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Chapter A3

MEASUREMENT OF PEAK DISCHARGE AT CULVERTS BY INDIRECT METHODS

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Book 3
APPLICATIONS OF HYDRAULICS

or wetted perimeter. The composite value of n for standard pipes and pipe-arches may be computed by the equation,

$$n_c=\frac{0.012P_p+0.024(P-P_p)}{P}, \qquad (12)$$

where

P_p=length of wetted perimeter that is paved, and
P=total length of wetted perimeter.

For multiplate construction the value of 0.024 must be replaced with the correct value corresponding to the size of the pipe.

Concrete

The roughness coefficient of concrete is dependent upon the condition of the concrete and the irregularities of the surface resulting from construction. Suggested values of n for general use are:

Condition of concrete	n
Very smooth (spun pipe)	0.010
Smooth (cast or tamped pipe)	.011–0.015
Ordinary field construction	.012– .015
Badly spalled	.015– .020

At times, sections of concrete pipe become displaced either vertically or laterally, resulting in a much rougher interior surface than normal. Where this occurs, increase n commensurate with the degree of displacement of the culvert sections. Laboratory tests have shown that the displacement must be considerable before the roughness coefficient is very much affected.

Slight bends or changes in alinement of the culvert will not affect the roughness coefficient. However, the effects of fairly sharp bends or angles can be compensated for by raising the n value, as is done in slope-area measurements. Russell (1935) showed that for extremely sharp bends (90°) the head loss may vary from 0.2 to to 1.0 times the velocity head, depending on the radius of the bend and the velocity. The lower value applies to velocities of 2 or 3 feet per second and radii of 1–8 feet, and the higher value to velocities of 15–20 feet per second and radii of 40–60 feet. King (1954) stated that the losses in a 45° bend may be about ¾ as great, and for a 22½° bend about ½ as great as those of a 90° bend.

Other materials

Occasionally culverts will be constructed of some material other than concrete or corrugated metal. Manning's coefficients (King, 1954) for some of these materials are:

Material	n
Welded steel	0.012
Wood stave	.012
Cast iron	.013
Vitrified clay	.013
Riveted steel	.015

Culverts made from cement rubble or rock may have roughness coefficients ranging from 0.020 to 0.030, depending on the type of material and the care with which it is laid.

Natural bottom

Many culverts, especially the large arch type, are constructed with the natural channel as the bottom. The bottom roughness usually weights the composite roughness coefficient quite heavily, especially when the bottom is composed of cobbles and large angular rock. The formula used for paved inverts can be used here if the correct n values are substituted therein.

Computation of Discharge

The first step in the computation of discharge is to determine the type of flow. Under low heads, headwater-diameter ratios less than 1.5, type 3 flow will occur if the elevation of the downstream water surface is higher than the water-surface elevation at critical depth. If the tailwater elevation is lower than the water-surface elevation at critical depth, type 1 flow will occur with the bed slope of the culvert greater than the critical slope, or type 2 flow will occur with the bed slope less than the critical slope. Type 5 or 6 flow will occur with high heads, headwater-diameter ratios greater than 1.5, depending on the steepness of the culvert and the entrance conditions.

Discharge coefficients are a vital part of each culvert computation. These are discussed in detail on pages 37–45.

Tables 2–4 have information that applies to circular sections, riveted pipe-arches, and multiplate pipe-arches. Figures 5–8 are graphs

Table 2.—Properties of circular pipes, riveted pipe-arches, and multiplate pipe-arches

Circular pipes

Diam (in)	Diam D (ft)	Area A_0 (sq ft)	D^2	$D^{5/2}$	$D^{8/3}$	Diam (in)	Diam D (ft)	Area A_0 (sq ft)	D^2	$D^{5/2}$	$D^{8/3}$
6	0.500	0.196	0.250	0.177	0.157	60	5.00	19.6	25.0	55.9	73.0
8	.667	.349	.444	.363	.339	66	5.50	23.8	30.2	71.0	94.1
10	.833	.545	.694	.634	.614	72	6.00	28.3	36.0	88.2	119
12	1.00	.785	1.00	1.00	1.00	78	6.50	33.2	42.2	108	147
15	1.25	1.23	1.56	1.75	1.81	84	7.00	38.5	49.0	130	179
18	1.50	1.77	2.25	2.76	2.95	96	8.00	50.3	64.0	181	256
21	1.75	2.41	3.06	4.05	4.44	108	9.00	63.6	81.0	243	351
24	2.00	3.14	4.00	5.66	6.34	120	10	78.5	100	316	464
30	2.50	4.91	6.25	9.88	11.5	132	11	95.0	121	401	599
36	3.00	7.07	9.00	15.6	18.7	144	12	113	144	499	755
42	3.50	9.62	12.2	22.9	28.1	156	13	133	169	609	935
48	4.00	12.6	16.0	32.0	40.3	168	14	154	196	733	1,140
54	4.50	15.9	20.2	43.0	55.1	180	15	177	225	871	1,370

Pipe-arches

[Span (b), maximum width; Rise (D), maximum height]

Nominal dimensions		Span (b)	Rise (D)	Area (A)	D^2	$D^{5/2}$	$D^{8/3}$	Nominal dimensions		Span (b)	Rise (D)	Area (A)	D^2	$D^{5/2}$	$D^{8/3}$
Inches × Inches		Feet		Square feet				Inches × Inches		Feet		Square feet			
Riveted pipe-arches															
18	11	1.50	0.92	1.07	0.84	0.80	0.79	50	31	4.17	2.58	8.47	6.67	10.7	12.6
22	13	1.83	1.08	1.48	1.17	1.22	1.24	58	36	4.83	3.00	11.4	9.00	15.6	18.7
29	18	2.42	1.50	2.86	2.25	2.76	2.95	65	40	5.42	3.33	14.1	11.1	20.3	24.8
36	22	3.00	1.83	4.27	3.36	4.55	5.03	72	44	6.00	3.67	17.0	13.4	25.8	32.0
43	27	3.58	2.25	6.43	5.06	7.59	8.69								

