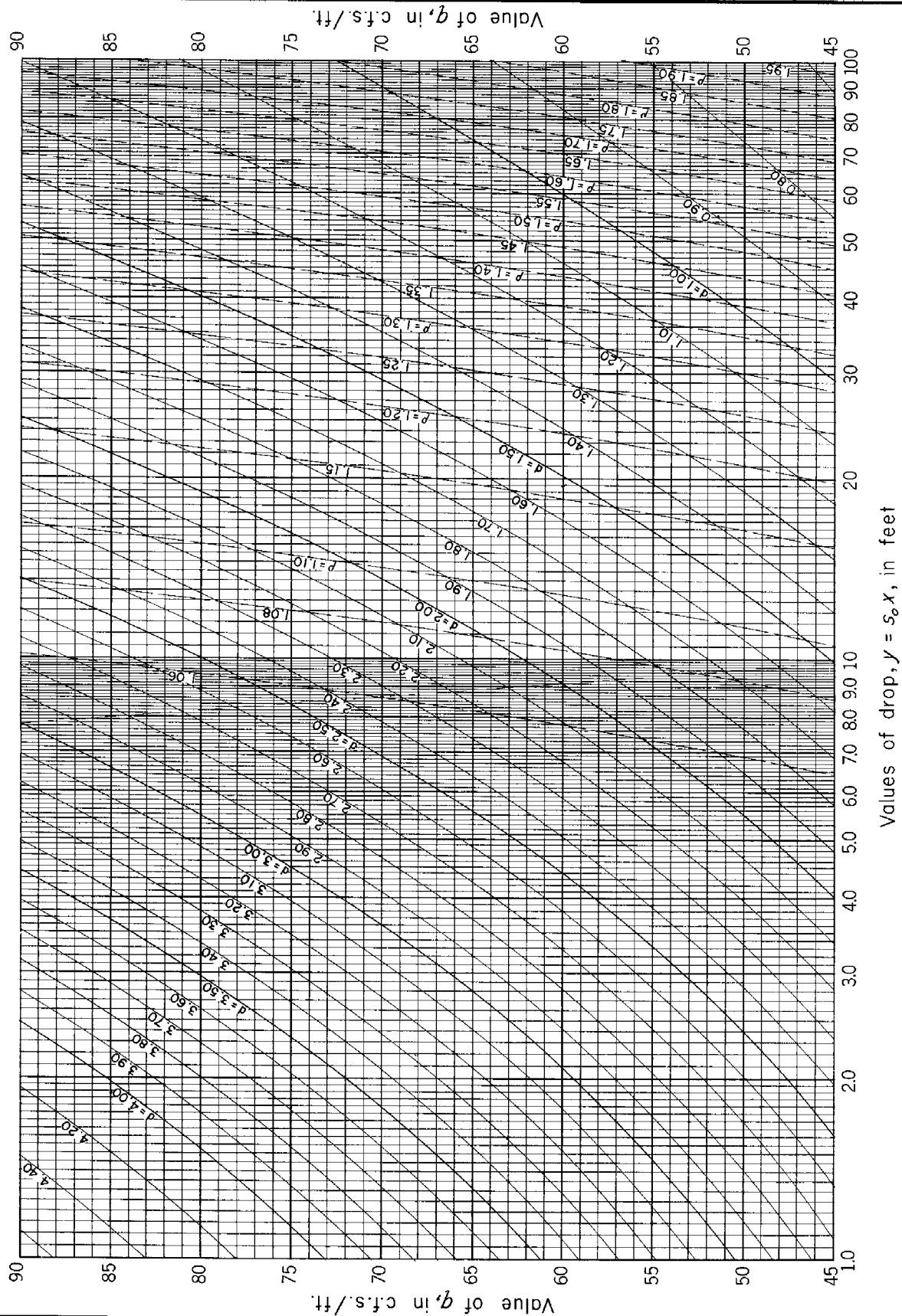
ES - 78

SHEET 13 OF 35

DATE 1-1-55

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

W = 30 feet
q = 45 to 90
s₀ = 3:1



REFERENCE

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

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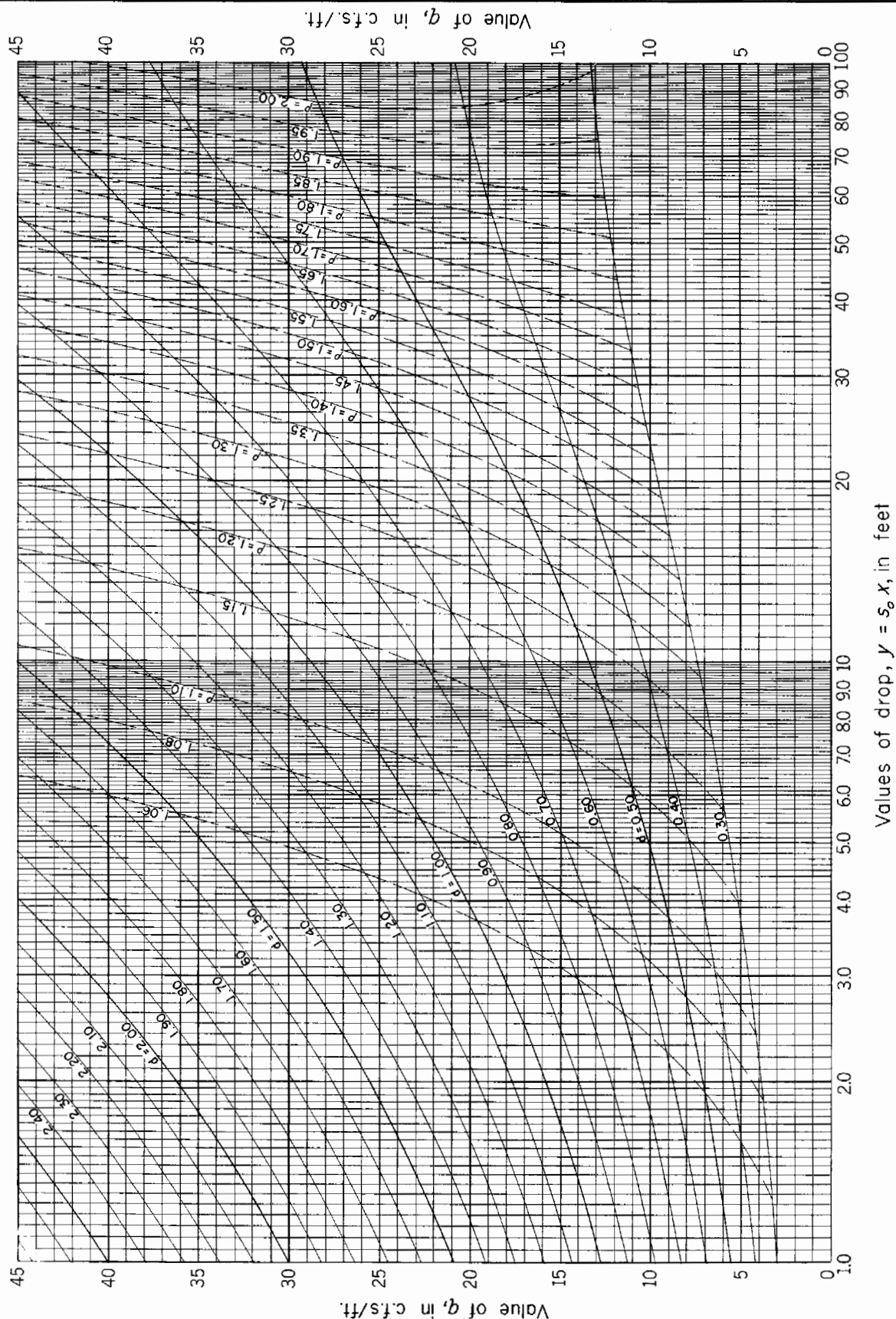
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SHEET 14 OF 35

DATE 1-14-55

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

W = 30 feet
 q = 0 to 45
 S₀ = 3:1



REFERENCE

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

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STANDARD DWG. NO.

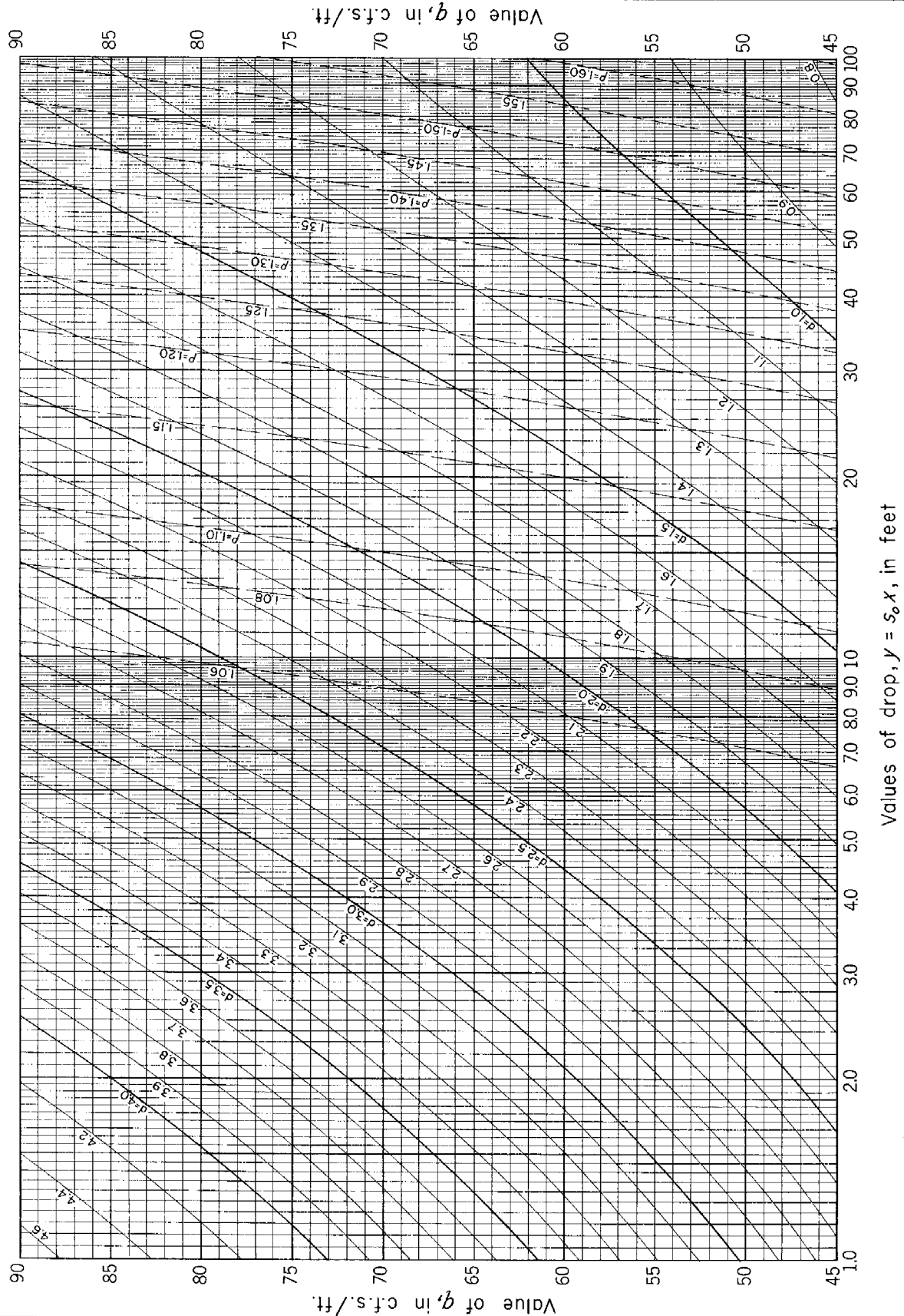
ES - 78

SHEET 15 OF 35

DATE 1-18-55

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

W = 4 feet
q = 45 to 90
s₀ = 4 : 1



REFERENCE

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

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STANDARD DWG. NO.

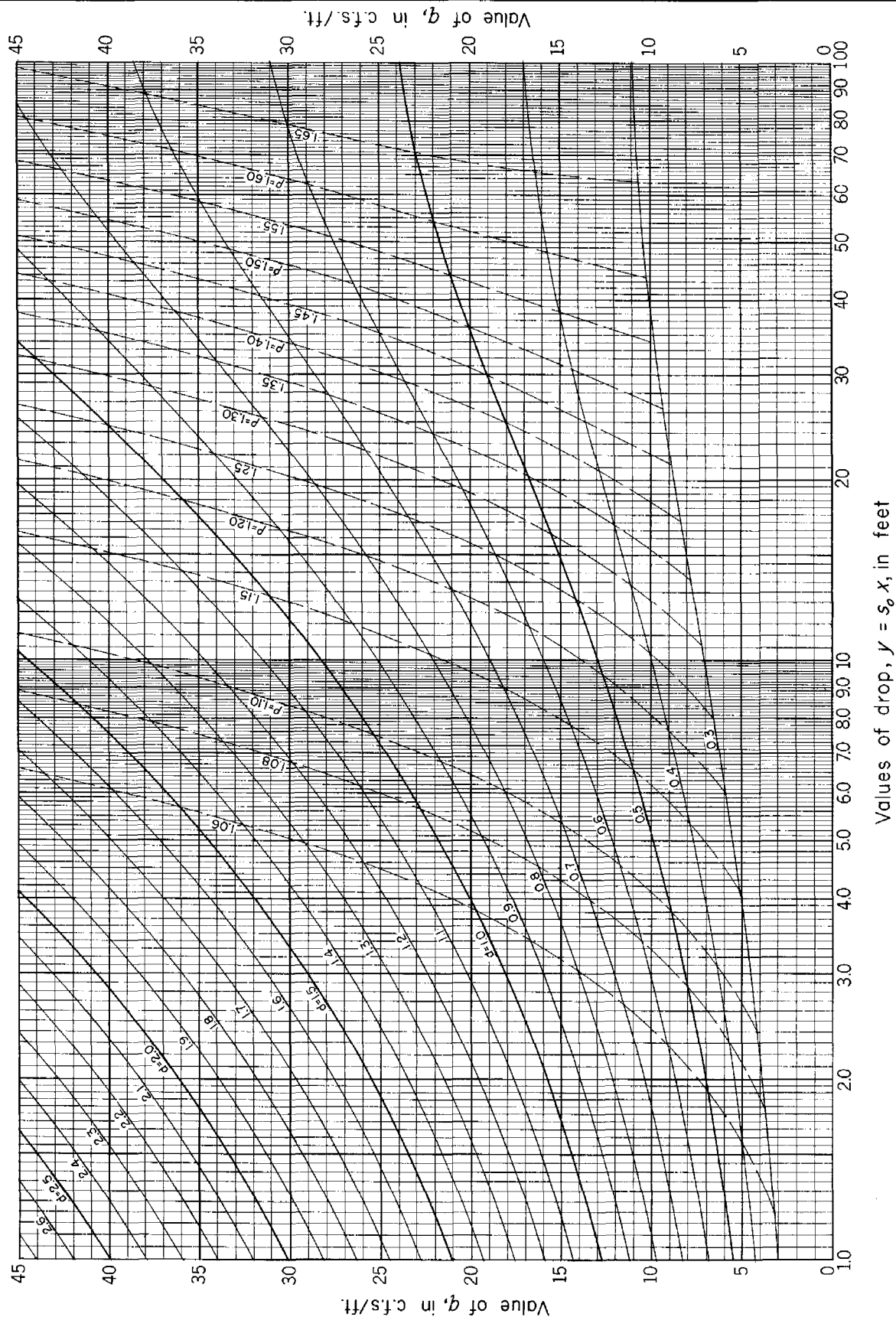
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SHEET 16 OF 35

DATE 1-14-56

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

W = 4 feet
 q = 0 to 45
 S₀ = 4 : 1



REFERENCE

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

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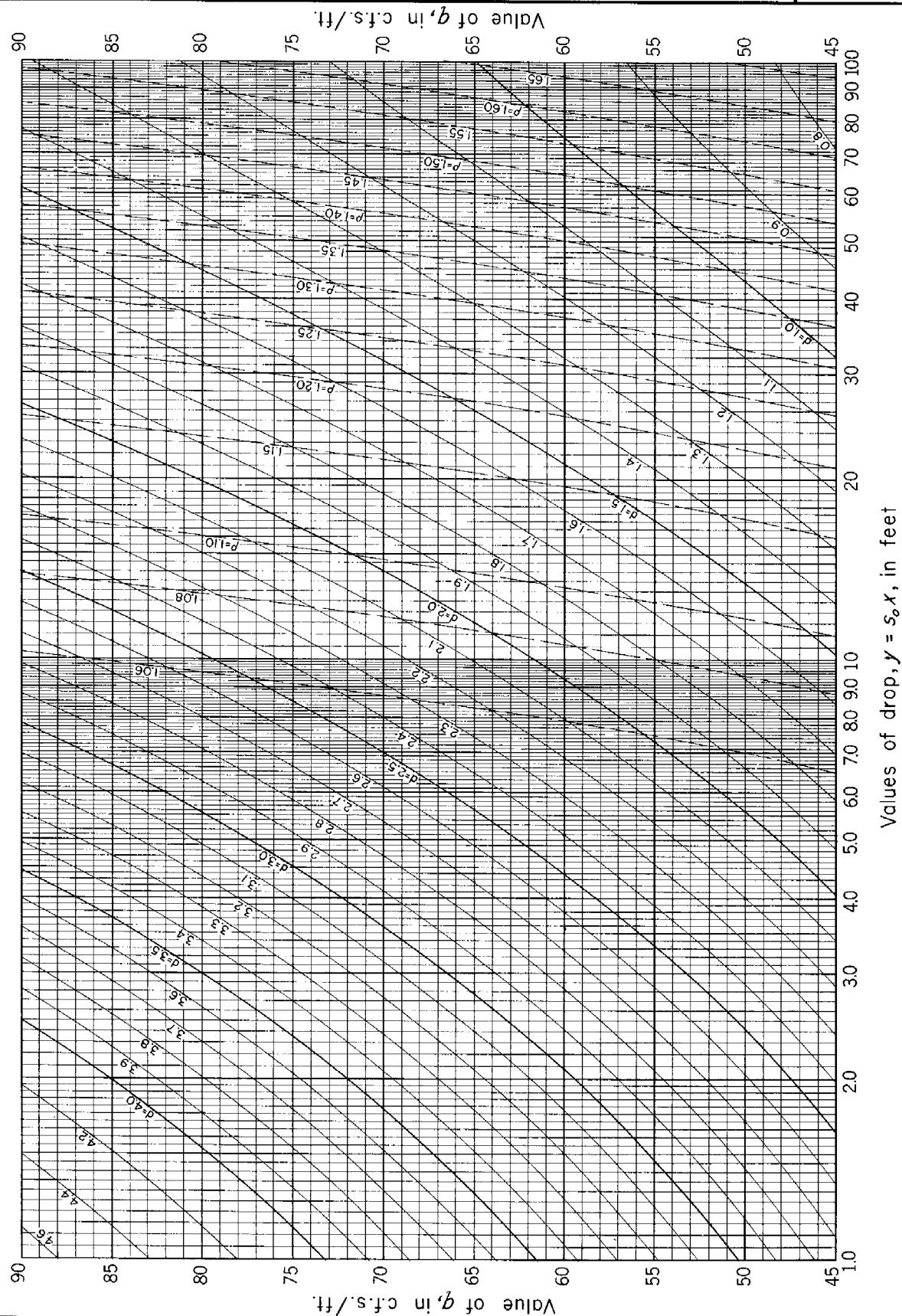
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SHEET 17 OF 35

DATE 1-24-50

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

W = 6 feet
q = 45 to 90
s₀ = 4 : 1



REFERENCE

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

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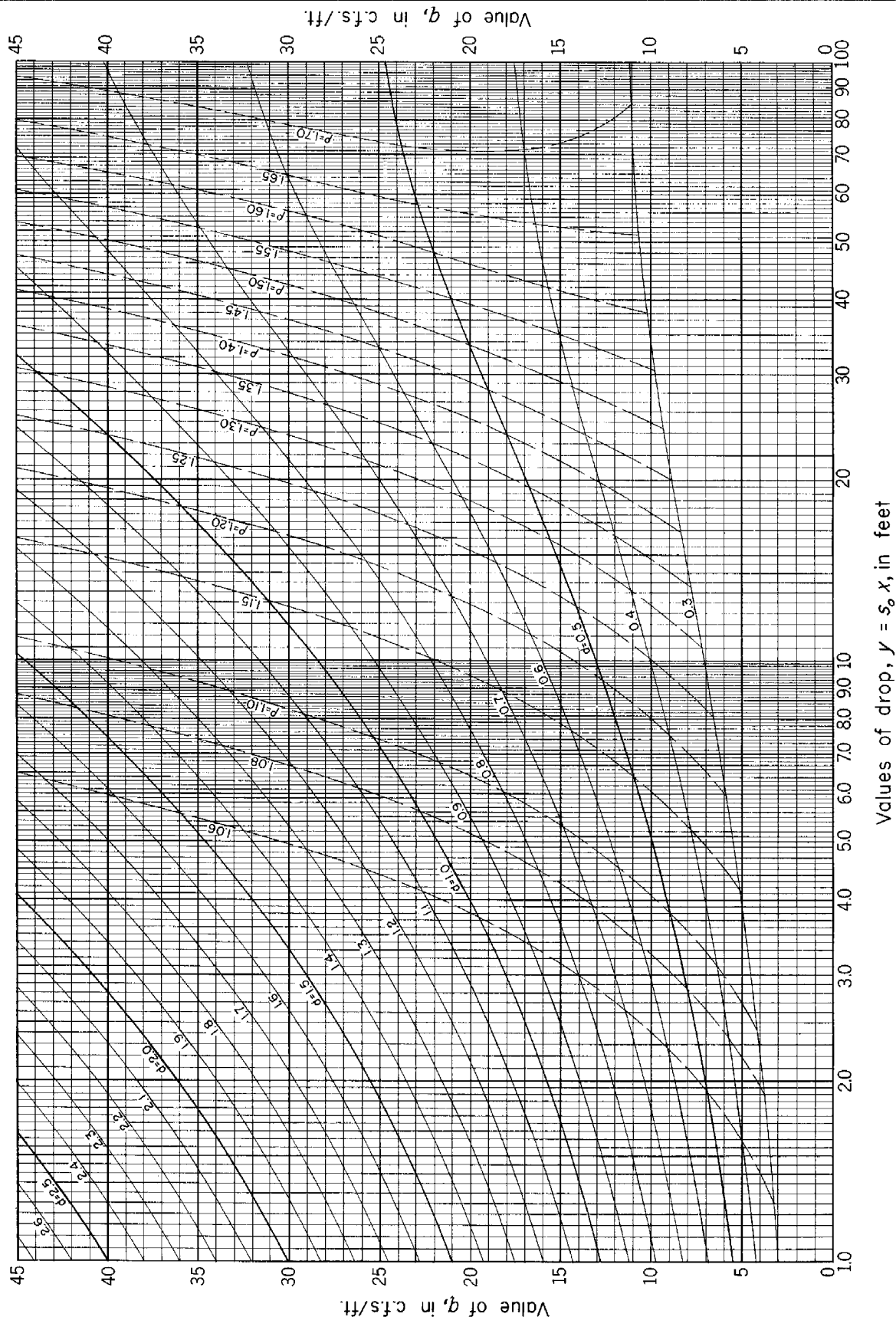
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SHEET 18 OF 35

DATE 1-14-55

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

W = 6 feet
 q = 0 to 45
 S₀ = 4 : 1



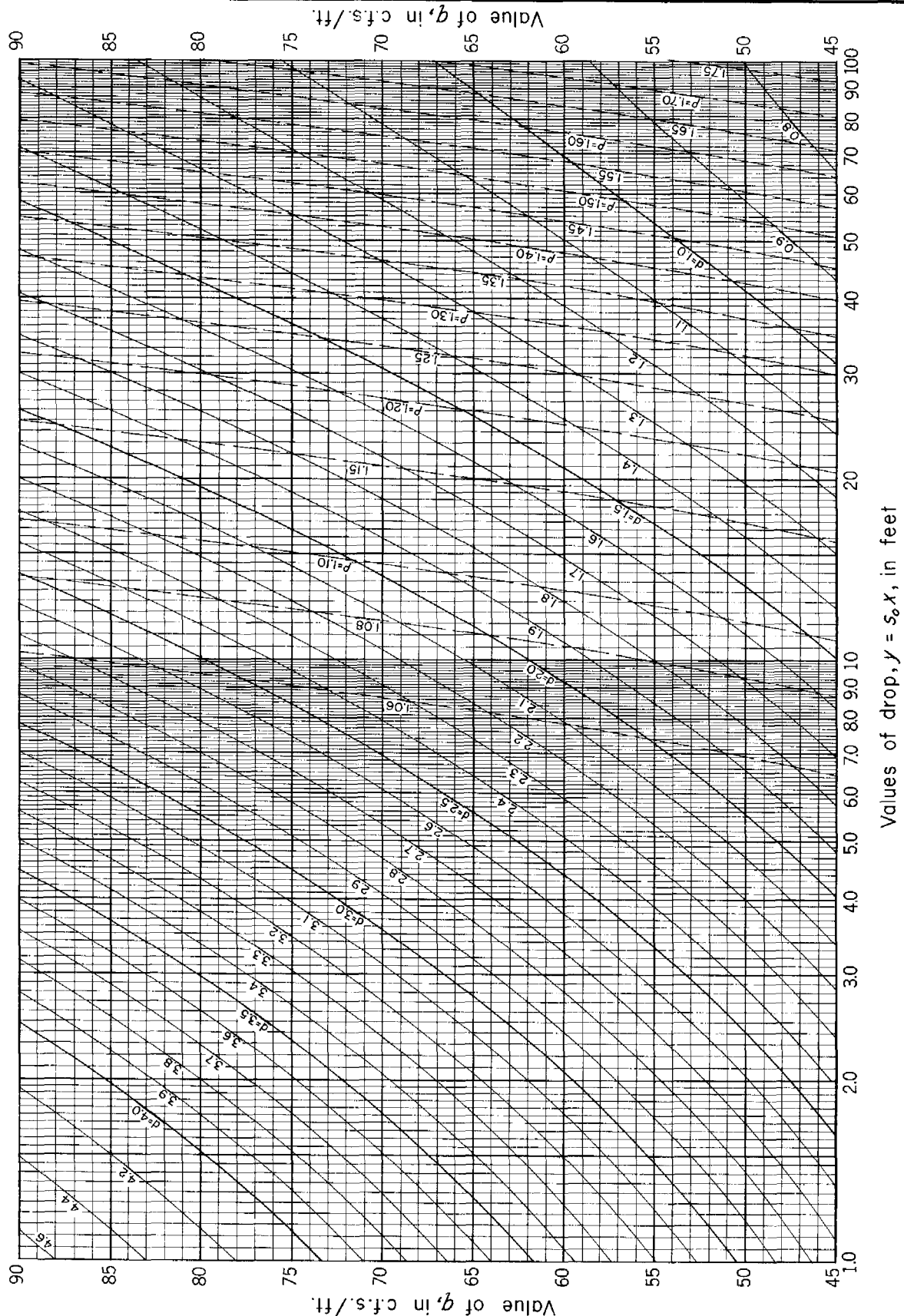
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STANDARD DWG. NO.
 ES - 78
 SHEET 19 OF 35
 DATE 1-14-58

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

W = 10 feet
Q = 45 to 90
S₀ = 4 : 1



REFERENCE

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

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STANDARD DWG. NO.

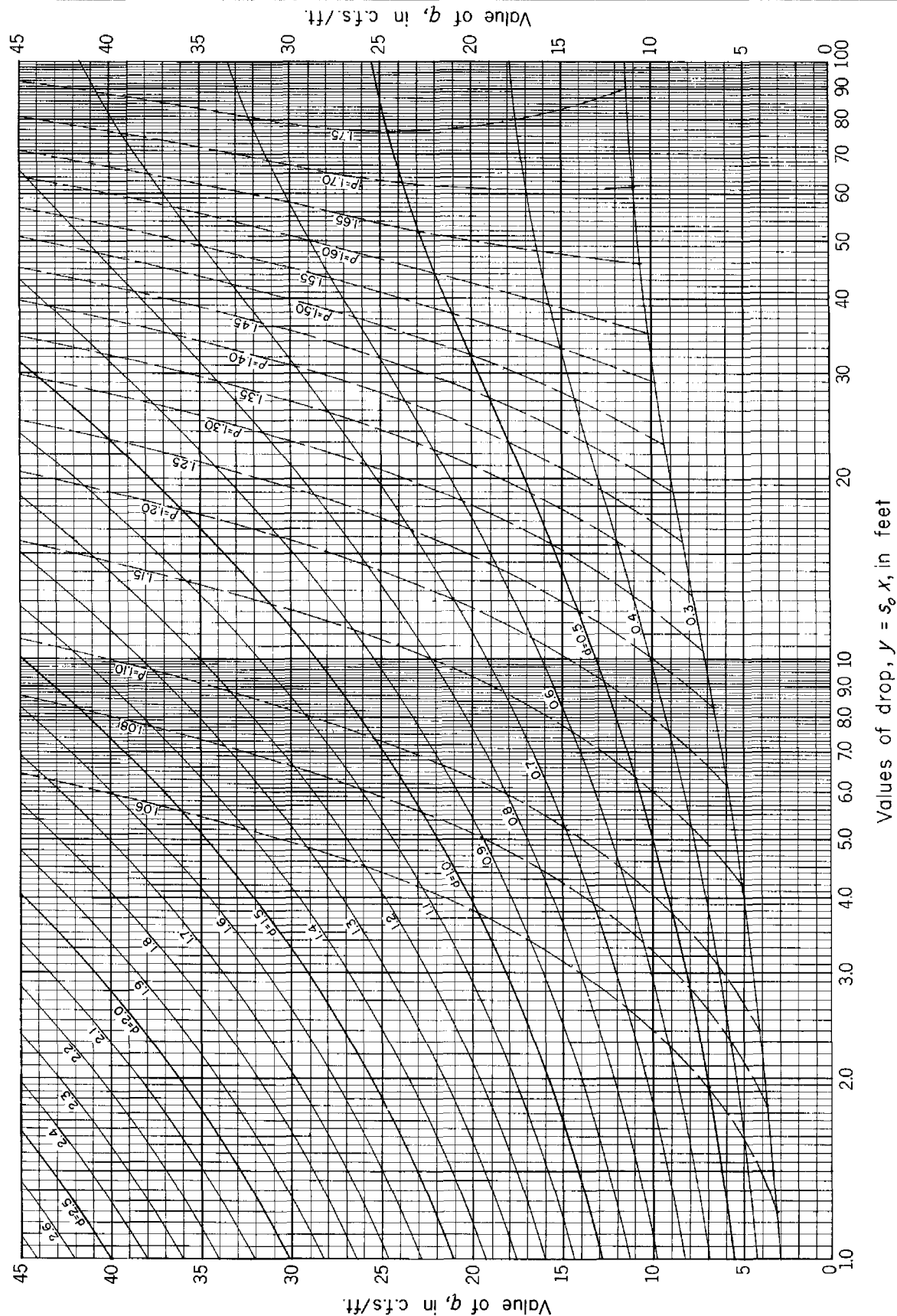
ES-78

SHEET 20 OF 35

DATE 1-14-59

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

W = 10 feet
q = 0 to 45
S₀ = 4 : 1



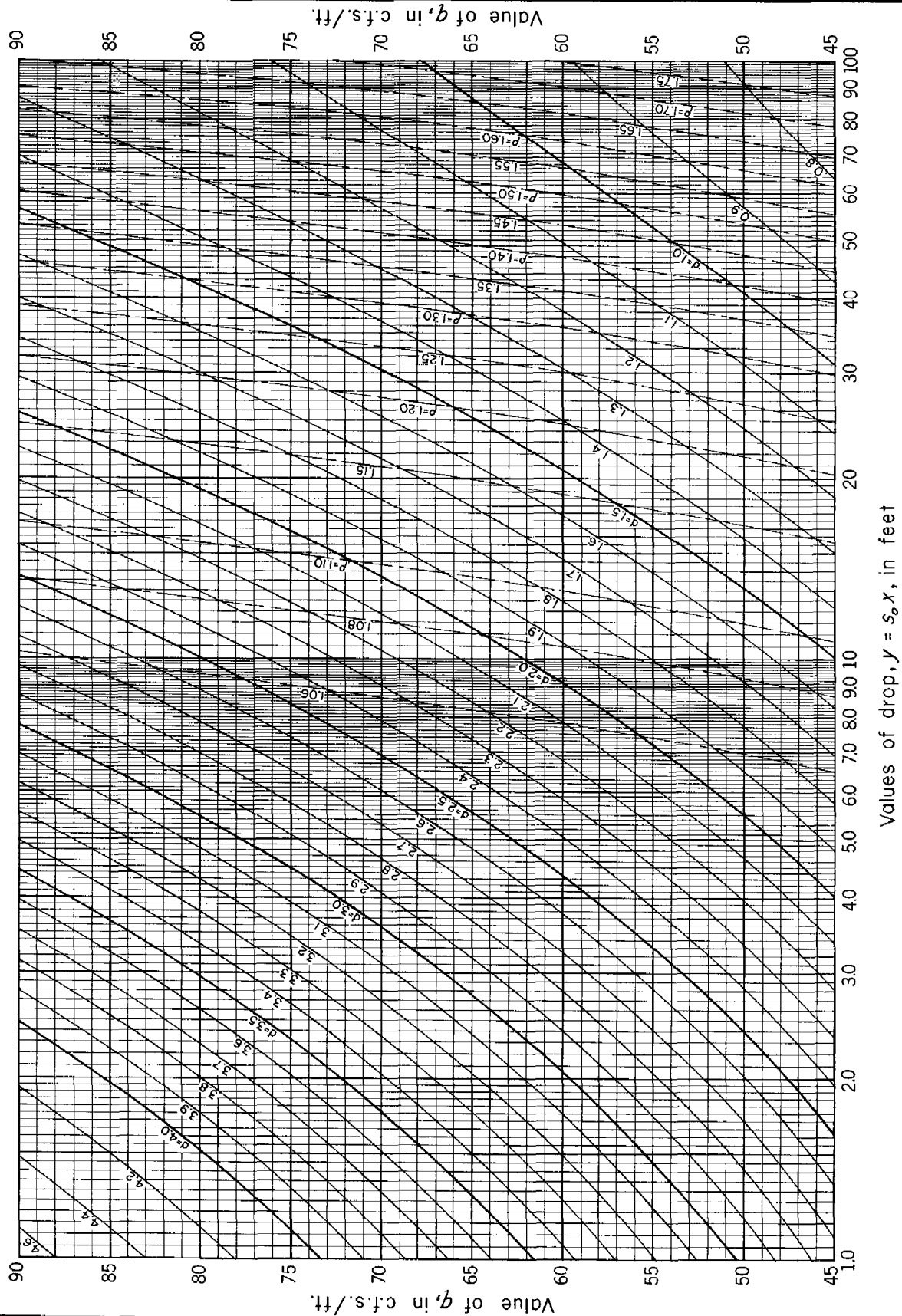
REFERENCE
This diagram was developed by Paul D. Doubt of the Design Section.