Multiplate pipe-arches

Ft	in	× Ft	in							Ft	in	× Ft	in						
6*	1	4	7	6.08	4.58	22	20.97	44.89	57.9	11	7	7	5	11.62	7.42	67	55.06	150.0	209
6	4	4	9	6.34	4.76	24	22.66	49.43	64.1	11	10	7	7	11.82	7.61	71	57.91	159.8	224
6	9	4	11	6.76	4.91	26	24.11	53.42	69.6	12	4	7	9	12.32	7.75	74	60.06	167.2	235
7*	0	5	1	7.02	5.09	28	25.91	58.45	76.7	12	6	7	11	12.52	7.93	78	62.88	177.1	250
7	3	5	3	7.24	5.27	31	27.77	63.76	84.1	12	8	8	1	12.70	8.12	81	65.93	187.9	266
7	8	5	5	7.70	5.42	33	29.38	68.39	90.6	12*	10	8	4	12.86	8.31	85	69.06	199.1	283
7	11	5	7	7.94	5.60	35	31.36	74.21	98.9	13	5	8	5	13.40	8.44	89	71.23	206.9	295
8*	2	5	9	8.14	5.78	38	33.41	80.32	108	13	11	8	7	13.94	8.58	93	73.62	215.6	309
8	7	5	11	8.62	5.92	40	35.05	85.27	115	14	1	8	9	14.12	8.77	97	76.91	227.8	327
8	10	6	1	8.84	6.11	43	37.33	92.28	125	14	3	8	11	14.28	8.96	101	80.28	240.3	346
9	4	6	3	9.32	6.26	46	39.19	98.05	133	14	10	9	1	14.82	9.10	105	82.81	249.8	361
9	6	6	5	9.52	6.44	49	41.47	105.2	144	15*	4	9	3	15.34	9.23	109	85.19	258.8	375
9	9	6	7	9.72	6.62	52	43.82	112.8	155	15	6	9	5	15.54	9.42	113	88.74	272.3	396
10	3	6	9	10.22	6.77	55	45.83	119.3	164	15	8	9	7	15.70	9.61	118	92.35	286.3	417
10	8	6	11	10.70	6.91	58	47.75	125.5	173	15	10	9	10	15.86	9.80	122	96.04	300.7	440
10	11	7	1	10.92	7.09	61	50.27	133.8	186	16	5	9	11	16.42	9.93	126	98.61	310.7	456
11*	5	7	3	11.40	7.24	64	52.42	141.0	196	16*	7	10	1	16.58	10.12	130	102.41	325.8	479

*Size for which coefficients are provided in table 4.
Dimensions are from "Handbook of Drainage and Construction Products," Armco Drainage & Metal Products, Inc., 1955.

Table 3.—Coefficients for pipe of circular section flowing partly full

[Coefficients for (1) area, (2) wetted perimeter, (3) hydraulic radius, (4) conveyance, (5) discharge for critical-depth flow, and (6) top width]

d/D [1]	(1)	(2)	(3)	(4)	(5)	(6)	d/D [1]	(1)	(2)	(3)	(4)	(5)	(6)
	$A=C_aD^2$	$P=C_pD$	$R=C_rD$	$K=C_k\frac{D^{8/3}}{n}$	$Q=C_qD^{5/2}$	$T=C_tD$		$A=C_aD^2$	$P=C_pD$	$R=C_rD$	$K=C_k\frac{D^{8/3}}{n}$	$Q=C_qD^{5/2}$	$T=C_tD$
	C_a	C_p	C_r	C_k	C_q	C_t		C_a	C_p	C_r	C_k	C_q	C_t
0.01	0.0013	0.2003	0.0066	0.000068	0.0006	0.199	0.51	0.4027	1.5908	0.2531	0.2394	1.449	1.000
.02	.0037	.2838	.0132	.000307	.0025	.280	.52	.4127	1.6108	.2562	.2472	1.504	.999
.03	.0069	.3482	.0197	.000747	.0055	.341	.53	.4227	1.6308	.2592	.2556	1.560	.998
.04	.0105	.4027	.0262	.001376	.0098	.392	.54	.4327	1.6509	.2621	.2630	1.616	.997
.05	.0147	.4510	.0325	.002228	.0153	.436	.55	.4426	1.6710	.2649	.2710	1.674	.995
.06	.0192	.4949	.0389	.00328	.0220	.475	.56	.4526	1.6911	.2676	.2791	1.733	.993
.07	.0242	.5355	.0451	.00457	.0298	.510	.57	.4625	1.7113	.2703	.2873	1.792	.990
.08	.0294	.5735	.0513	.00601	.0389	.543	.58	.4724	1.7315	.2728	.2955	1.853	.987
.09	.0350	.6094	.0575	.00775	.0491	.572	.59	.4822	1.7518	.2753	.3031	1.915	.984
.10	.0409	.6435	.0635	.00966	.0605	.600	.60	.4920	1.7722	.2776	.3115	1.977	.980
.11	.0470	.6761	.0695	.0118	.0731	.626	.61	.5018	1.7926	.2799	.3192	2.041	.975
.12	.0534	.7075	.0755	.0142	.0868	.650	.62	.5115	1.8132	.2821	.3268	2.106	.971
.13	.0600	.7377	.0813	.0168	.1016	.673	.63	.5212	1.8338	.2842	.3346	2.172	.966
.14	.0668	.7670	.0871	.0195	.1176	.694	.64	.5308	1.8546	.2862	.3423	2.239	.960
.15	.0739	.7954	.0929	.0225	.1347	.714	.65	.5404	1.8755	.2882	.3501	2.307	.954
.16	.0811	.8230	.0985	.0257	.1530	.733	.66	.5499	1.8965	.2900	.3579	2.376	.947
.17	.0885	.8500	.1042	.0291	.1724	.751	.67	.5594	1.9177	.2917	.3658	2.446	.940
.18	.0961	.8763	.1097	.0327	.1928	.768	.68	.5687	1.9391	.2933	.3727	2.518	.933
.19	.1039	.9020	.1152	.0366	.2144	.785	.69	.5780	1.9606	.2948	.3805	2.591	.925
.20	.1118	.9273	.1206	.0405	.2371	.800	.70	.5872	1.9823	.2962	.3874	2.666	.917
.21	.1199	.9521	.1259	.0446	.2609	.815	.71	.5964	2.0042	.2975	.3953	2.741	.908
.22	.1281	.9764	.1312	.0491	.2857	.828	.72	.6054	2.0264	.2987	.4021	2.819	.898
.23	.1365	1.0003	.1364	.0537	.3116	.842	.73	.6143	2.0488	.2998	.4090	2.898	.888
.24	.1449	1.0239	.1416	.0586	.3386	.854	.74	.6231	2.0714	.3008	.4157	2.978	.877
.25	.1535	1.0472	.1466	.0634	.3666	.866	.75	.6319	2.0944	.3017	.4226	3.061	.866
.26	.1623	1.0701	.1516	.0685	.3957	.877	.76	.6405	2.1176	.3024	.4283	3.145	.854
.27	.1711	1.0928	.1566	.0740	.4259	.888	.77	.6489	2.1412	.3031	.4349	3.231	.842
.28	.1800	1.1152	.1614	.0792	.4571	.898	.78	.6573	2.1652	.3036	.4415	3.320	.828
.29	.1890	1.1373	.1662	.0848	.4893	.908	.79	.6655	2.1895	.3039	.4470	3.411	.815
.30	.1982	1.1593	.1709	.0907	.523	.917	.80	.6736	2.2143	.3042	.4524	3.505	.800
.31	.2074	1.1810	.1756	.0968	.557	.925	.81	.6815	2.2395	.3043	.4578	3.602	.785
.32	.2167	1.2025	.1802	.1027	.592	.933	.82	.6893	2.2653	.3043	.4630	3.702	.768
.33	.2260	1.2239	.1847	.1088	.628	.940	.83	.6969	2.2916	.3041	.4681	3.806	.751
.34	.2355	1.2451	.1891	.1155	.666	.947	.84	.7043	2.3186	.3038	.4731	3.914	.733
.35	.2450	1.2661	.1935	.1220	.704	.954	.85	.7115	2.3462	.3033	.4768	4.028	.714
.36	.2546	1.2870	.1978	.1283	.743	.960	.86	.7186	2.3746	.3026	.4816	4.147	.694
.37	.2642	1.3078	.2020	.1350	.784	.966	.87	.7254	2.4038	.3018	.4851	4.272	.673
.38	.2739	1.3284	.2062	.1421	.825	.971	.88	.7320	2.4341	.3007	.4884	4.406	.650
.39	.2836	1.3490	.2102	.1488	.867	.975	.89	.7384	2.4655	.2995	.4916	4.549	.626
.40	.2934	1.3694	.2142	.1561	.910	.980	.90	.7445	2.4981	.2980	.4935	4.70	.600
.41	.3032	1.3898	.2182	.1631	.955	.984	.91	.7504	2.5322	.2963	.4951	4.87	.572
.42	.3130	1.4101	.2220	.1702	1.000	.987	.92	.7560	2.5681	.2944	.4966	5.06	.543
.43	.3229	1.4303	.2258	.1780	1.046	.990	.93	.7612	2.6061	.2921	.4977	5.27	.510
.44	.3328	1.4505	.2295	.1854	1.093	.993	.94	.7662	2.6467	.2895	.4979	5.52	.475
.45	.3428	1.4706	.2331	.1931	1.141	.995	.95	.7707	2.6906	.2865	.4970	5.81	.436
.46	.3527	1.4907	.2366	.2002	1.190	.997	.96	.7749	2.7389	.2829	.4963	6.18	.392
.47	.3627	1.5108	.2401	.2080	1.240	.998	.97	.7785	2.7934	.2787	.4940	6.67	.341
.48	.3727	1.5308	.2435	.2160	1.291	.999	.98	.7817	2.8578	.2735	.4902	7.41	.280
.49	.3827	1.5508	.2468	.2235	1.343	1.000	.99	.7841	2.9412	.2666	.4824	8.83	.199
.50	.3927	1.5708	.2500	.2317	1.396	1.000	1.00	.7854	3.1416	.2500	.4633	-------	.000

[1] d=maximum depth of water in feet; D=diameter of pipe, in feet.

Table 4.—Coefficients for pipe-arches flowing partly full

[Coefficients for (1) area, (2) hydraulic radius, (3) conveyance, (4) mean depth, (5) discharge for critical-depth flow]

d/D[1]	(1) $A=C_aD^2$	(2) $R=C_rD$	(3) $K=C_k\frac{D^{8/3}}{n}$	(4) $d_m=C_mD$	(5) $Q=C_qD^{5/2}$	d/D[1]	(1) $A=C_aD^2$	(2) $R=C_rD$	(3) $K=C_k\frac{D^{8/3}}{n}$	(4) $d_m=C_mD$	(5) $Q=C_qD^{5/2}$
	C_a	C_r	C_k	C_m	C_q		C_a	C_r	C_k	C_m	C_q
A. Nominal size 6 feet 1 inch × 4 feet 7 inches											
0.01	0.005	0.016	0.000	0.016	0.003	0.51	0.586	0.289	0.380	0.450	2.23
.02	.009	.019	.001	.019	.007	.52	.600	.292	.393	.463	2.32
.03	.014	.025	.002	.025	.012	.53	.614	.296	.406	.476	2.41
.04	.019	.029	.003	.029	.018	.54	.628	.300	.419	.490	2.50
.05	.026	.036	.004	.035	.028	.55	.643	.304	.431	.504	2.59
.06	.033	.042	.006	.041	.038	.56	.657	.307	.445	.519	2.69
.07	.042	.048	.008	.048	.052	.57	.671	.311	.458	.535	2.79
.08	.050	.054	.011	.054	.066	.58	.686	.314	.471	.551	2.89
.09	.059	.061	.014	.061	.082	.59	.700	.318	.484	.568	2.99
.10	.068	.067	.017	.067	.099	.60	.714	.321	.497	.584	3.10
.11	.078	.075	.021	.076	.122	.61	.724	.321	.505	.597	3.17
.12	.089	.082	.025	.084	.145	.62	.733	.322	.512	.609	3.25
.13	.099	.089	.029	.091	.170	.63	.743	.322	.519	.621	3.32
.14	.110	.096	.034	.099	.195	.64	.752	.323	.526	.634	3.40
.15	.120	.102	.039	.106	.221	.65	.762	.323	.533	.647	3.48
.16	.131	.109	.044	.114	.251	.66	.776	.327	.547	.666	3.59
.17	.142	.115	.050	.122	.282	.67	.790	.330	.561	.686	3.71
.18	.154	.121	.056	.129	.314	.68	.805	.334	.576	.706	3.84
.19	.165	.127	.062	.137	.346	.69	.819	.337	.590	.727	3.96
.20	.176	.132	.068	.144	.380	.70	.833	.341	.604	.749	4.09
.21	.189	.139	.075	.153	.418	.71	.843	.341	.611	.766	4.19
.22	.201	.145	.082	.162	.458	.72	.852	.341	.619	.784	4.28
.23	.213	.151	.090	.170	.499	.73	.862	.342	.626	.803	4.38
.24	.226	.157	.098	.178	.541	.74	.871	.342	.633	.822	4.48
.25	.238	.163	.105	.186	.583	.75	.881	.342	.640	.841	4.58
26	.252	.170	.115	.197	.635	.76	.890	.343	.649	.864	4.70
.27	.267	.177	.125	.207	.688	.77	.900	.345	.657	.889	4.81
.28	.281	.184	.135	.217	.742	.78	.909	.346	.666	.914	4.93
.29	.295	.191	.145	.227	.797	.79	.919	.347	.675	.940	5.06
.30	.309	.197	.156	.236	.854	.80	.928	.349	.684	.967	5.18
.31	.324	.203	.166	.246	.912	.81	.936	.347	.687	.998	5.31
.32	.338	.209	.177	.256	.972	.82	.944	.345	.690	1.03	5.43
.33	.352	.215	.188	.266	1.03	.83	.951	.344	.694	1.06	5.57
.34	.367	.221	.199	.276	1.09	.84	.959	.342	.697	1.10	5.70
.35	.381	.227	.210	.286	1.16	.85	.966	.341	.701	1.14	5.85
.36	.392	.231	.219	.295	1.21	.86	.973	.338	.702	1.18	6.01
.37	.404	.234	.228	.303	1.26	.87	.980	.336	.704	1.23	6.18
.38	.415	.238	.237	.312	1.32	.88	.986	.334	.706	1.29	6.35
.39	.427	.241	.246	.320	1.37	.89	.993	.332	.707	1.35	6.54
.40	.438	.245	.255	.329	1.42	.90	1.00	.330	.709	1.41	6.74
.41	.450	.249	.265	.338	1.49	.91	1.00	.326	.707	1.50	6.98
.42	.463	.252	.275	.347	1.55	.92	1.01	.323	.705	1.60	7.23
.43	.475	.256	.285	.357	1.61	.93	1.01	.319	.704	1.71	7.52
.44	.488	.260	.295	.366	1.67	.94	1.02	.316	.702	1.83	7.82
.45	.500	.263	.305	.376	1.74	.95	1.02	.313	.701	2.02	8.25
.46	.514	.268	.317	.388	1.82	.96	1.03	.304	.691	--------	--------
.47	.528	.272	.330	.400	1.90	.97	1.03	.296	.682	--------	--------
.48	.543	.276	.342	.412	1.98	.98	1.04	.288	.673	--------	--------
.49	.557	.281	.355	.424	2.06	.99	1.04	.281	.665	--------	--------
.50	.571	.285	.367	.436	2.14	1.00	1.05	.274	.658	--------	--------