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ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.
ES - 78
SHEET 21 OF 35
DATE 1-14-56

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

W = 15 feet
q = 45 to 90
s₀ = 4 : 1



REFERENCE

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

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SOIL CONSERVATION SERVICE

ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.

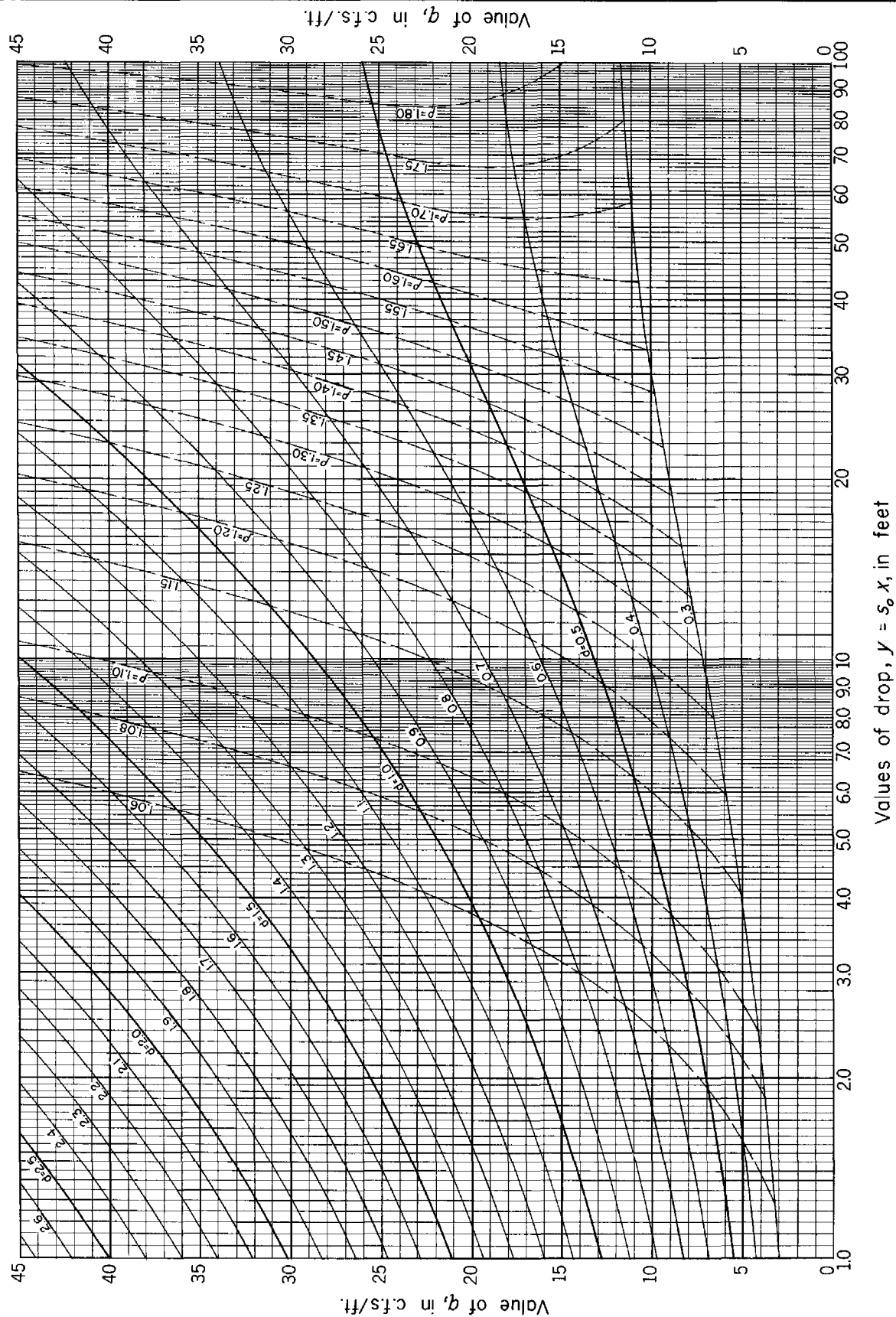
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SHEET 22 OF 35

DATE 1-14-55

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

W = 15 feet
 $q = 0$ to 45
 $S_0 = 4:1$



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.

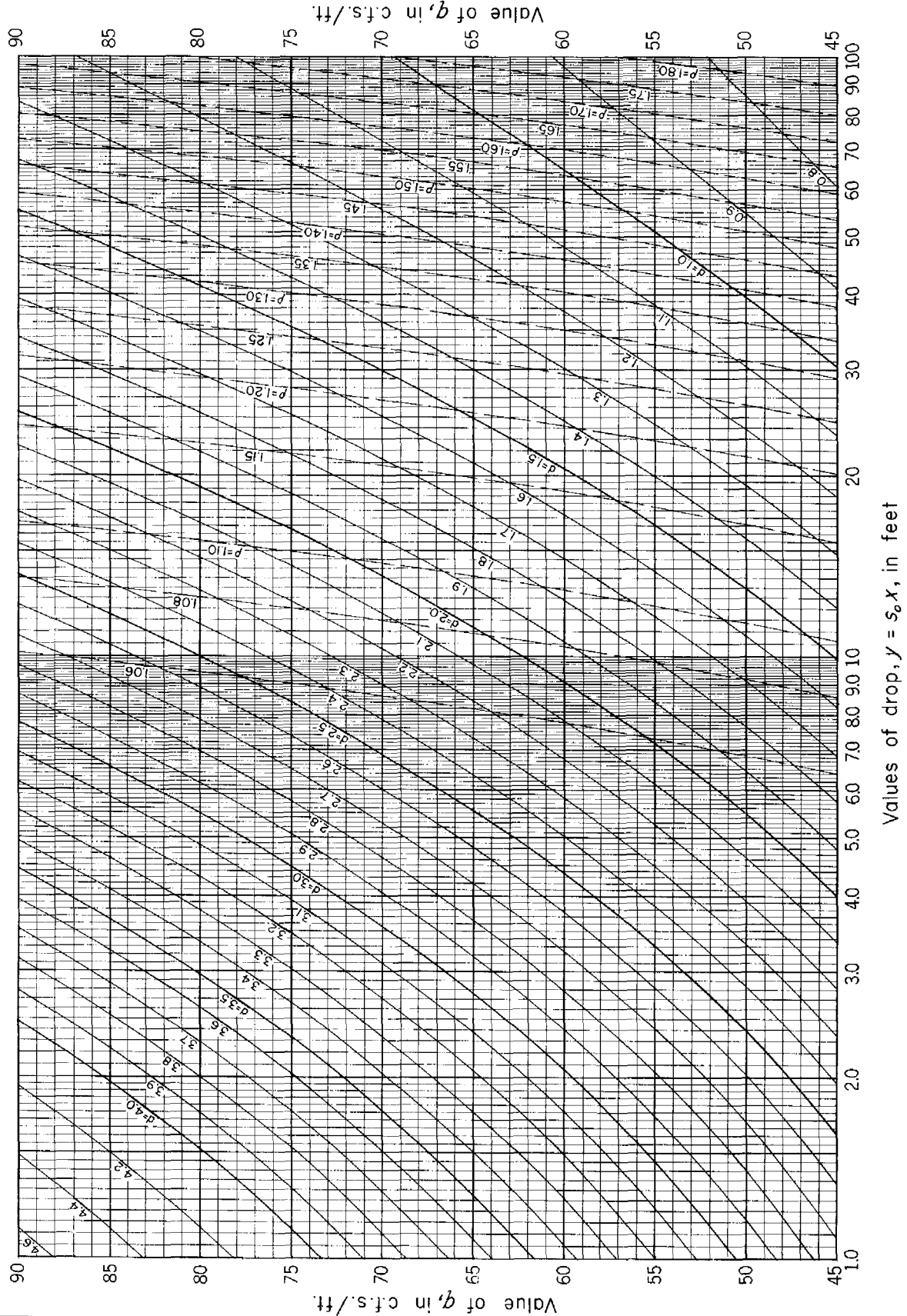
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SHEET 23 OF 35

DATE 1-14-58

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

W = 30 feet
q = 45 to 90
s₀ = 4 : 1



REFERENCE

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

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ENGINEERING DIVISION-DESIGN SECTION

STANDARD DWG. NO.

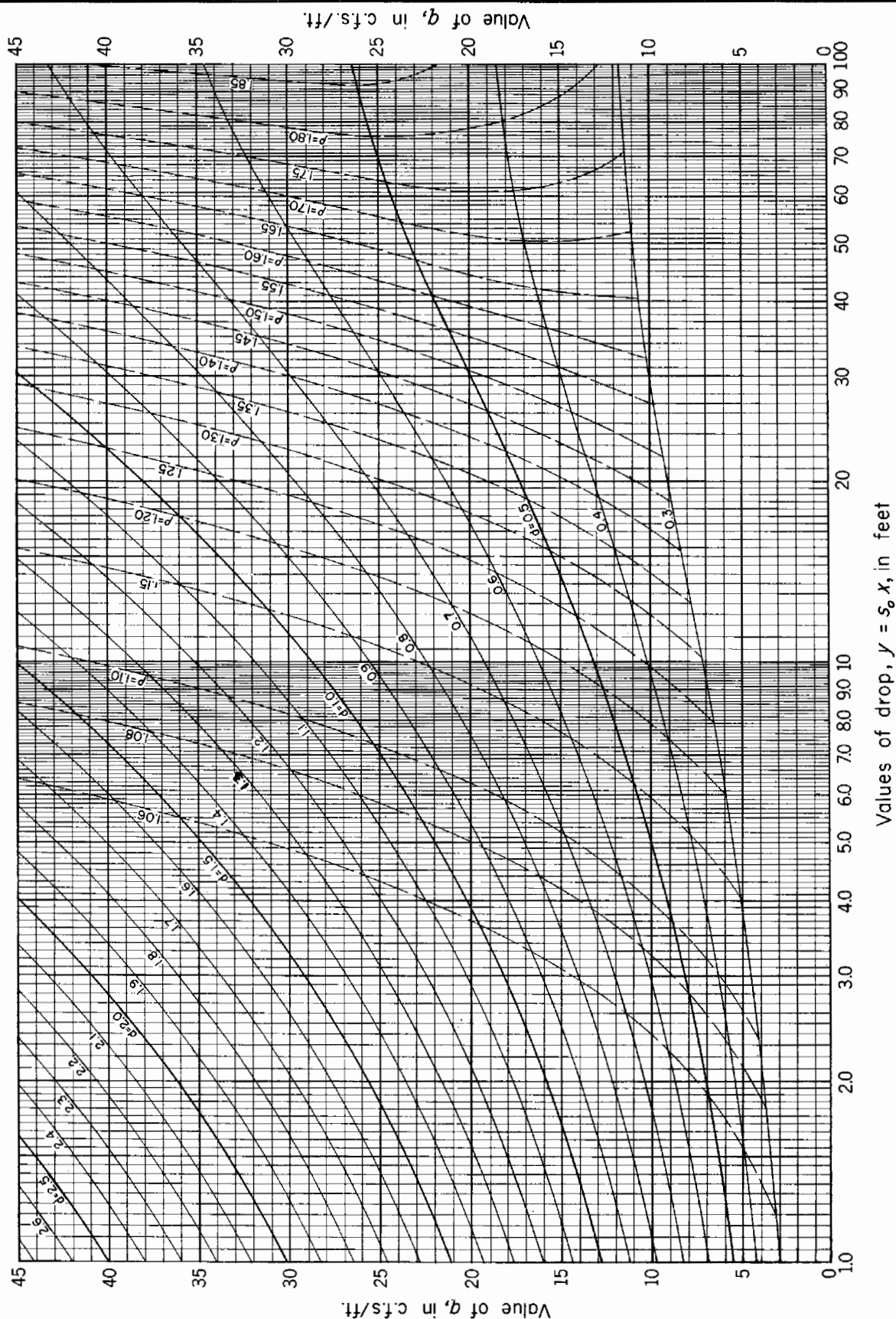
ES - 78

SHEET 24 OF 35

DATE 3-14-55

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

W = 30 feet
 q = 0 to 45
 S₀ = 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

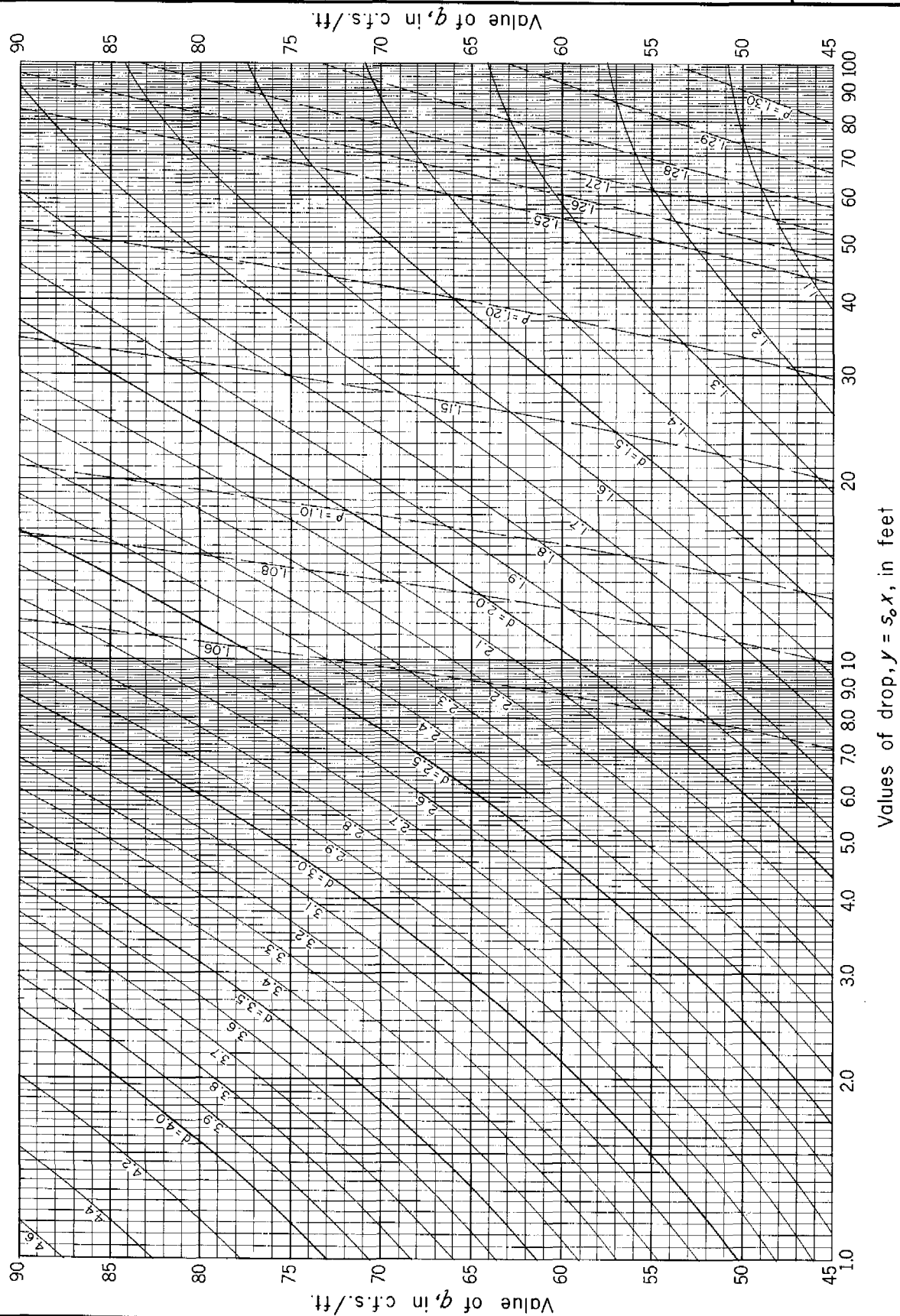
SHEET 25 OF 35

DATE 1-18-66

Revised 10/77

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

W = 4 feet
q = 45 to 90
s₀ = 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.

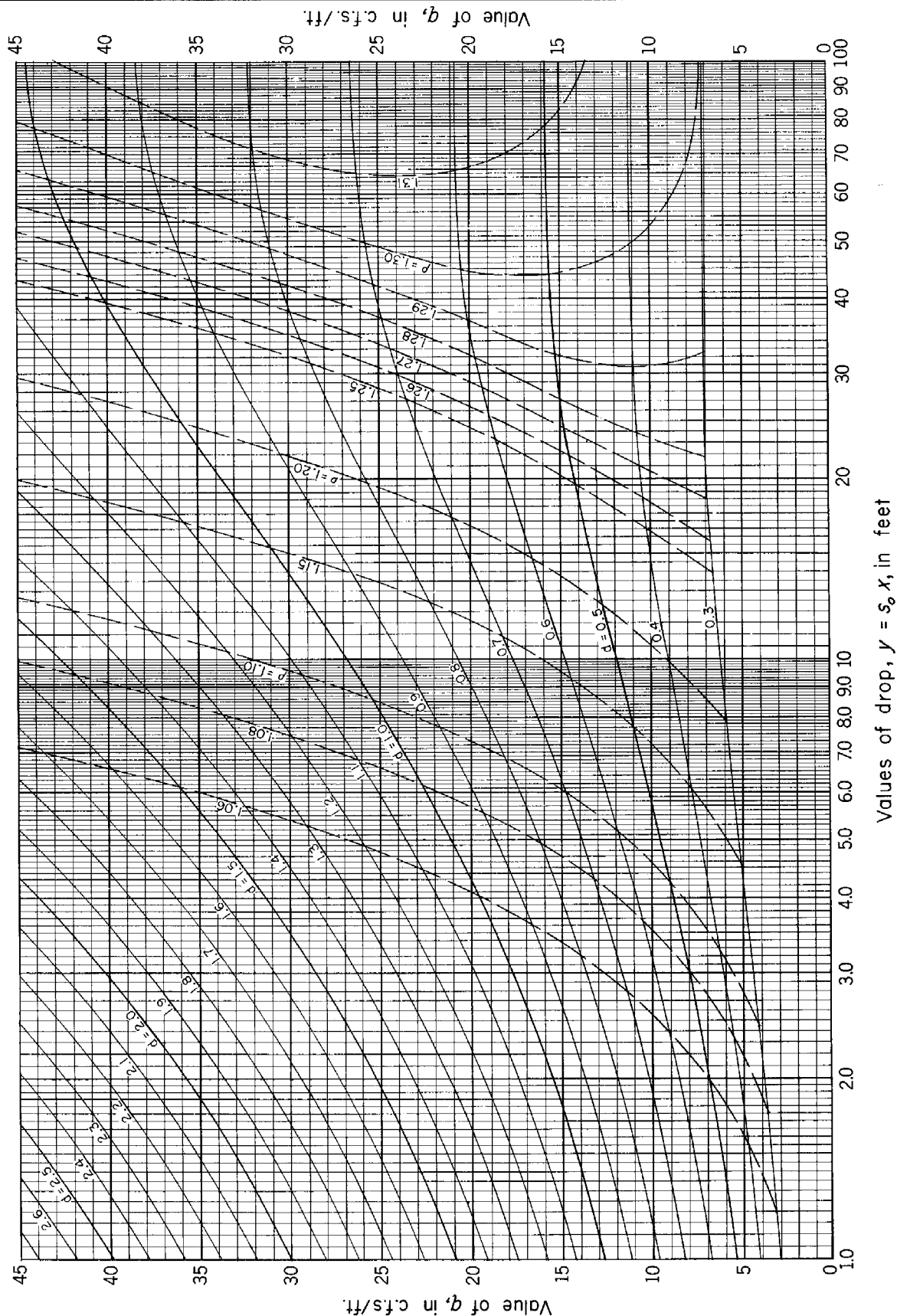
ES - 78

SHEET 26 OF 35

DATE 1-14-58

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

W = 4 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.

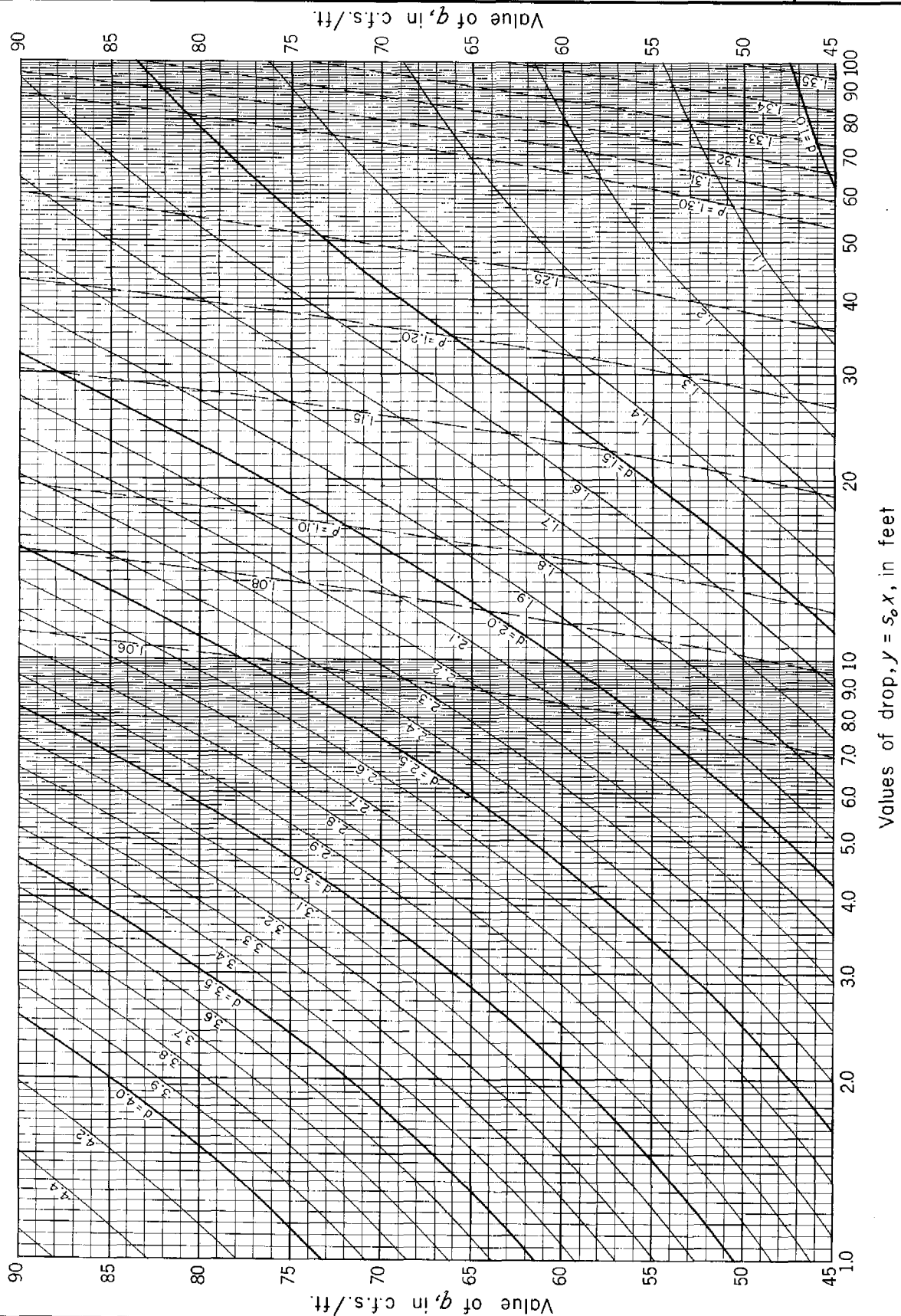
ES - 78

SHEET 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
s₀ = 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.

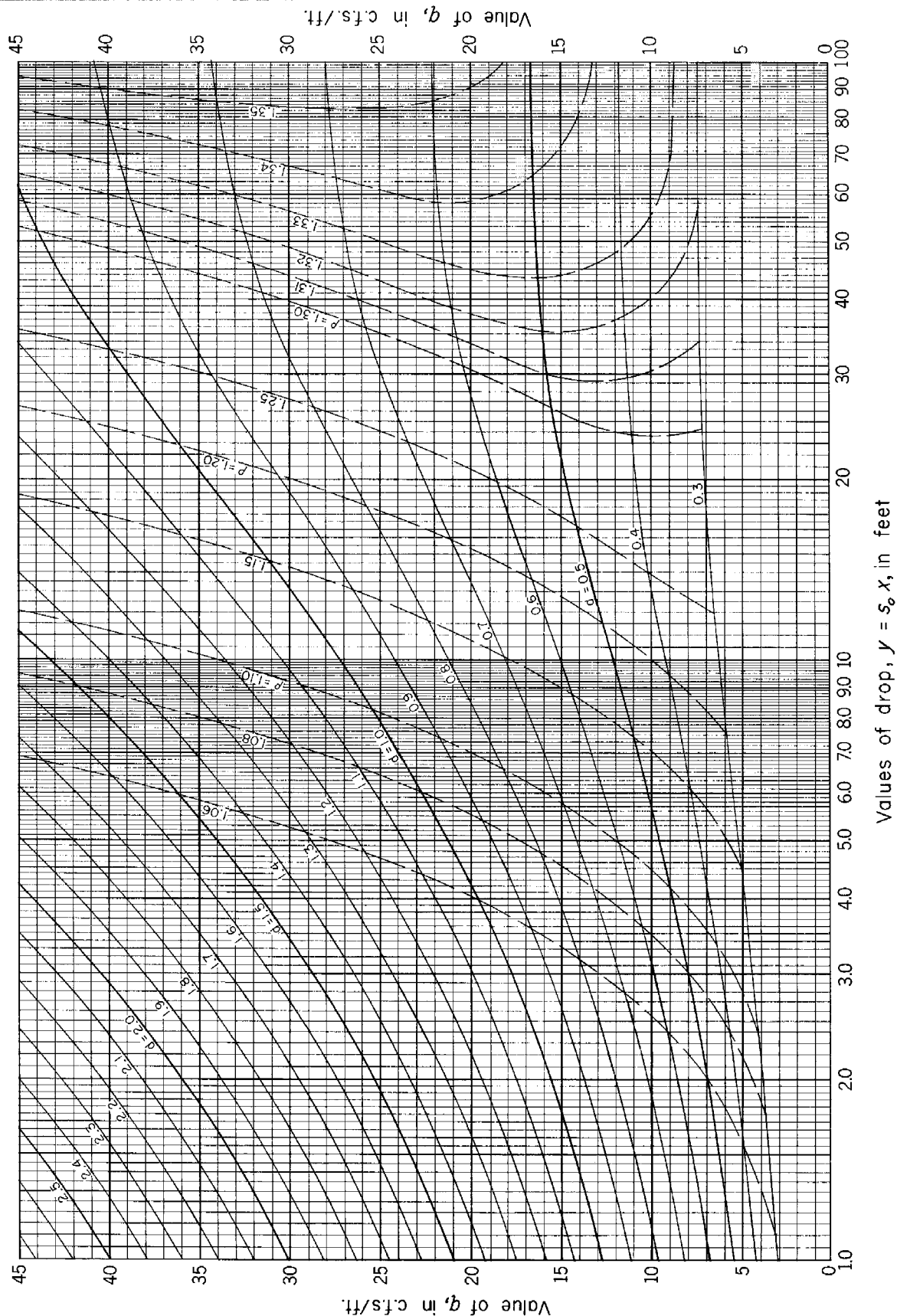
ES - 78

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
S₀ = 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.

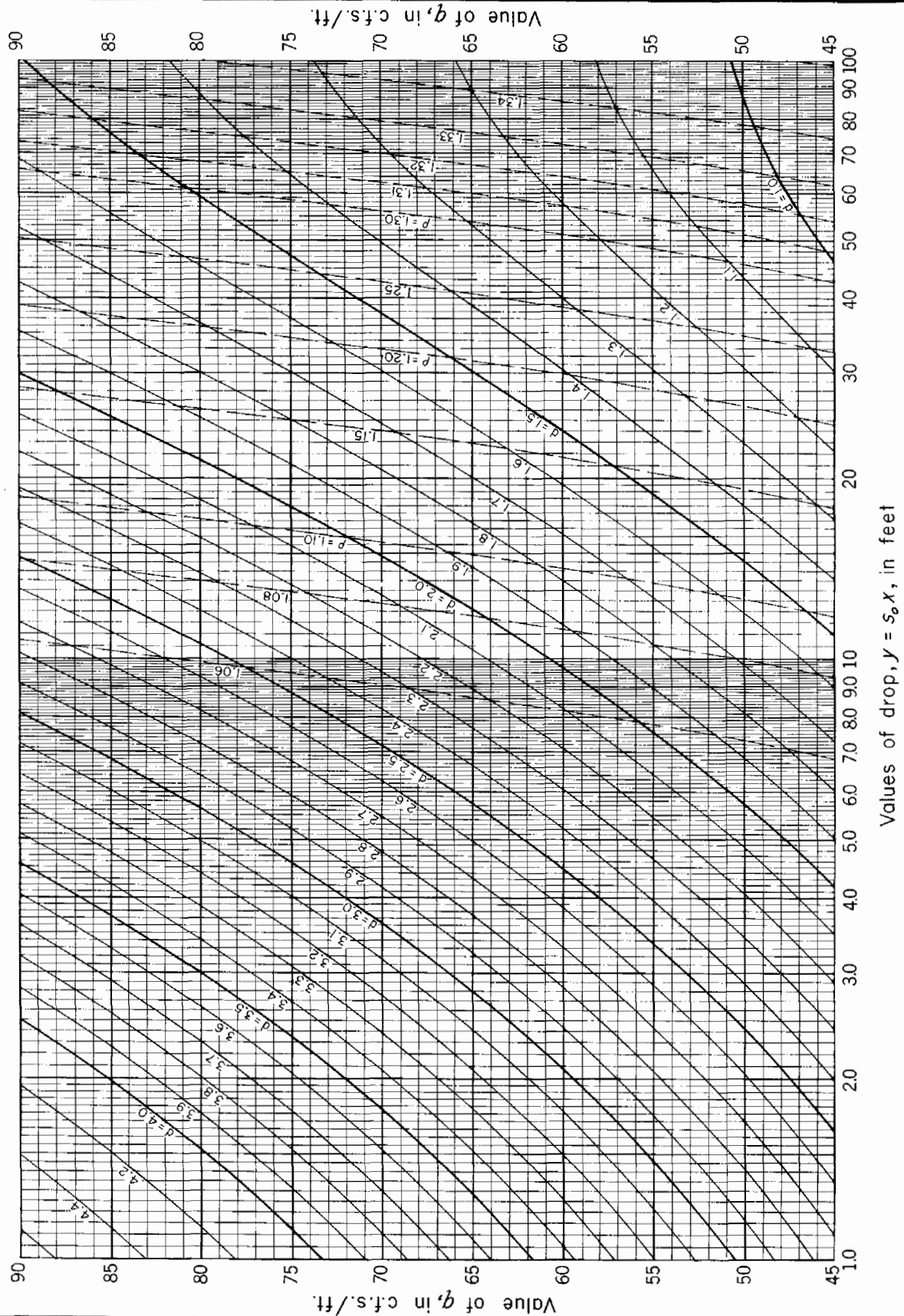
ES - 78

SHEET 29 OF 35

DATE 1-14-50

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.

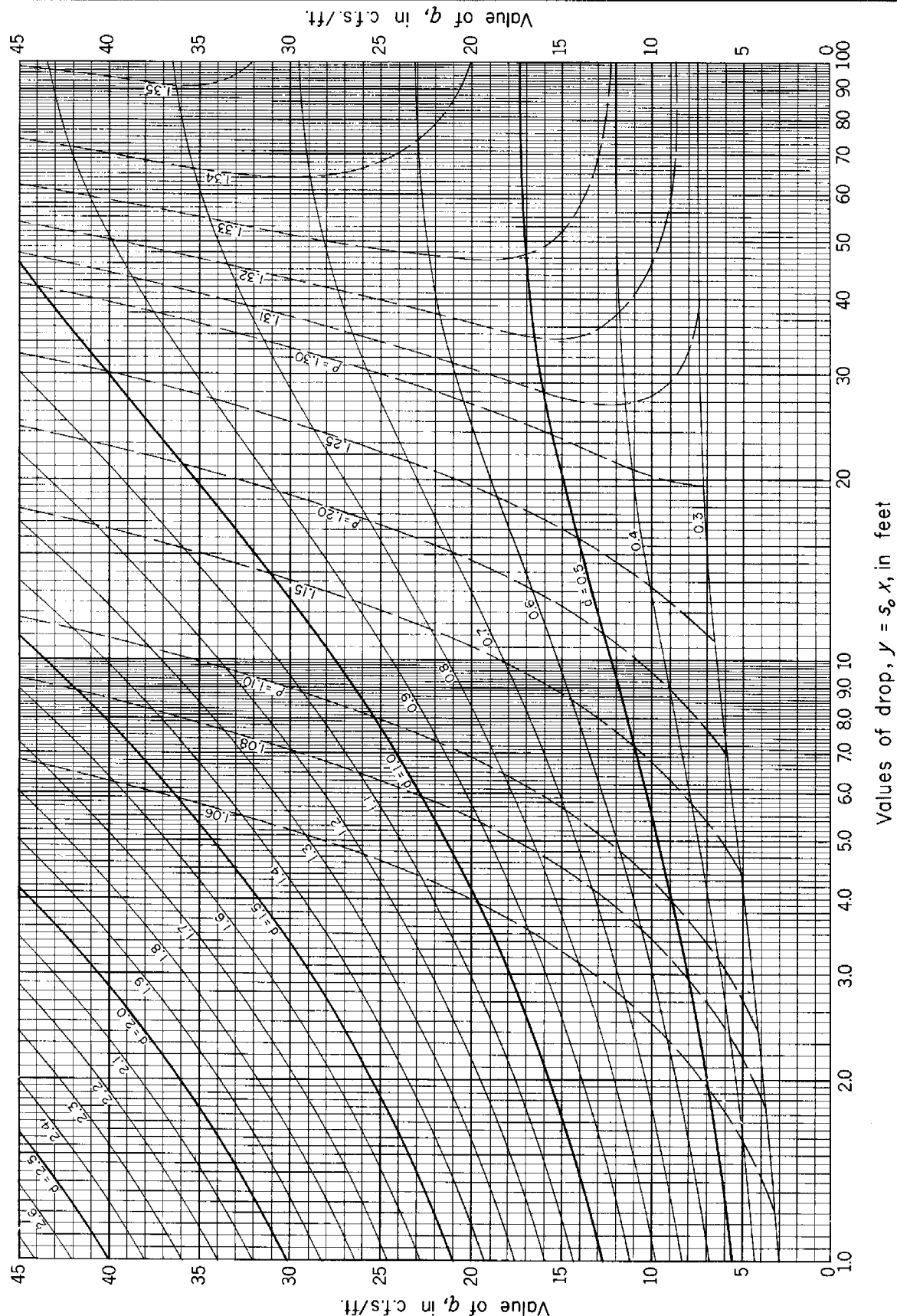
ES - 78

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
S₀ = 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.