[1] d=depth of water, in feet; D=rise, in feet.

Table 4.—Coefficients for pipe-arches flowing partly full—Continued

d/D[1]	(1) $A=C_aD^2$ C_a	(2) $R=C_rD$ C_r	(3) $K=C_k\frac{D^{8/3}}{n}$ C_k	(4) $d_m=C_mD$ C_m	(5) $Q=C_qD^{5/2}$ C_q	d/D	(1) $A=C_aD^2$ C_a	(2) $R=C_rD$ C_r	(3) $K=C_k\frac{D^{8/3}}{n}$ C_k	(4) $d_m=C_mD$ C_m	(5) $Q=C_qD^{5/2}$ C_q
B. Nominal size 7 feet 0 inch × 5 feet 1 inch											
0.01	0.006	0.017	0.001	0.017	0.004	0.51	0.594	0.283	0.380	0.447	2.25
.02	.012	.022	.001	.022	.010	.52	.609	.287	.394	.462	2.35
.03	.016	.026	.002	.026	.015	.53	.625	.292	.409	.476	2.45
.04	.021	.029	.003	.029	.020	.54	.640	.296	.423	.491	2.55
.05	.028	.035	.004	.035	.029	.55	.656	.301	.437	.506	2.65
.06	.035	.040	.006	.039	.039	.56	.667	.303	.447	.518	2.72
.07	.044	.047	.009	.047	.055	.57	.679	.305	.457	.530	2.80
.08	.054	.054	.011	.054	.071	.58	.690	.307	.467	.542	2.89
.09	.064	.061	.015	.061	.089	.59	.702	.309	.476	.555	2.97
.10	.073	.067	.018	.067	.108	.60	.714	.311	.486	.568	3.05
.11	.085	.075	.022	.076	.133	.61	.725	.313	.497	.582	3.14
.12	.096	.083	.027	.084	.159	.62	.737	.315	.507	.597	3.23
.13	.108	.090	.032	.092	.186	.63	.748	.317	.517	.613	3.32
.14	.120	.096	.037	.100	.215	.64	.760	.320	.528	.628	3.42
.15	.131	.103	.043	.107	.244	.65	.771	.322	.538	.644	3.51
.16	.141	.108	.048	.114	.270	.66	.784	.324	.550	.662	3.62
.17	.151	.114	.053	.120	.298	.67	.798	.326	.562	.681	3.74
.18	.161	.119	.058	.127	.326	.68	.811	.329	.574	.701	3.85
.19	.171	.124	.063	.133	.354	.69	.824	.331	.586	.721	3.97
.20	.181	.128	.068	.139	.383	.70	.837	.333	.597	.741	4.09
.21	.194	.135	.076	.147	.422	.71	.848	.335	.608	.761	4.20
.22	.206	.141	.083	.156	.461	.72	.860	.337	.619	.781	4.31
.23	.218	.147	.090	.164	.502	.73	.872	.339	.629	.801	4.43
.24	.231	.153	.098	.172	.544	.74	.883	.341	.640	.822	4.54
.25	.243	.159	.106	.181	.586	.75	.895	.343	.651	.844	4.66
.26	.258	.166	.115	.191	.639	.76	.905	.343	.659	.868	4.78
.27	.272	.172	.125	.201	.693	.77	.915	.344	.667	.892	4.90
.28	.287	.179	.135	.211	.749	.78	.925	.345	.676	.918	5.03
.29	.302	.185	.146	.222	.806	.79	.935	.345	.684	.945	5.16
.30	.316	.192	.156	.232	.864	.80	.945	.346	.692	.972	5.29
.31	.330	.198	.167	.242	.921	.81	.956	.346	.700	1.01	5.45
.32	.344	.204	.177	.251	.979	.82	.968	.346	.709	1.04	5.61
.33	.358	.209	.188	.261	1.04	.83	.980	.345	.717	1.08	5.78
.34	.372	.215	.198	.271	1.10	.84	.991	.345	.725	1.12	5.95
.35	.386	.221	.209	.281	1.16	.85	1.003	.345	.733	1.16	6.13
.36	.401	.226	.221	.292	1.23	.86	1.009	.342	.734	1.21	6.30
.37	.417	.232	.234	.304	1.30	.87	1.015	.340	.735	1.26	6.47
.38	.432	.238	.246	.316	1.38	.88	1.021	.338	.736	1.32	6.65
.39	.447	.243	.259	.327	1.45	.89	1.027	.335	.737	1.38	6.84
.40	.463	.248	.272	.339	1.53	.90	1.034	.333	.738	1.44	7.04
.41	.474	.252	.281	.348	1.59	.91	1.039	.330	.737	1.52	7.28
.42	.486	.255	.290	.357	1.65	.92	1.044	.327	.736	1.61	7.52
.43	.498	.259	.300	.366	1.71	.93	1.050	.324	.735	1.72	7.82
.44	.509	.262	.310	.375	1.77	.94	1.055	.321	.734	1.85	8.15
.45	.521	.265	.319	.384	1.83	.95	1.061	.318	.734	2.04	8.59
.46	.532	.268	.329	.394	1.90	.96	1.064	.310	.724	--------	--------
.47	.544	.270	.338	.404	1.96	.97	1.068	.302	.715	--------	--------
.48	.555	.273	.347	.413	2.03	.98	1.072	.295	.706	--------	--------
.49	.567	.275	.357	.423	2.09	.99	1.076	.288	.698	--------	--------
.50	.579	.278	.366	.433	2.16	1.00	1.081	.282	.691	--------	--------

[1] d=depth of water, in feet; D=rise, in feet.