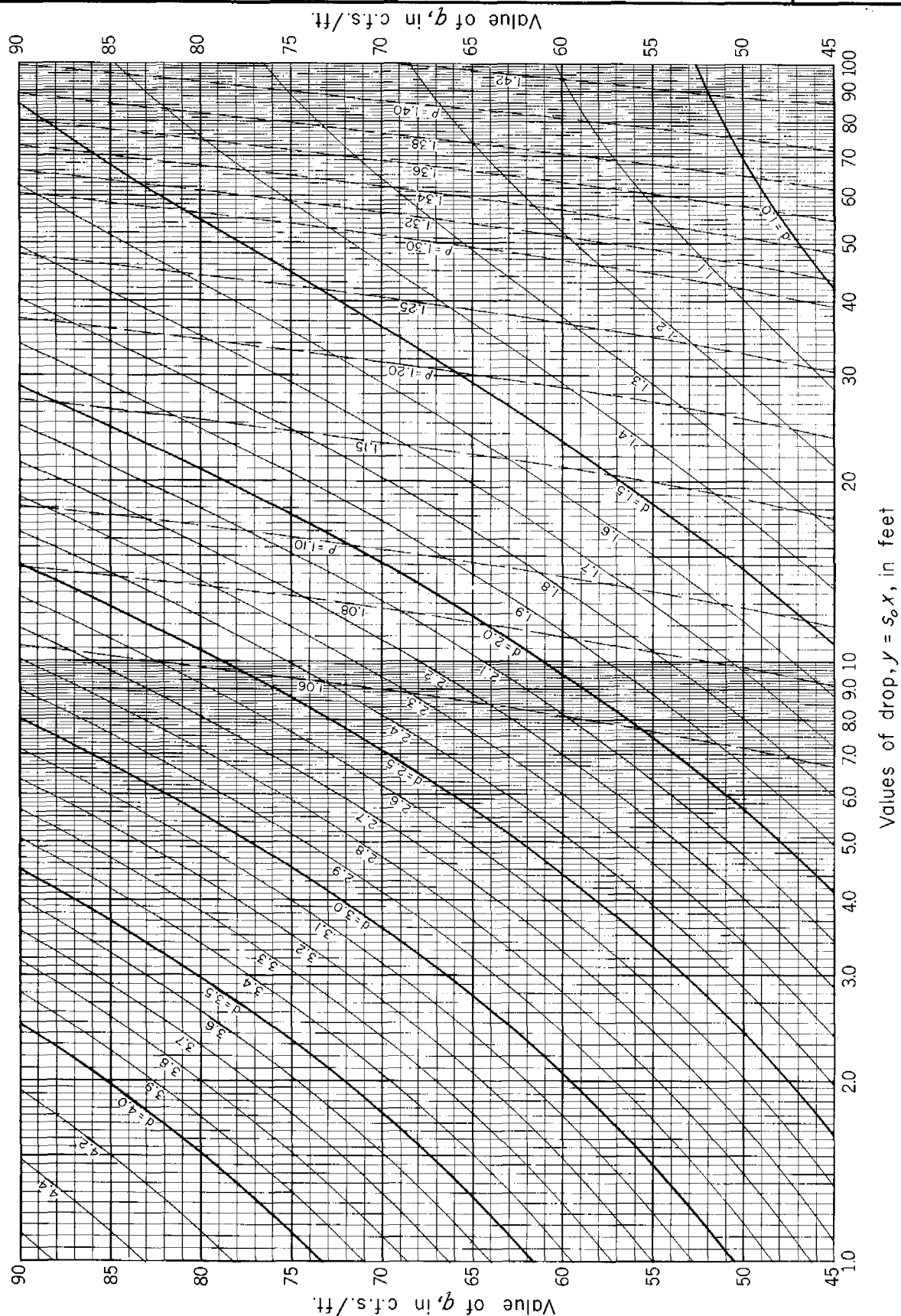
ES - 78

SHEET 31 OF 35

DATE 1-14-58

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

W = 15 feet
q = 45 to 90
s₀ = 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.

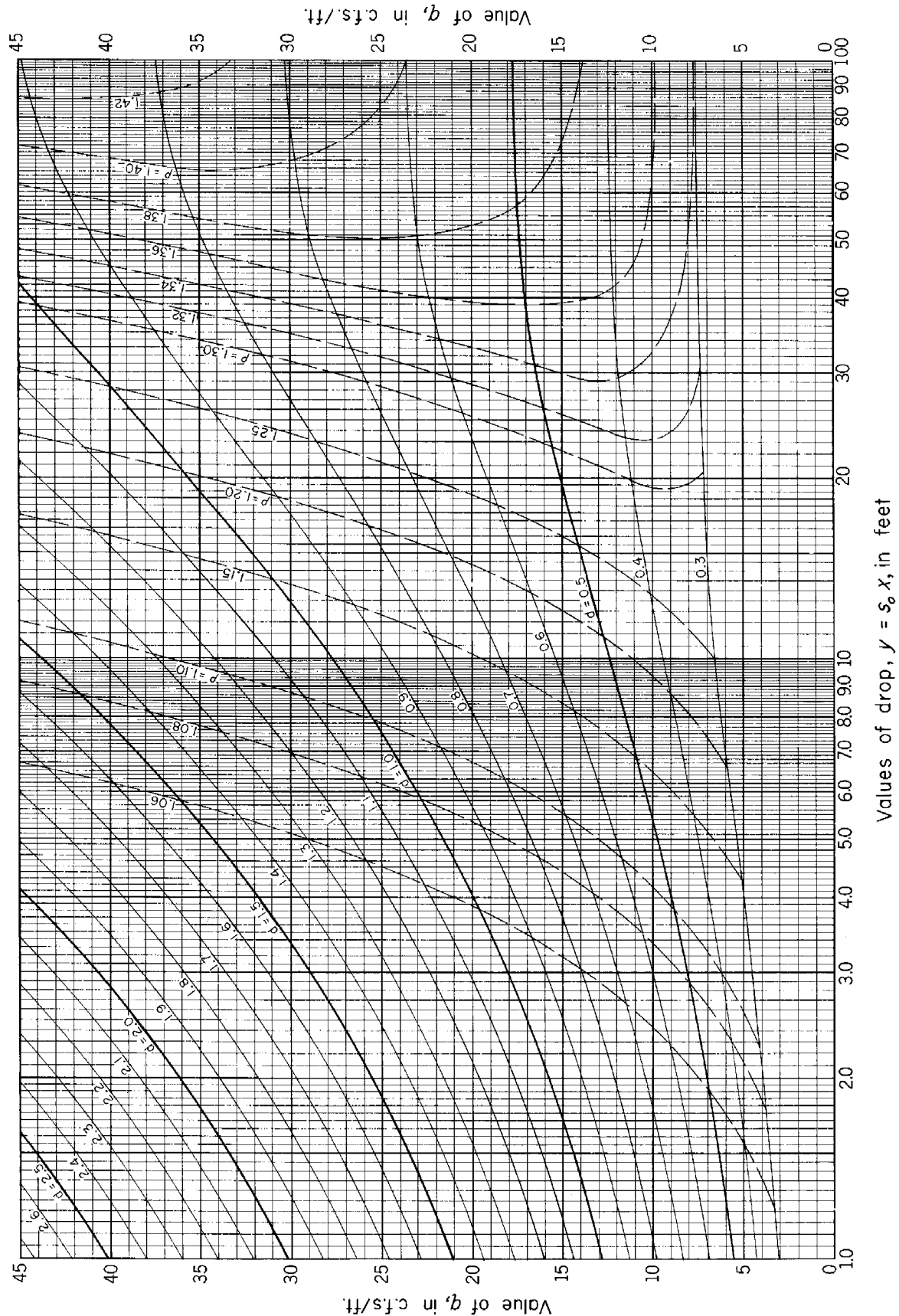
ES - 78

SHEET 32 OF 35

DATE 1-14-59

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

W = 15 feet
q = 0 to 45
S₀ = 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.

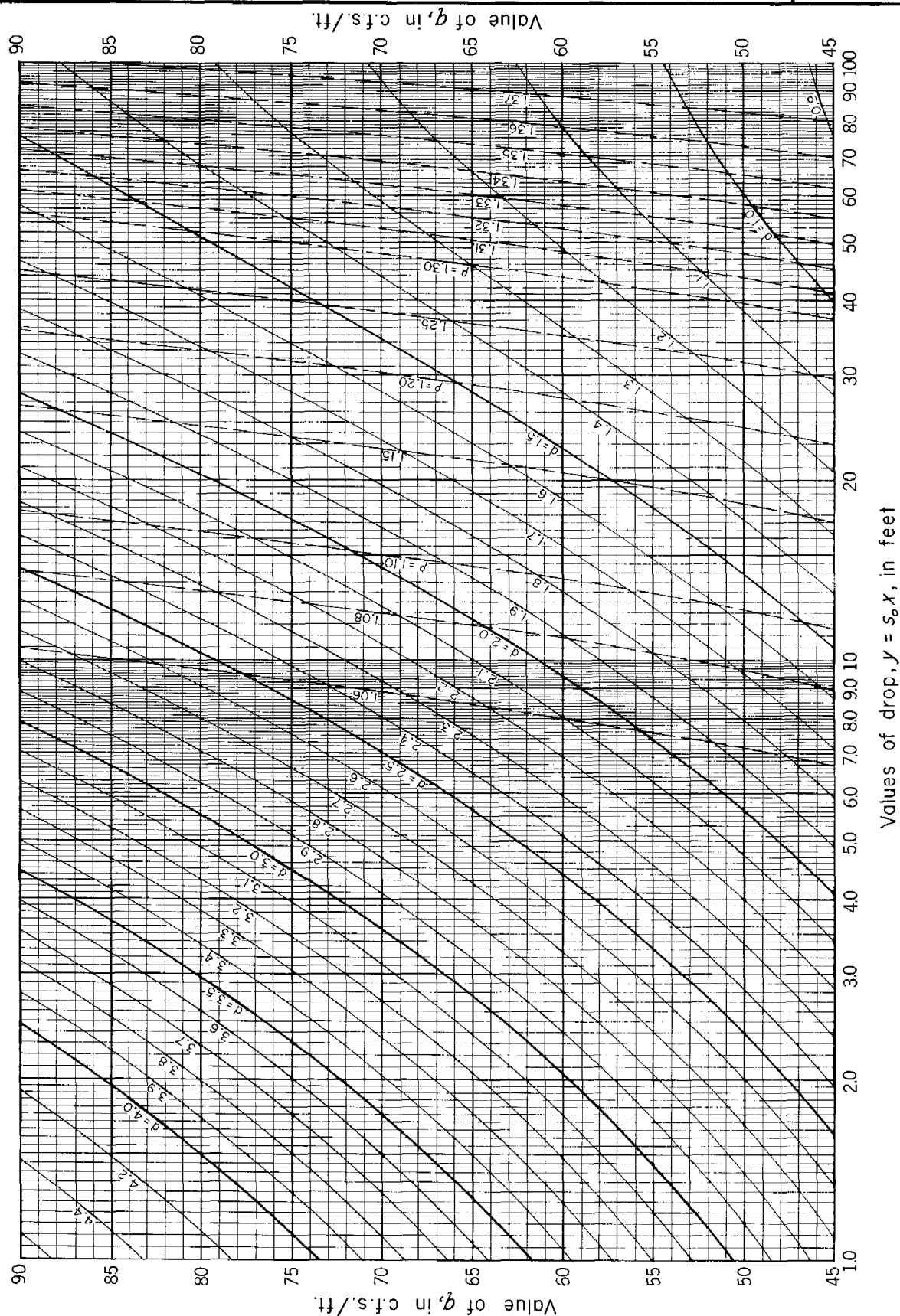
ES - 78

SHEET 33 OF 35

DATE 1-11-58

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

W = 30 feet
Q = 45 to 90
S₀ = 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.

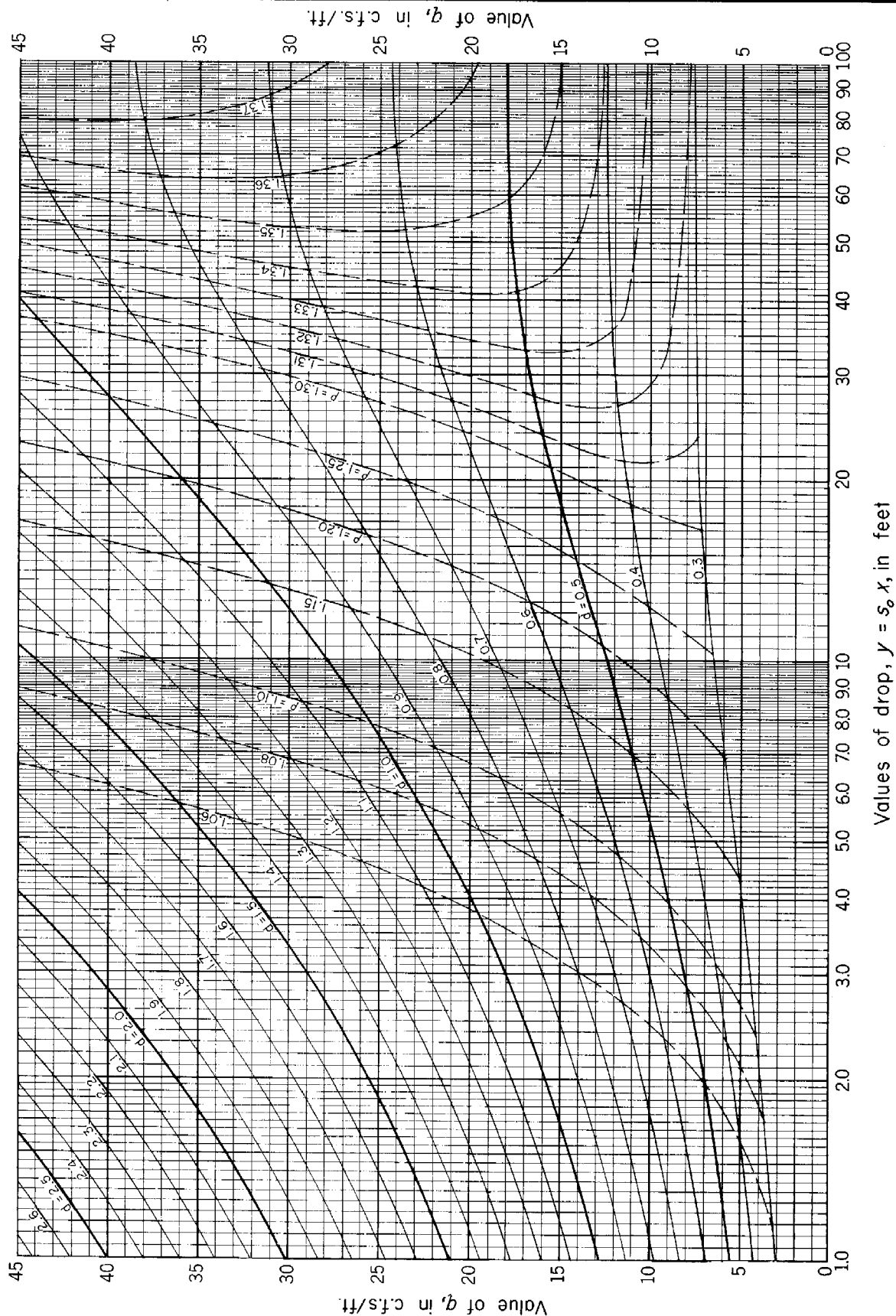
ES - 78

SHEET 34 OF 35

DATE 1-14-58

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.

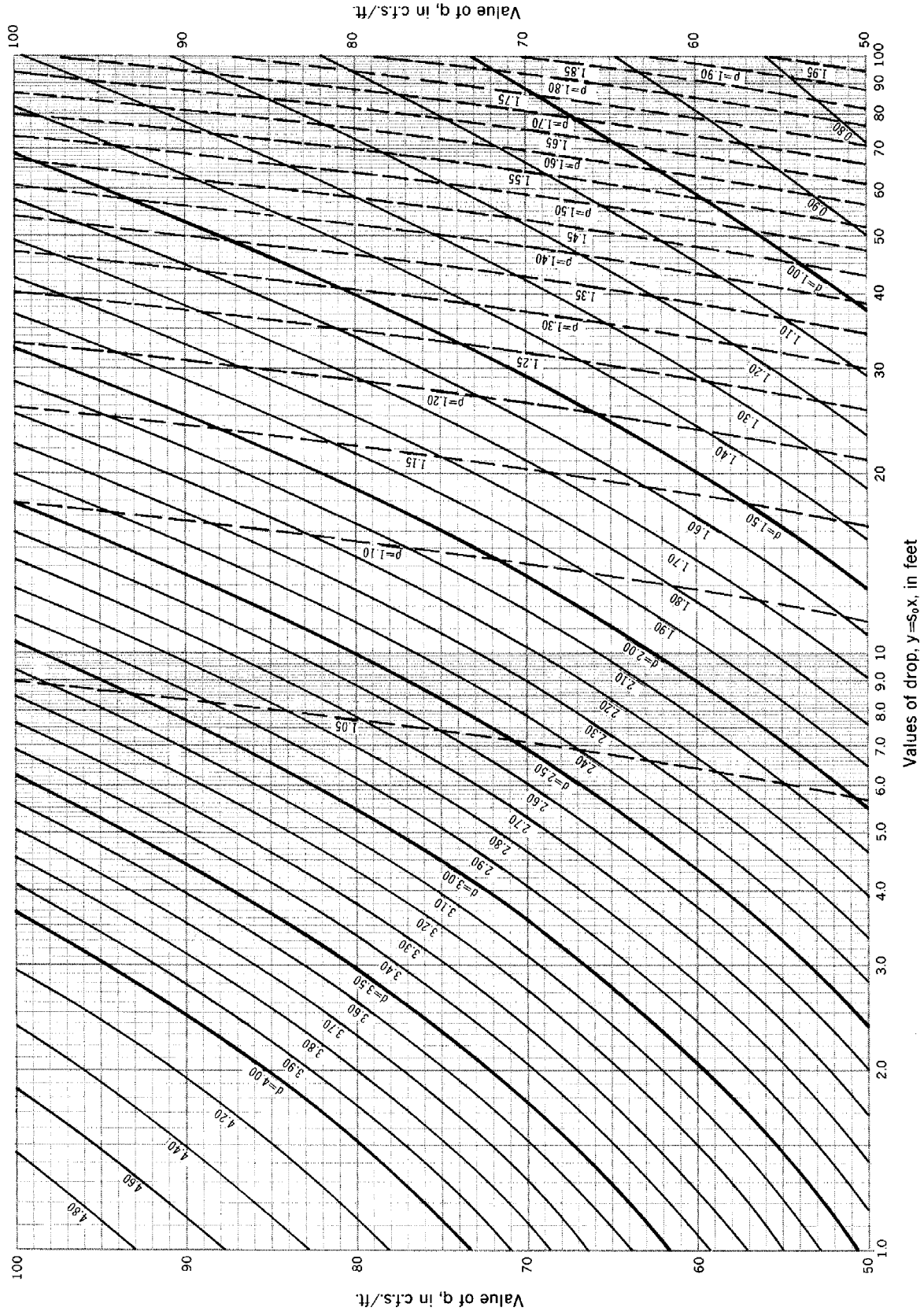
ES - 78

SHEET 35 OF 35

DATE 1-14-56

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

W=100 feet
q=50 to 100
s₀=3:1



REFERENCE

ES-78

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

STANDARD DWG. NO.

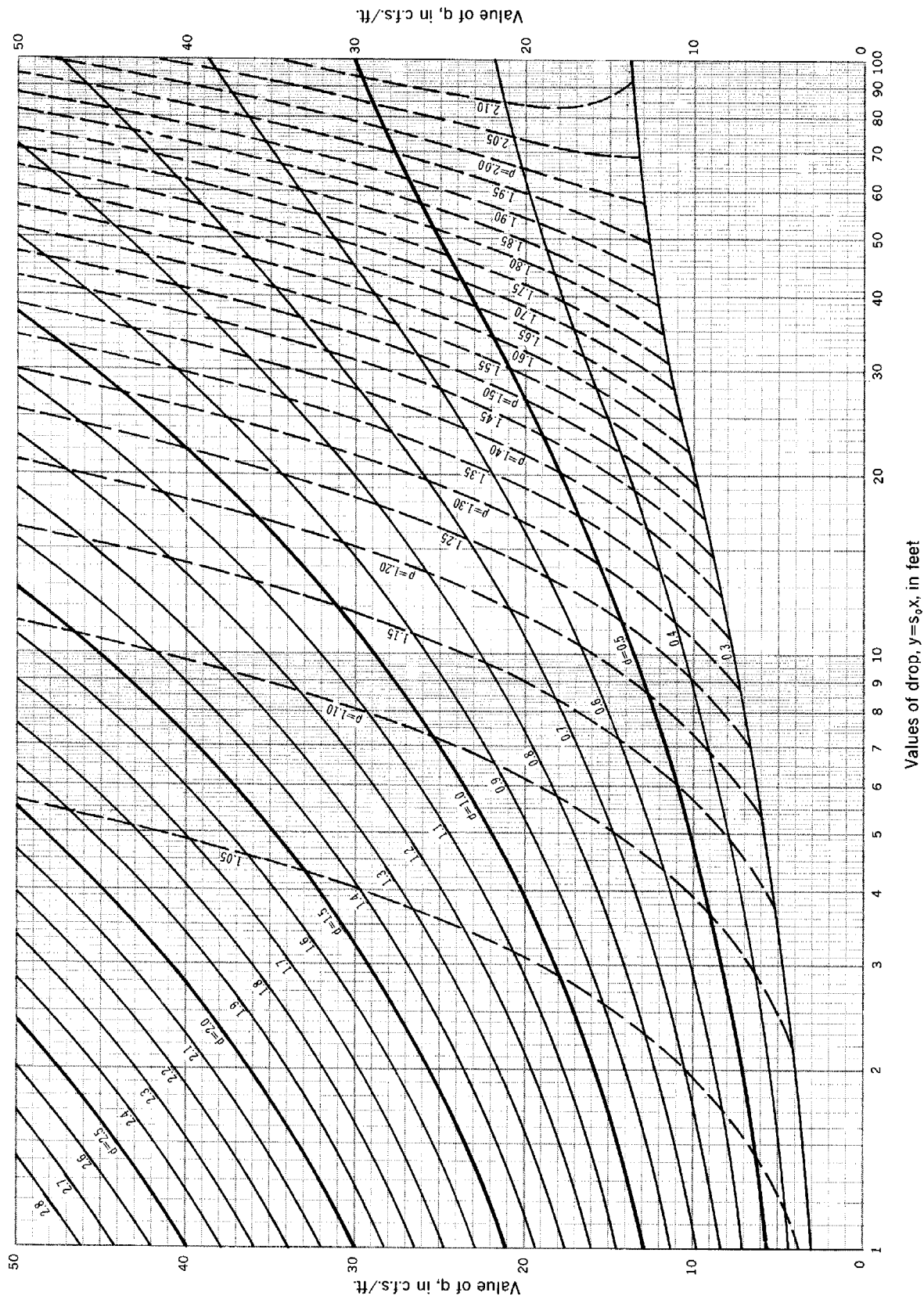
ES-147

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_o=3:1



REFERENCE

ES-78

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

STANDARD DWG. NO.

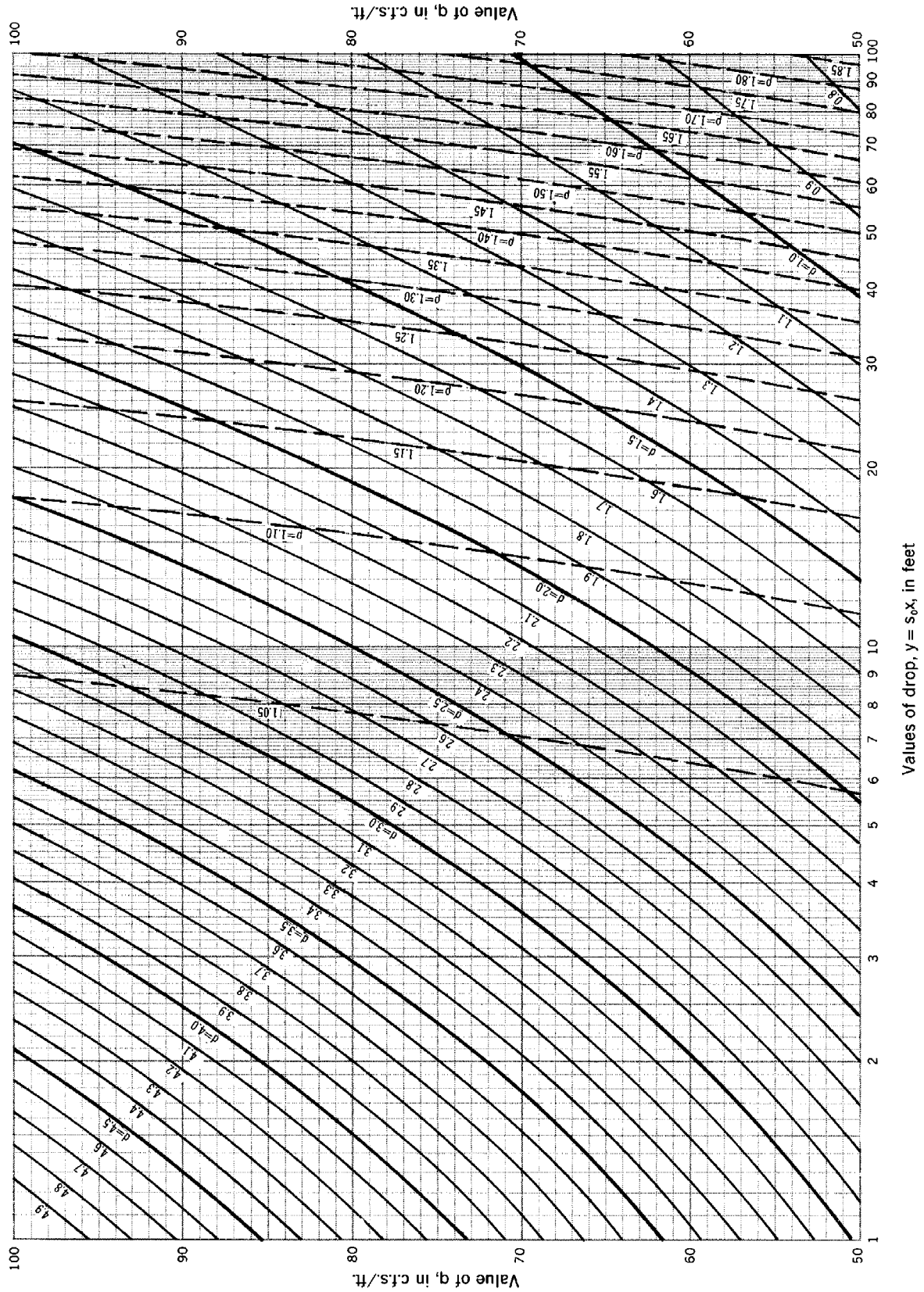
ES-147

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_b=4:1



REFERENCE
ES-78

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

STANDARD DWG. NO.

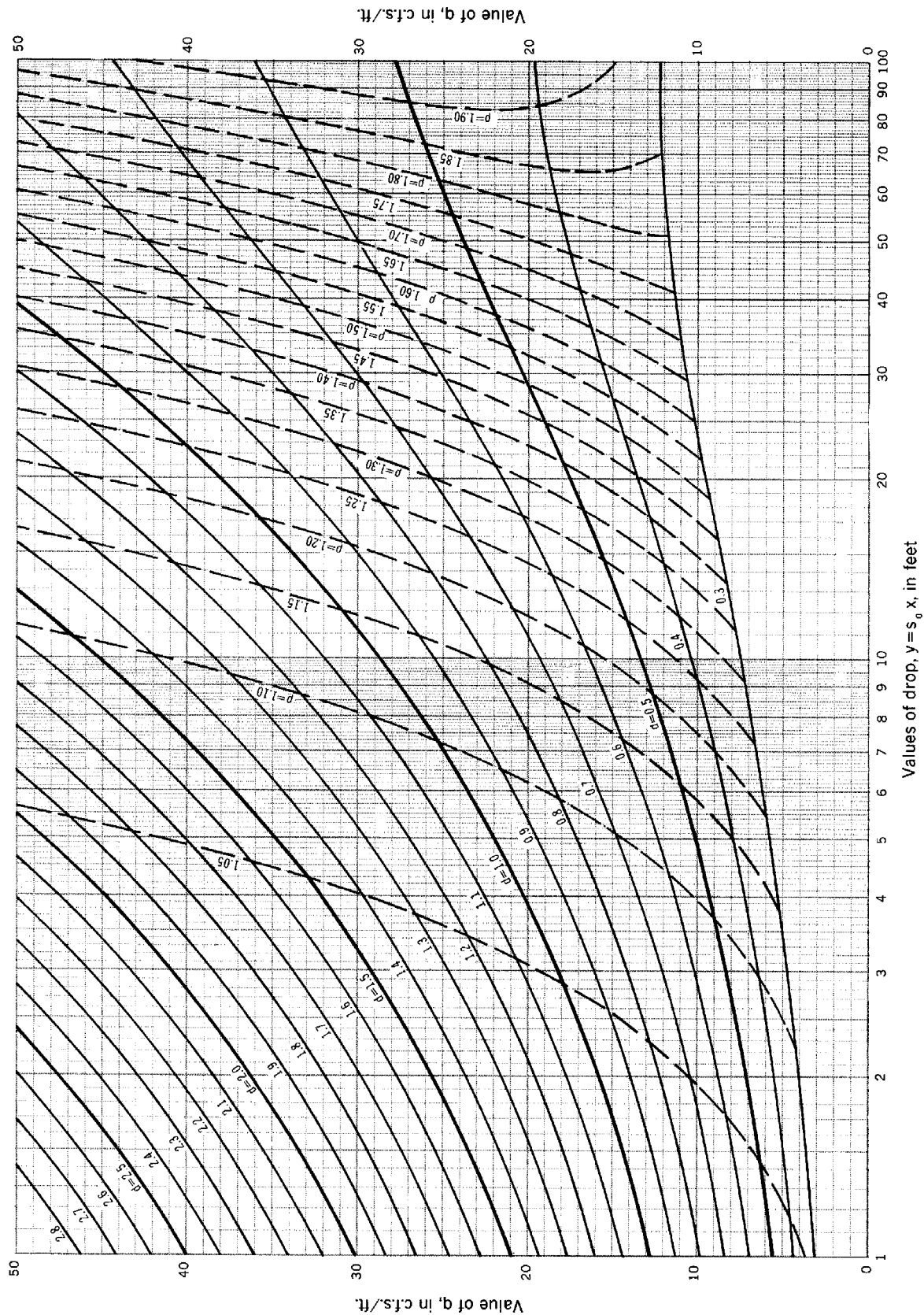
ES-147

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
s₀=4:1



REFERENCE

ES-78

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

STANDARD DWG. NO.

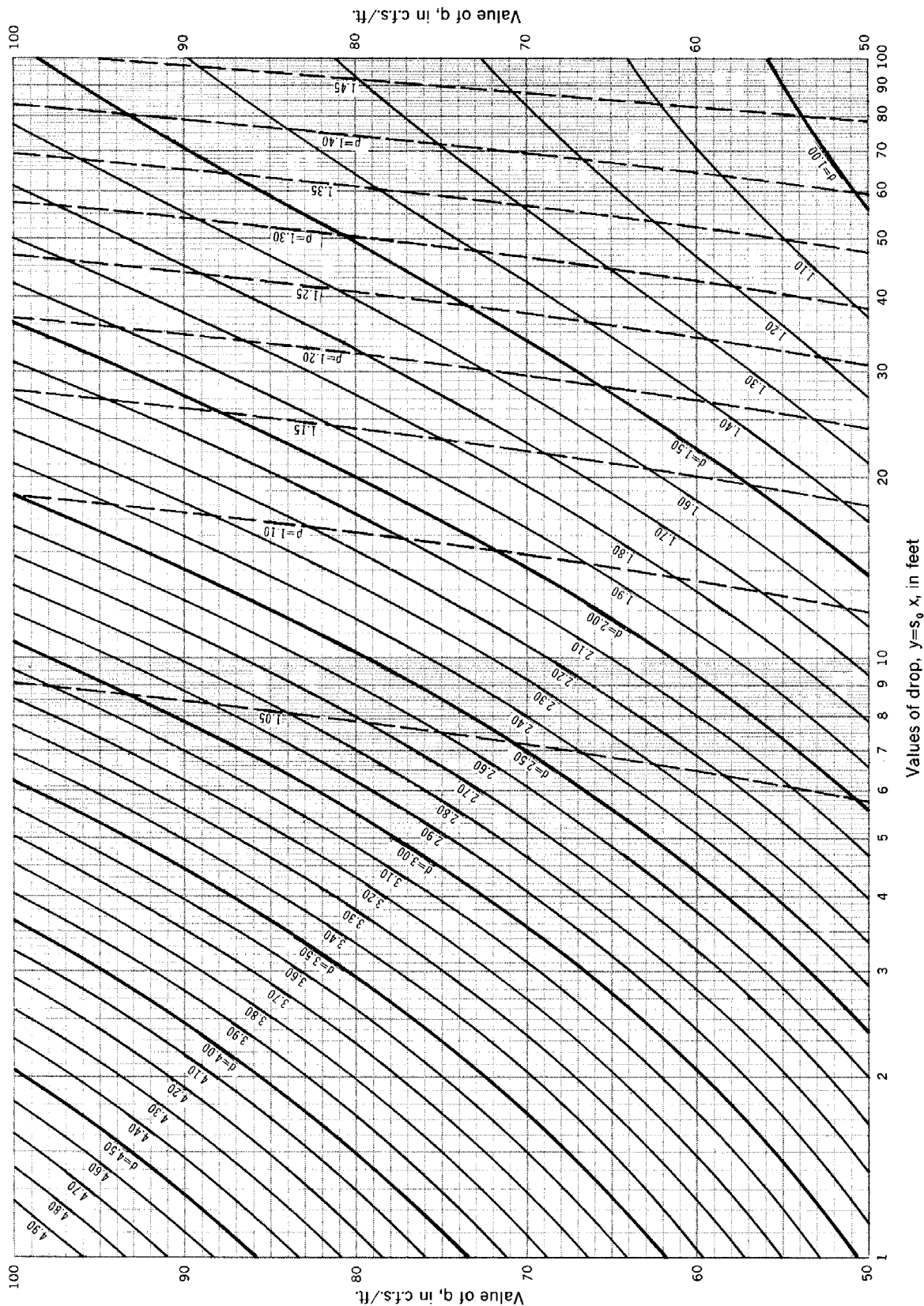
ES-147

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_b=10:1



REFERENCE

ES-78

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

STANDARD DWG. NO.