Table 4.—Coefficients for pipe-arches flowing partly full—Continued

d/D[1]	(1) $A=C_aD^2$	(2) $R=C_rD$	(3) $K=C_k\frac{D^{8/3}}{n}$	(4) $d_m=C_mD$	(5) $Q=C_qD^{5/2}$	d/D[1]	(1) $A=C_aD^2$	(2) $R=C_rD$	(3) $K=C_k\frac{D^{8/3}}{n}$	(4) $d_m=C_mD$	(5) $Q=C_qD^{5/2}$
	C_a	C_r	C_k	C_m	C_q		C_a	C_r	C_k	C_m	C_q
C. Nominal size 8 feet 2 inches × 5 feet 9 inches											
0. 01	0. 007	0. 015	0. 001	0. 015	0. 005	0. 51	0. 658	0. 304	0. 442	0. 497	2. 63
. 02	. 013	. 021	. 002	. 021	. 011	. 52	. 673	. 308	. 456	. 511	2. 73
. 03	. 020	. 026	. 003	. 026	. 019	. 53	. 688	. 312	. 470	. 525	2. 83
. 04	. 027	. 030	. 004	. 030	. 026	. 54	. 703	. 315	. 484	. 539	2. 93
. 05	. 036	. 037	. 006	. 036	. 039	. 55	. 718	. 319	. 498	. 553	3. 03
. 06	. 045	. 044	. 008	. 042	. 052	. 56	. 730	. 322	. 509	. 566	3. 11
. 07	. 063	. 057	. 014	. 056	. 085	. 57	. 742	. 324	. 520	. 578	3. 20
. 08	. 081	. 070	. 020	. 070	. 121	. 58	. 754	. 326	. 531	. 590	3. 29
. 09	. 087	. 073	. 023	. 073	. 133	. 59	. 765	. 328	. 541	. 603	3. 37
. 10	. 093	. 077	. 025	. 077	. 146	. 60	. 777	. 331	. 552	. 616	3. 46
. 11	. 106	. 085	. 030	. 086	. 177	. 61	. 789	. 333	. 563	. 631	3. 56
. 12	. 119	. 094	. 036	. 096	. 209	. 62	. 801	. 335	. 574	. 645	3. 65
. 13	. 132	. 101	. 043	. 105	. 243	. 63	. 813	. 337	. 585	. 661	3. 75
. 14	. 145	. 109	. 049	. 114	. 279	. 64	. 825	. 339	. 596	. 676	3. 85
. 15	. 158	. 116	. 056	. 123	. 315	. 65	. 837	. 341	. 607	. 692	3. 95
. 16	. 172	. 123	. 063	. 132	. 354	. 66	. 849	. 342	. 618	. 708	4. 05
. 17	. 185	. 131	. 071	. 141	. 394	. 67	. 861	. 344	. 628	. 724	4. 16
. 18	. 198	. 138	. 078	. 149	. 434	. 68	. 873	. 345	. 639	. 740	4. 26
. 19	. 211	. 144	. 086	. 158	. 476	. 69	. 885	. 347	. 649	. 757	4. 37
. 20	. 224	. 151	. 094	. 166	. 519	. 70	. 897	. 348	. 660	. 774	4. 48
. 21	. 239	. 159	. 104	. 176	. 570	. 71	. 909	. 350	. 671	. 796	4. 60
. 22	. 254	. 166	. 114	. 186	. 622	. 72	. 921	. 352	. 682	. 819	4. 73
. 23	. 269	. 174	. 124	. 196	. 676	. 73	. 933	. 354	. 693	. 843	4. 86
. 24	. 284	. 181	. 135	. 205	. 731	. 74	. 945	. 355	. 704	. 867	4. 99
. 25	. 299	. 188	. 146	. 215	. 786	. 75	. 957	. 357	. 716	. 892	5. 13
. 26	. 314	. 194	. 157	. 225	. 845	. 76	. 966	. 357	. 722	. 916	5. 24
. 27	. 329	. 201	. 168	. 235	. 905	. 77	. 975	. 357	. 729	. 940	5. 36
. 28	. 344	. 207	. 179	. 245	. 966	. 78	. 984	. 357	. 736	. 964	5. 48
. 29	. 359	. 213	. 190	. 255	1. 03	. 79	. 993	. 357	. 743	. 990	5. 61
. 30	. 374	. 218	. 201	. 265	1. 09	. 80	1. 002	. 358	. 750	1. 02	5. 73
. 31	. 386	. 223	. 211	. 273	1. 14	. 81	1. 011	. 357	. 756	1. 03	5. 83
. 32	. 398	. 227	. 220	282	1. 20	. 82	1. 020	. 356	. 761	1. 05	5. 93
. 33	. 410	. 231	. 229	. 290	1. 25	. 83	1. 029	. 355	. 767	1. 07	6. 03
. 34	. 422	. 235	. 239	. 299	1. 31	. 84	1. 038	. 355	. 772	1. 08	6. 13
. 35	. 434	. 239	. 248	. 308	1. 36	. 85	1. 047	. 354	. 778	1. 10	6. 23
. 36	. 449	. 244	260	. 319	1. 44	. 86	1. 054	. 352	. 780	1. 17	6. 46
. 37	. 463	. 250	. 273	. 330	1. 51	. 87	1. 062	. 349	. 783	1. 24	6. 71
. 38	. 478	. 255	. 286	. 342	1. 59	. 88	1. 070	. 347	. 785	1. 32	6. 97
. 39	. 493	. 260	. 299	. 354	1. 66	. 89	1. 078	. 345	. 788	1. 41	7. 26
. 40	. 508	. 265	. 312	. 365	1. 74	. 90	1. 085	. 343	. 790	1. 51	7. 58
. 41	. 521	. 268	. 322	. 376	1. 81	. 91	1. 091	. 339	. 789	1. 60	7. 83
. 42	. 535	. 272	. 333	. 387	1. 89	. 92	1. 097	. 336	. 788	1. 69	8. 10
. 43	. 548	. 275	. 344	. 398	1. 96	. 93	1. 103	. 332	. 787	1. 82	8. 45
. 44	. 561	. 278	. 355	. 409	2. 04	. 94	1. 109	. 329	. 786	1. 97	8. 85
. 45	. 574	. 281	. 366	. 420	2. 11	. 95	1. 115	. 326	. 785	2. 17	9. 32
. 46	. 588	. 285	. 378	. 433	2. 19	. 96	1. 119	. 318	. 775	--------	--------
. 47	. 602	. 289	. 391	. 445	2. 28	. 97	1. 123	. 311	. 765	--------	--------
. 48	. 615	. 293	. 403	. 457	2. 36	. 98	1. 127	. 304	. 756	--------	--------
. 49	. 629	. 296	. 415	. 470	2. 45	. 99	1. 130	. 297	. 748	--------	--------
. 50	. 643	. 300	. 428	. 483	2. 54	1. 00	1. 137	. 291	. 739	--------	--------

[1] d=depth of water, in feet; D=rise, in feet.

Table 4.—Coefficients for pipe-arches flowing partly full—Continued

d/D[1]	(1) $A=C_aD^2$	(2) $R=C_rD$	(3) $K=C_k\frac{D^{8/3}}{n}$	(4) $d_m=C_mD$	(5) $Q=C_qD^{5/2}$	d/D[1]	(1) $A=C_aD^2$	(2) $R=C_rD$	(3) $K=C_k\frac{D^{8/3}}{n}$	(4) $d_m=C_mD$	(5) $Q=C_qD^{5/2}$
	C_a	C_r	C_k	C_m	C_q		C_a	C_r	C_k	C_m	C_q
D. Nominal sizes 11 feet 5 inches × 7 feet 3 inches and 12 feet 10 inches × 8 feet 4 inches											
0.01	0.007	0.014	0.001	0.014	0.004	0.51	0.710	.0311	0.484	0.488	2.81
.02	.013	.021	.002	.021	.011	.52	.724	.315	.498	.501	2.91
.03	.020	.027	.003	.027	.019	.53	.739	.318	.512	.514	3.01
.04	.027	.032	.004	.032	.028	.54	.754	.321	.526	.527	3.11
.05	.037	.038	.006	.038	.041	.55	.769	.324	.539	.541	3.21
.06	.046	.044	.009	.043	.054	.56	.783	.327	.553	.555	3.31
.07	.057	.050	.012	.050	.072	.57	.797	.330	.566	.569	3.41
.08	.068	.056	.015	.056	.091	.58	.811	.333	.580	.584	3.52
.09	.079	.063	.019	.063	.113	.59	.825	.336	.593	.599	3.63
.10	.091	.069	.023	.069	.136	.60	.840	.339	.607	.614	3.73
.11	.104	.078	.028	.078	.165	.61	.854	.342	.620	.630	3.85
.12	.117	.085	.034	.086	.196	.62	.867	.344	.633	.647	3.96
.13	.131	.093	.040	.094	.228	.63	.881	.347	.646	.664	4.08
.14	.144	.100	.046	.101	.261	.64	.895	.349	.659	.682	4.20
.15	.158	.107	.053	.109	.296	.65	.909	.351	.673	.700	4.32
.16	.173	.115	.061	.118	.337	.66	.921	.352	.683	.716	4.42
.17	.188	.123	.069	.127	.380	.67	.934	.354	.694	.733	4.53
.18	.203	.130	.077	.136	.424	.68	.946	.355	.704	.750	4.65
.19	.218	.137	.086	.144	.470	.69	.958	.356	.715	.767	4.76
.20	.233	.144	.095	.153	.517	.70	.970	.357	.725	.785	4.88
.21	.248	.151	.105	.162	.569	.71	.982	.358	.735	.806	5.00
.22	.264	.159	.115	.172	.622	.72	.994	.359	.746	.827	5.13
.23	.280	.166	.126	.181	.676	.73	1.005	.360	.756	.848	5.26
.24	.295	.173	.136	.191	.732	.74	1.017	.361	.766	.871	5.39
.25	.311	.180	.147	.200	.789	.75	1.029	.362	.776	.894	5.52
.26	.328	.188	.160	.211	.856	.76	1.039	.361	.783	.918	5.65
.27	.345	.195	.173	.222	.924	.77	1.048	.361	.790	.944	5.78
.28	.363	.203	.186	.233	.994	.78	1.058	.361	.796	.971	5.92
.29	.380	.210	.199	.244	1.07	.79	1.068	.360	.803	.999	6.05
.30	.397	.217	.213	.255	1.14	.80	1.077	.360	.810	1.03	6.20
.31	.411	.222	.224	.264	1.20	.81	1.086	.359	.815	1.06	6.35
.32	.425	.227	.235	.274	1.26	.82	1.096	.358	.821	1.10	6.51
.33	.440	.232	.247	.283	1.33	.83	1.105	.357	.827	1.13	6.68
.34	.454	.237	.258	.293	1.39	.84	1.114	.357	.832	1.17	6.85
.35	.468	.241	.269	.302	1.46	.85	1.123	.356	.838	1.22	7.03
.36	.484	.247	.283	.313	1.54	.86	1.132	.354	.842	1.27	7.24
.37	.499	.252	.296	.324	1.61	.87	1.140	.353	.846	1.33	7.46
.38	.515	.257	.309	.335	1.69	.88	1.149	.352	.851	1.39	7.69
.39	.530	.262	.323	.346	1.77	.89	1.158	.350	.855	1.46	7.93
.40	546	.267	.337	.357	1.85	.90	1.167	.349	.859	1.53	8.19
.41	.561	.272	.349	.369	1.93	.91	1.173	.346	.858	1.62	8.46
.42	.576	.276	.362	.380	2.01	.92	1.179	.342	.857	1.71	8.75
.43	.591	.280	.376	.391	2.10	.93	1.185	.339	.856	1.85	9.14
.44	.605	.284	.389	.403	2.18	.94	1.191	.336	.855	2.00	9.57
.45	.620	.288	.402	.415	2.27	.95	1.197	.332	.854	2.22	10.1
.46	.635	.292	.416	.427	2.35	.96	1.203	.324	.844	--------	--------
.47	.650	.296	429	.439	2.44	.97	1.209	.317	.835	--------	--------
.48	.665	.300	.443	.451	2.53	.98	1.215	.310	.826	--------	--------
.49	.680	.304	.457	.463	2.63	.99	1.220	.303	.818	--------	--------
.50	.695	.308	.471	.476	2.72	1.00	1.226	.297	.810	--------	--------

[1] d=depth of water, in feet; D=rise, in feet.