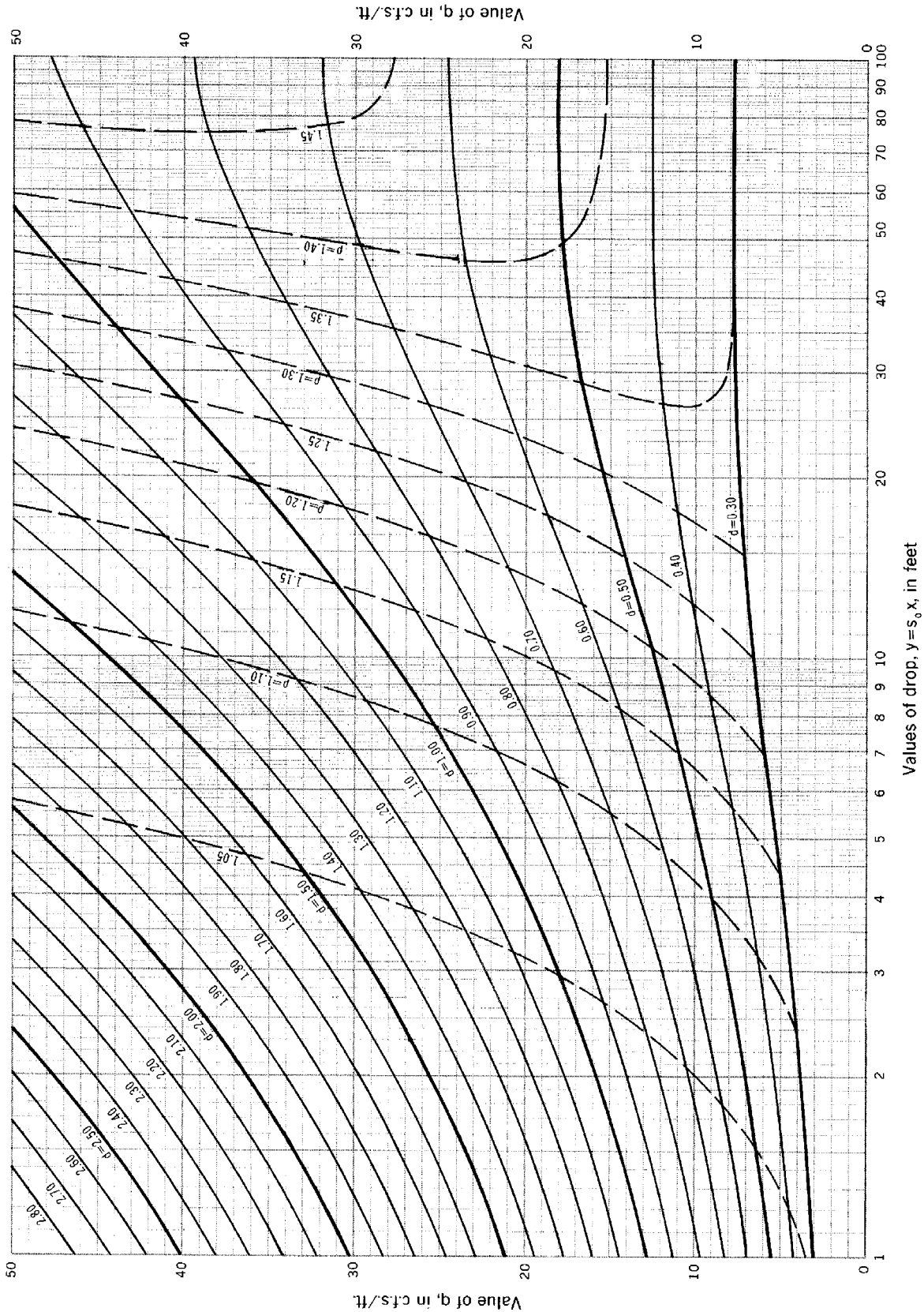
ES-147

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
s₀=10:1



REFERENCE

ES-78

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

STANDARD DWG. NO.

ES-147

SHEET 6 OF 6

DATE 1-8-76

The image contains three technical drawings of a ramped floor system:

- RIGHT AUXILIARY:** A perspective view of the ramped floor system. It shows a rectangular floor slab labeled "FLOOR" with a width dimension "W". The ramped side walls are shown with a thickness dimension of $1-0\frac{1}{4}$ and a height dimension of $1-0\frac{1}{4}$. An "ALTERNATE JOINT DETAIL" is shown at the bottom left.
- SECTION ALONG CENTER LINE:** A cross-sectional view of the ramped floor system. It shows the "SIDE WALLS" and the "FLOOR" slab. The side walls have a thickness dimension of $1-0\frac{1}{4}$ and a height dimension of $1-0\frac{1}{4}$. The floor slab has a thickness dimension of $1-0\frac{1}{4}$. The ramp angle is labeled θ and the slope is indicated as $\frac{1}{3}$. The total height of the side wall is labeled "F". The width of the floor slab is labeled "N". An "ALTERNATE JOINT DETAIL" is shown at the bottom left.
- ISOMETRIC VIEW:** A three-dimensional perspective view of the ramped floor system. It shows the "FLOOR" slab and the "SIDE WALLS". The side walls have a thickness dimension of $1-0\frac{1}{4}$ and a height dimension of $1-0\frac{1}{4}$. The floor slab has a thickness dimension of $1-0\frac{1}{4}$. The ramp angle is labeled θ and the slope is indicated as $\frac{1}{3}$. An "ALTERNATE JOINT DETAIL" is shown at the bottom left.

Numerical values shown are suggested minimums.

Numerical values shown
are suggested minimums.

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}	$N \cos \theta^\dagger$
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 $\bar{z} = 8$ ft. For other values of $\bar{z}$ see table 2, ES-88.

†Values are for channels of $\bar{z}$ to 1 slope.

DEFINITION OF SYMBOLS

- N = Height normal to slope s_o of side-wall 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
 $\bar{z}$ = Vertical drop of vertical curve section in ft
 W = Width of vertical curve section in ft
 n = Number of channel sections required
 $\theta = \tan^{-1} s_o$
 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

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

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

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

REFERENCE

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

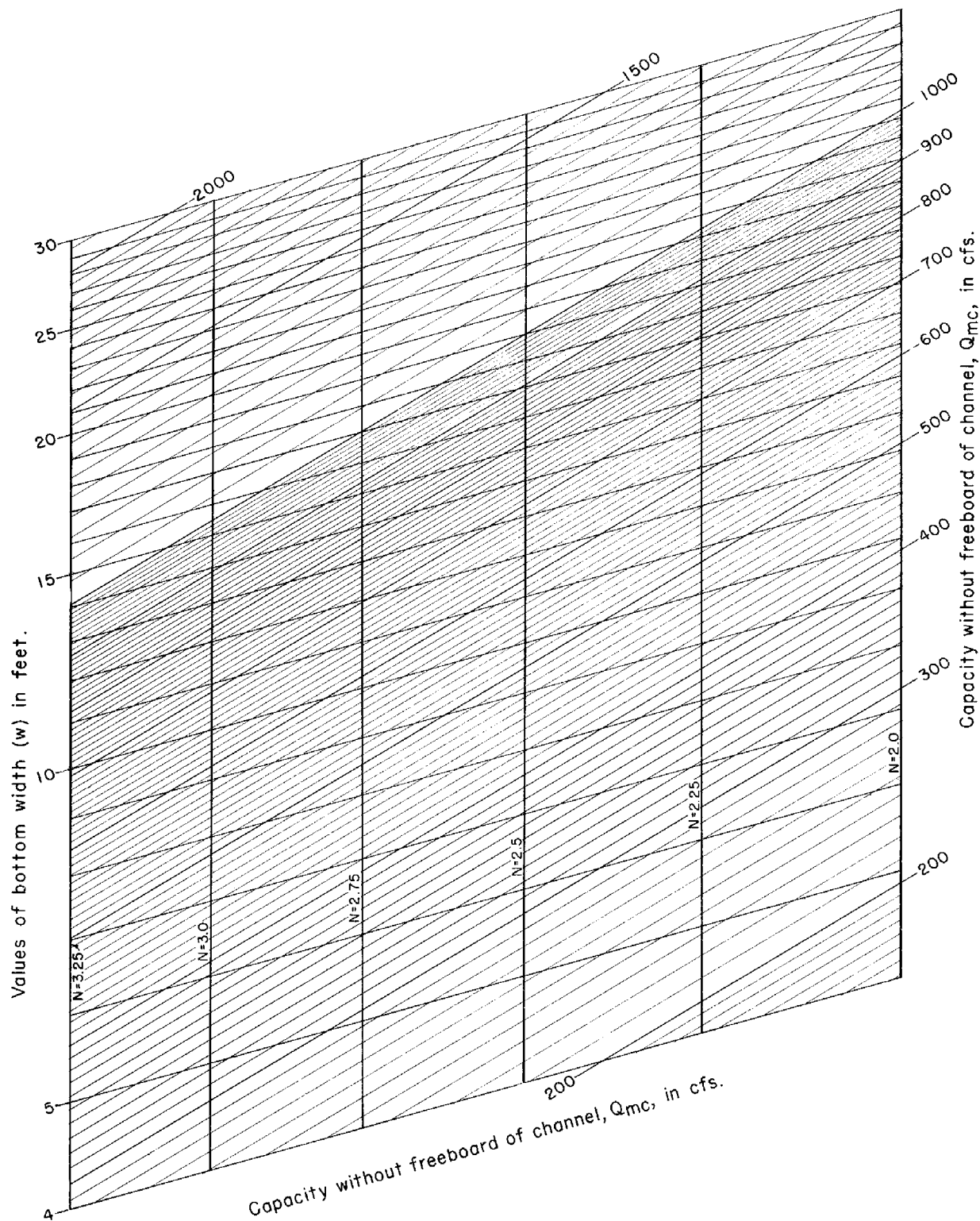
STANDARD DWG. NO.

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 $\bar{z} = 8$ ft and the SAR 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

$$\begin{aligned} \text{(i)} \quad Q_{fr} &= (1.20 + 0.003 Z) Q_r \\ Q_{fr} &= [1.20 + 0.003 (47)] 380 \\ Q_{fr} &= 509.6 \text{ cfs} \end{aligned}$$

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

2. (a) The required height of the sidewalls of the channel may 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 ($D = 0$)

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

$$F = 47 + 2.37 - (15 + 8)$$

$$F = 26.37 \text{ ft}$$

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 $\bar{z} + F$ 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

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

$$p = 1.33$$

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

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

REFERENCE

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

STANDARD DWG. NO.

ES-84

SHEET 4 OF 4

DATE March 1954

SAF OUTLETS

The criteria for the dimensions of the SAF outlet were developed by Fred W. Blaisdell¹, 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 erodible 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

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

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° 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

¹Blaisdell, 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.

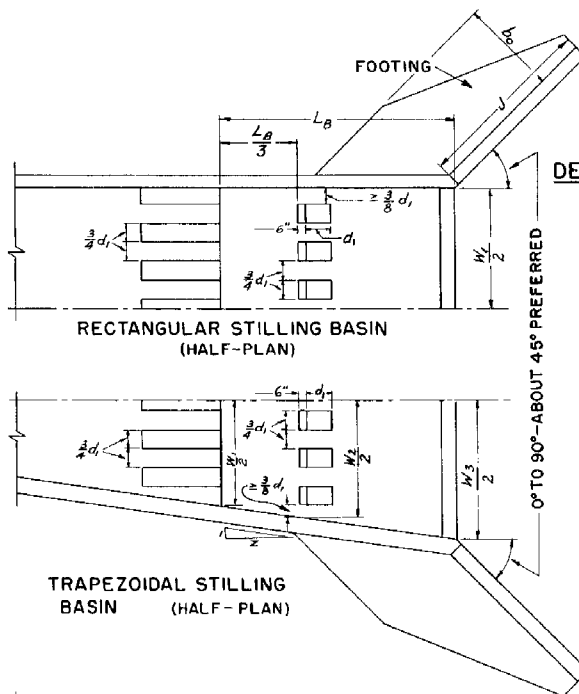
The basin having diverging sidewalls appears to be slightly more effective than the basin with parallel sidewalls.

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

¹Thomas, 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



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

$$3 \leq F_1 \leq 300$$

$$1. \quad F_1 = \frac{v_1^2}{g d_1}$$

$$2. \quad d_2 = \frac{d_1}{2} (-1 + \sqrt{8 F_1 + 1})$$

$$3. \quad d_2' = 1.4 d_1 F_1^{0.45}$$

$$4. \quad L_B = \frac{4.5 d_2}{F_1^{0.38}}$$

$$5. \quad J = \frac{d_2}{3} + d_2'$$

$$6. \quad s = 0.07 d_2$$

$$7. \quad z \geq 3 \sqrt{F_1}$$

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
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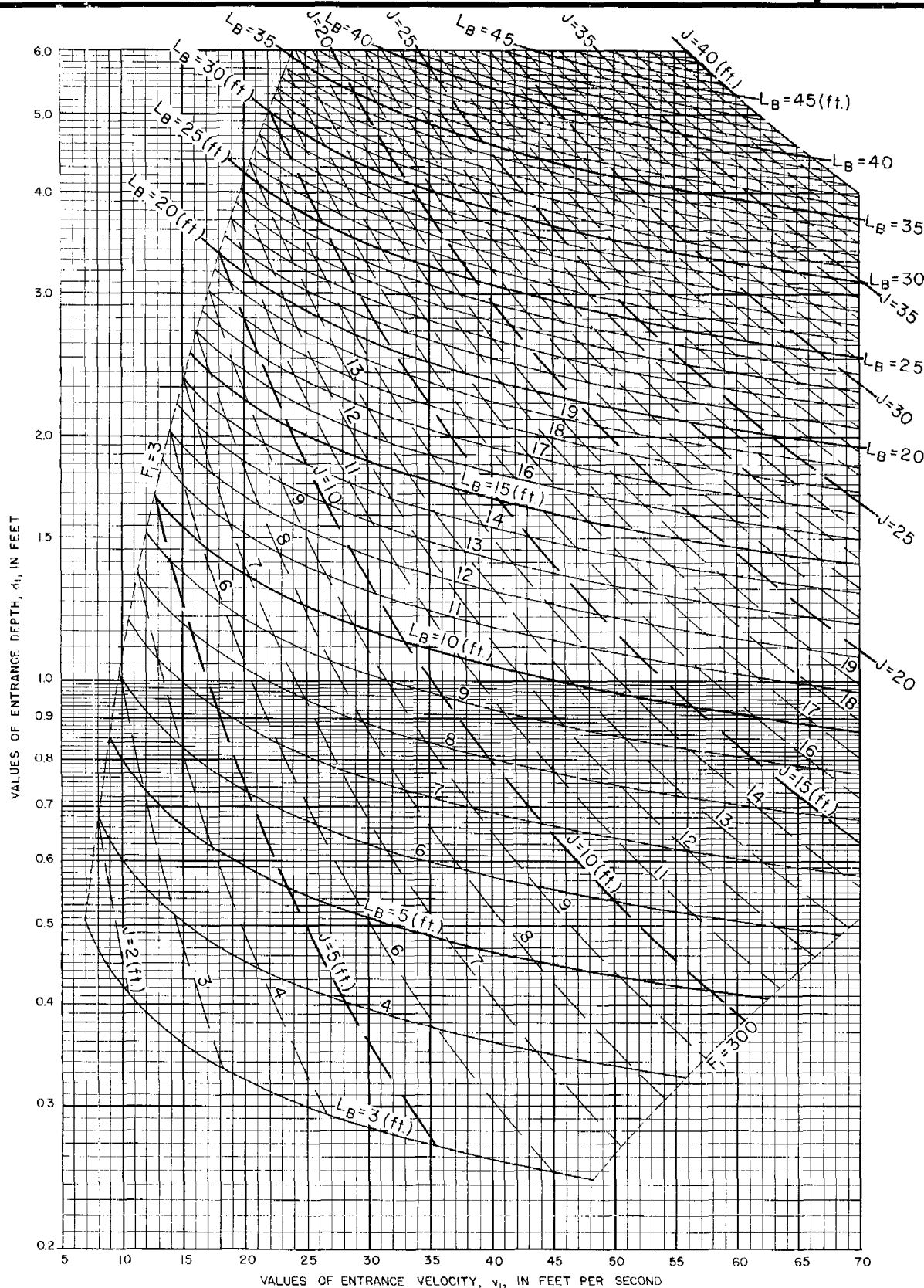
ES-73