Table 4.—Coefficients for pipe-arches flowing partly full—Continued

d/D[1]	(1) $A=C_aD^2$ C_a	(2) $R=C_rD$ C_r	(3) $K=C_k\frac{D^{8/3}}{n}$ C_k	(4) $d_m=C_mD$ C_m	(5) $Q=C_qD^{5/2}$ C_q	d/D[1]	(1) $A=C_aD^2$ C_a	(2) $R=C_rD$ C_r	(3) $K=C_k\frac{D^{8/3}}{n}$ C_k	(4) $d_m=C_mD$ C_m	(5) $Q=C_qD^{5/2}$ C_q
E. Nominal sizes 16 feet 7 inches × 10 feet 1 inch and 15 feet 4 inches × 9 feet 3 inches, and all riveted pipe-arches											
0.01	0.013	0.031	0.002	0.031	0.013	0.51	0.747	0.318	0.517	0.494	2.98
.02	0.27	0.43	.005	0.43	.031	.52	.761	.321	.531	.506	3.07
.03	.040	.053	.008	.053	.052	.53	.775	.324	.544	.518	3.17
.04	.053	.060	.012	.060	.073	.54	.789	.327	.557	.531	3.26
.05	.066	.069	.017	.069	.098	.55	.804	.330	.571	.544	3.36
0.6	.080	.076	.021	.075	.124	.56	.819	.333	.585	.558	3.47
.07	.093	.082	.026	.082	.150	.57	.834	.336	.599	.573	3.58
.08	.106	.087	.031	.087	.177	.58	.849	.339	.613	.587	3.69
.09	.119	.093	.036	.093	.205	.59	.864	.342	.627	.602	3.80
.10	.131	.098	.042	.098	.234	.60	.879	.343	.642	.617	3.92
.11	.144	.105	.048	.105	.265	.61	.892	.343	.651	.632	4.03
.12	.157	.110	.054	.111	.296	.62	.905	.344	.659	.648	4.14
.13	.169	.116	.060	.117	.329	.63	.919	.344	.668	.663	4.25
.14	.182	.121	.066	.122	.362	.64	.932	.344	.677	.679	4.36
.15	.195	.126	.073	.128	.395	.65	.945	.345	.686	.696	4.47
.16	.209	.132	.081	.135	.437	.66	.959	.345	.701	.714	4.60
.17	.223	.139	.089	.143	.480	.67	.972	.349	.716	.732	4.72
.18	.238	.145	.097	.151	.523	.68	.985	.353	.731	.751	4.85
.19	.252	.150	.106	.158	.568	.69	.998	.357	.746	.771	4.97
.20	.266	.156	.114	.165	.614	.70	1.012	.361	.762	.791	5.11
.21	.280	.162	.124	.173	.661	.71	1.024	.362	.772	.811	5.23
.22	.294	.168	.133	.181	.709	.72	1.036	.362	.783	.832	5.37
.23	.308	.173	.142	.188	.758	.73	1.049	.363	.793	.854	5.50
.24	.322	.179	.152	.196	.808	.74	1.061	.364	.803	.876	5.64
.25	.335	.185	.162	.204	.859	.75	1.073	.365	.814	.899	5.77
.26	.351	.191	.173	.213	.919	.76	1.084	.364	.821	.925	5.91
.27	.366	.197	.184	.223	.981	.77	1.094	.364	.829	.952	6.06
.28	.382	.203	.196	.232	1.04	.78	1.105	.364	.837	.979	6.21
.29	.397	.209	.208	.242	1.11	.79	1.116	.364	.845	1.01	6.36
.30	.413	.215	.220	.251	1.17	.80	1.126	.363	.852	1.04	6.51
.31	.430	.222	.234	.262	1.25	.81	1.136	.362	.858	1.07	6.68
.32	.447	.229	.248	.273	1.33	.82	1.147	.361	.864	1.11	6.86
.33	.464	.235	.262	.284	1.40	.83	1.157	.361	.871	1.15	7.04
.34	.481	.241	.277	.296	1.48	.84	1.167	.360	.877	1.19	7.23
.35	.498	.247	.292	.307	1.57	.85	1.177	.359	.883	1.24	7.43
.36	.513	.252	.305	.318	1.64	.86	1.186	.357	.886	1.29	7.65
.37	.529	.257	.318	.328	1.72	.87	1.195	.355	.890	1.35	7.88
.38	.544	.262	.331	.339	1.80	.88	1.204	.353	.894	1.41	8.12
.39	.560	.267	.345	.350	1.88	.89	1.213	.352	.898	1.48	8.37
.40	.575	.272	.358	.361	1.96	.90	1.222	.350	.902	1.55	8.64
.41	.591	.277	.373	.372	2.05	.91	1.228	.346	.900	1.64	8.93
.42	.607	.282	.388	.384	2.14	.92	1.235	.343	.899	1.74	9.25
.43	.623	.286	.402	.396	2.23	.93	1.241	.340	.898	1.87	9.64
.44	.639	.291	.417	.408	2.32	.94	1.247	.336	.897	2.02	10.0
.45	.655	.296	.432	.420	2.41	.95	1.254	.333	.896	2.22	10.6
.46	.671	.300	.446	.432	2.50	.96	1.259	.326	.886	--------	--------
.47	.686	.304	.461	.444	2.59	.97	1.264	.319	.876	--------	--------
.48	.702	.308	.475	.456	2.69	.98	1.268	.312	.867	--------	--------
.49	.717	.311	.489	.469	2.79	.99	1.273	.306	.859	--------	--------
.50	.732	.315	.504	.481	2.88	1.00	1.280	.300	.848	--------	--------

[1] d=depth of water, in feet: D=rise, in feet.