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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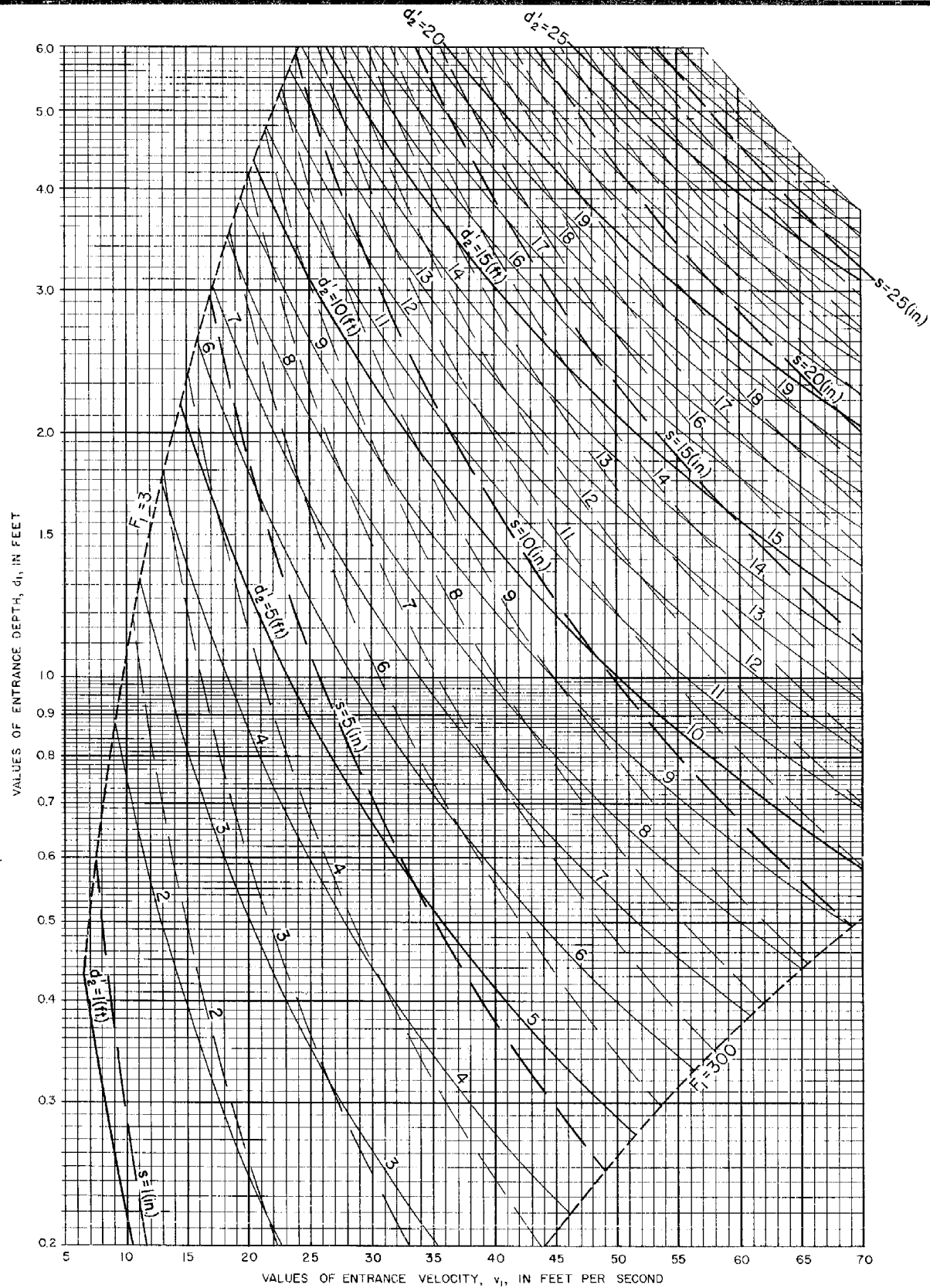
ES-73

SHEET 2 OF 3

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

HYDRAULIC DESIGN CRITERIA AND CHARTS FOR SAF STILLING BASIN

s - Inches
d₂ - Feet



REFERENCE

Elaisdell, 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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STANDARD DRAWING NO.

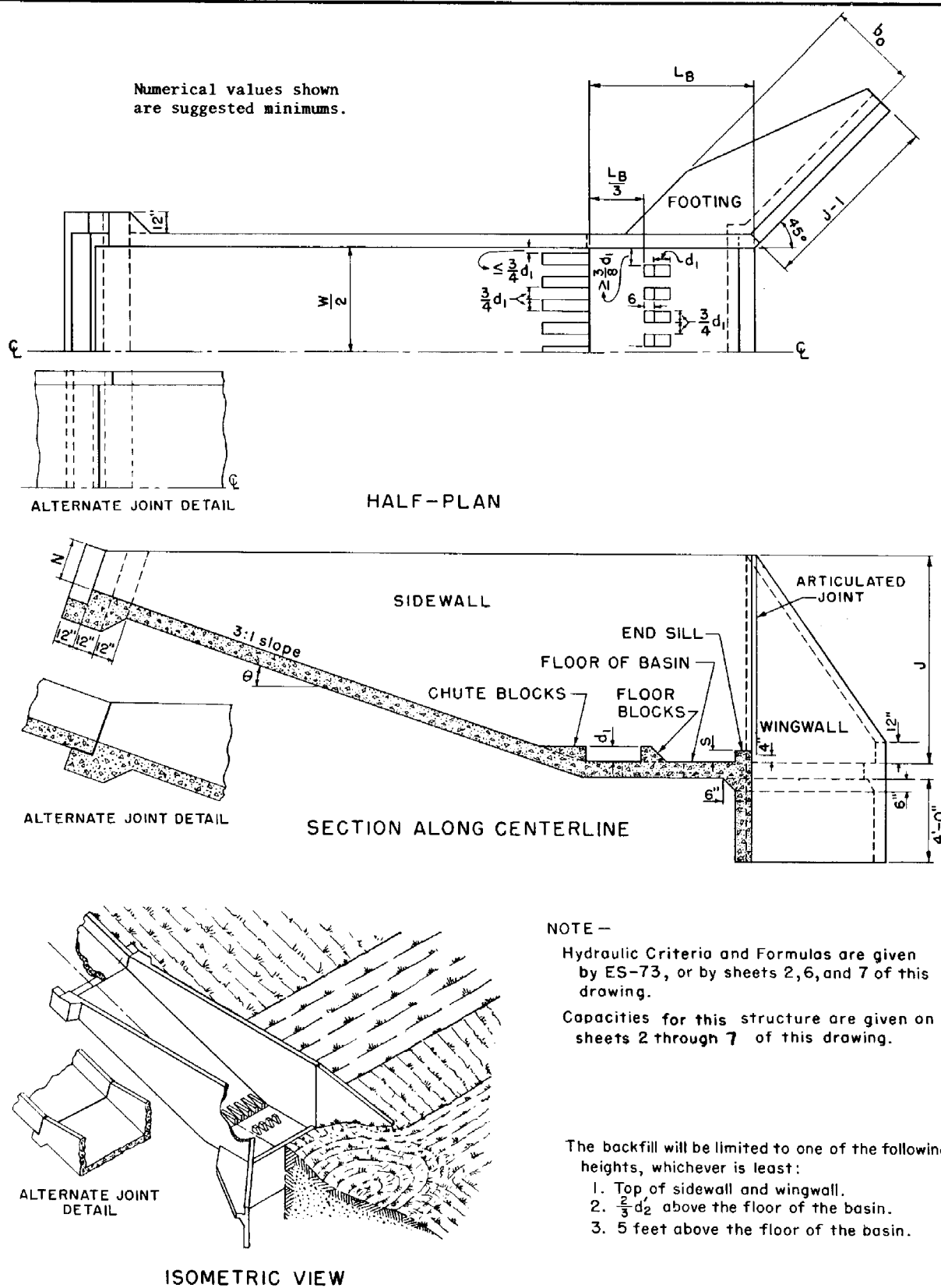
ES-73

SHEET 3 OF 3

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

CHUTE SPILLWAYS: SAF OUTLETS

The General Layout Drawing



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:

Revised: 11-1-54

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 10/77

CHUTE SPILLWAYS: SAF OUTLETS;

Definition of symbols and Formulas

DEFINITION OF SYMBOLS

- F_1 = Froude's number $= \frac{v_1^2}{gd_1}$ 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_{60} = 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/sec²

DESIGN FORMULAS

$$3 \leq F_1 \leq 300$$

$$1. \quad F_1 = \frac{v_1^2}{gd_1}$$

$$4. \quad L_B = \frac{4.5 d_2}{F_1^{0.38}}$$

$$2. \quad d_2 = \frac{d_1}{2} (-1 + \sqrt{8 F_1 + 1})$$

$$5. \quad J = \frac{d_2}{3} + d_2'$$

$$3. \quad d_2' = 1.4 d_1 F_1^{0.45}$$

$$6. \quad s = 0.07 d_2$$

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

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	4.25	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

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

J = 10.5 to 13.0

J	L _B	N	b ₀	d ₁	q _{mc}
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	4.25	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	39.879
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	2.50	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 ₀	d ₁	q _{mc}
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	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	48.966
13.0	11.0	2.50	5.50	1.1300	48.966

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 ₀	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

J	L _B	N	b ₀	d ₁	q _{mo}
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	6.00	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	49.273
14.5	9.5	2.50	6.00	0.8760	49.273
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	4.00	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:

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SHEET 5 OF 8

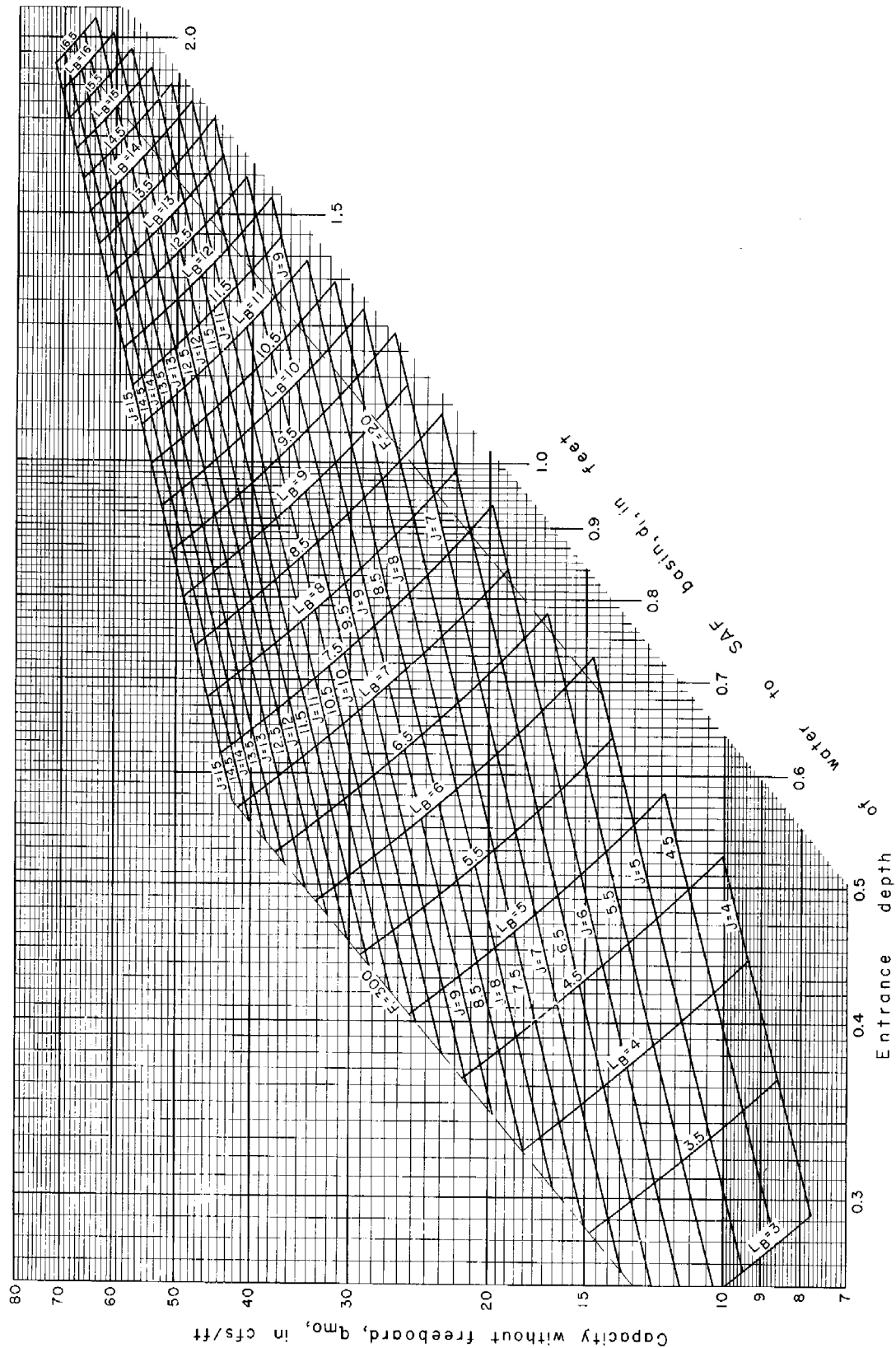
DATE 9-8-54

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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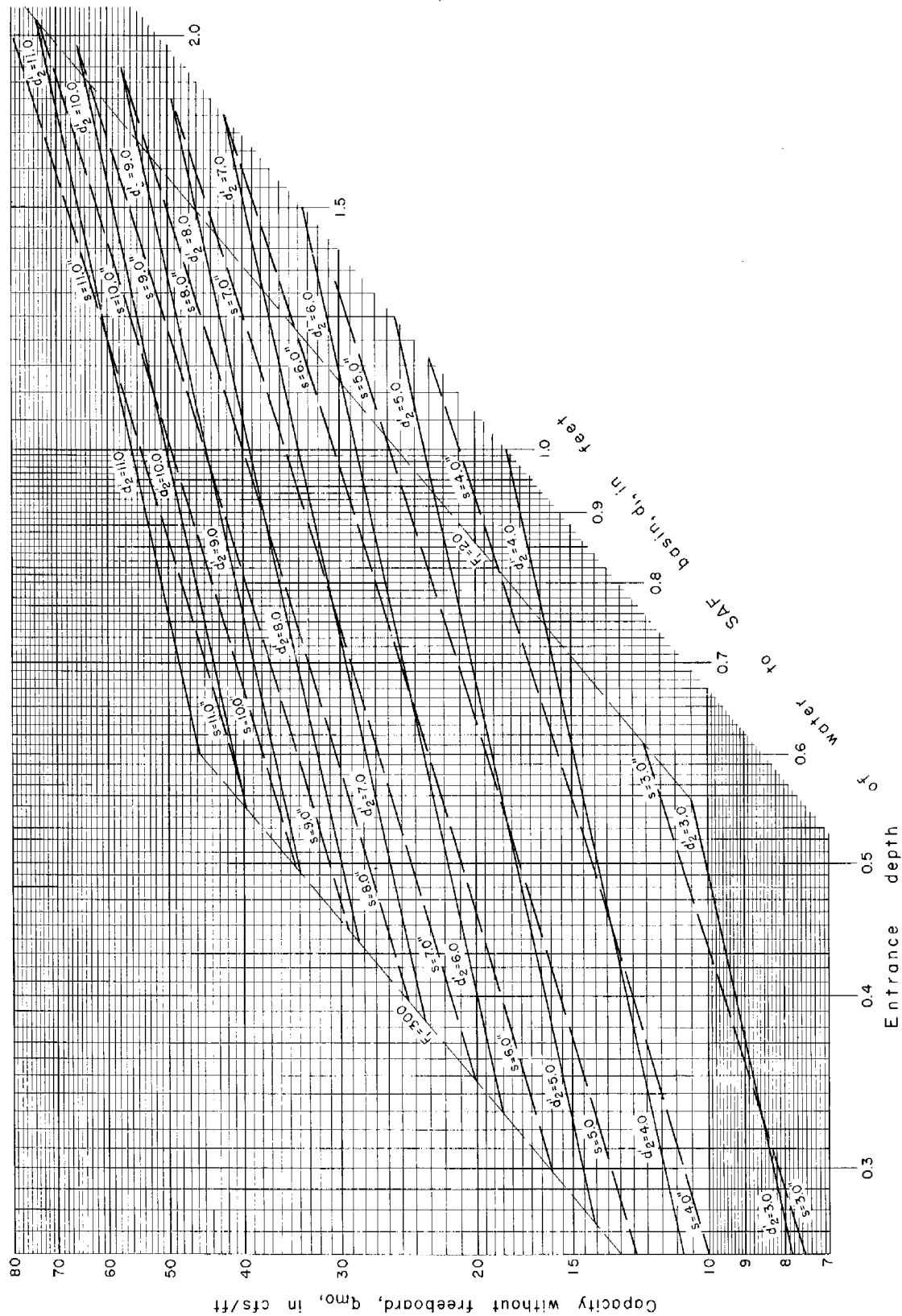
ES-86

SHEET 6 OF
DATE 3-2-54

CHUTE SPILLWAYS: SAF OUTLETS

Tailwater requirement 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)
Trans. ASCE 113P, 483-561, 1948

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

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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 $J = 8$ 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.

$$d_2' = 8.1 \text{ ft}$$

REFERENCE

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ES-86

SHEET 8 OF 8
DATE February 1954

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