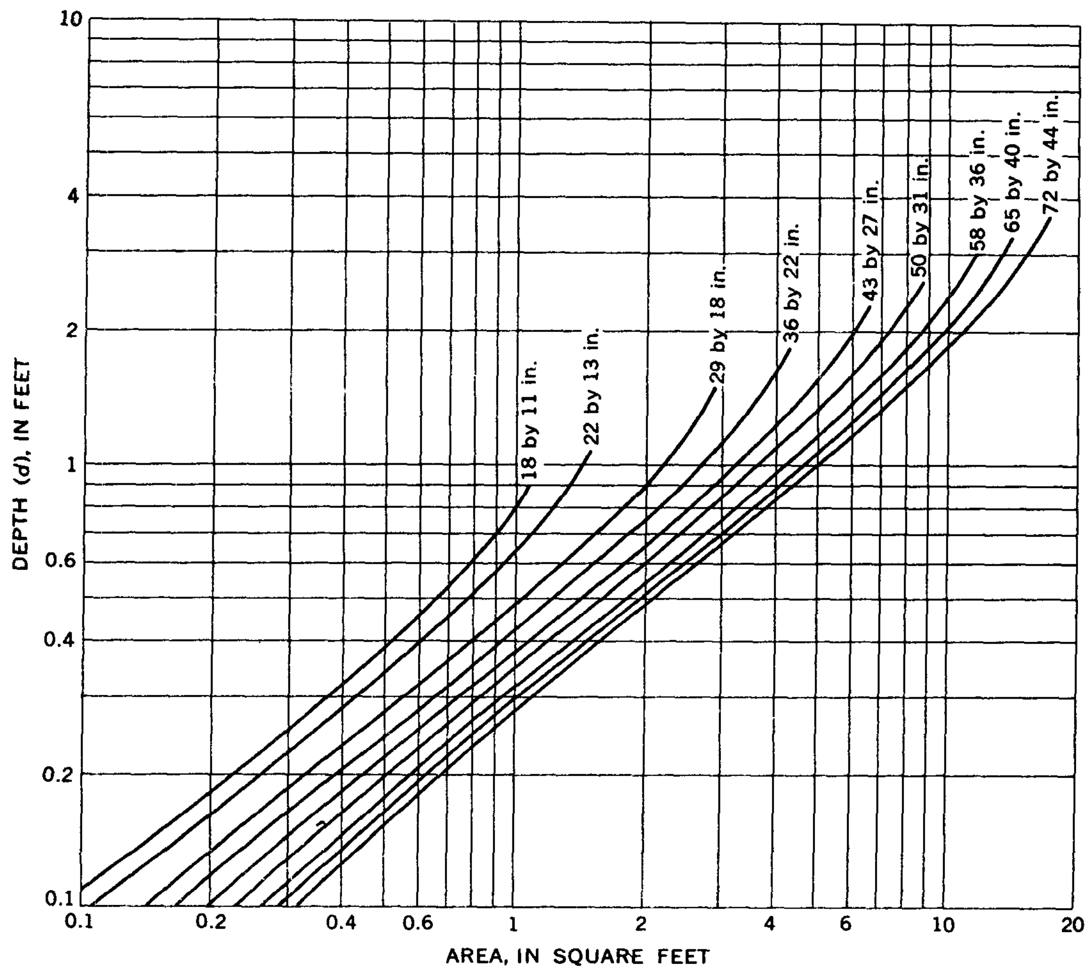

Figure 5.—Depth-area curves for riveted pipe-arches.

showing properties of certain size pipes, and pipe-arches. The purpose of these figures is to show the general shape these curves will follow as well as to show certain types of curves that may be of value for simplifying computations of odd-shaped culverts.

Flow at critical depth

At first glance, it may not be possible to tell whether type 1, 2, or 3 (a backwater condition) flow occurred. If the culvert is very steep and the getaway conditions are good, the flow will be type 1. For culverts set on zero grade with good getaway conditions and no backwater, type 2 flow is well assured. In both cases the type of flow must be proved. For fairly flat slopes and when backwater may be a factor, there is always the possibility of type 3 flow occurring. The following computational procedures will identify the type of flow.

Type 1 flow

The general procedure is to (1) assume that type 1 flow occurred, (2) compute the elevation of the water surface at critical depth and the critical slope, and (3) compare the critical slope with the bed slope, and the water-surface elevation at critical depth with the tailwater elevation. This will generally result in positive identification of types 1 or 3 flow or narrow the possible flow conditions to types 2 or 3.

If critical depth occurs at the inlet, the discharge may be computed with the applicable critical-depth equations, 1, 2, 3, 4, and the energy equation 5 as written between the approach section and the inlet.

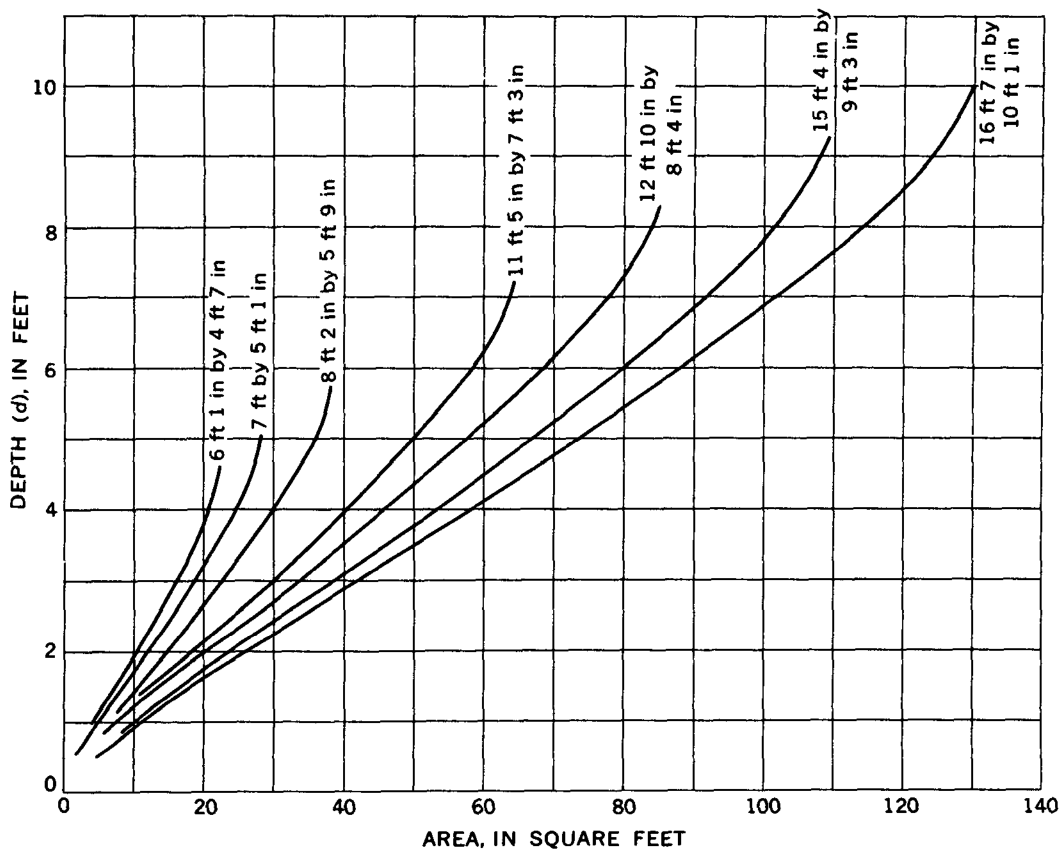

Figure 6.—Depth-area curves for multiplate pipe-arches.

In type 1 flow critical depth normally is assumed to occur at the inlet or upstream end of the culvert. However, a limited number of current-meter measurements have shown that, for mitered pipes on steep slopes, this assumption will show less water than is actually flowing through the culvert. For mitered pipes, assume that critical depth occurs at the point where the headwater elevation intersects the mitered entrance. For large culverts the difference in elevation between the inverts at each end of the miter may be several tenths of a foot. Computations of type 1 flow for these two invert elevations will show considerably different discharges.

Normally, a critical depth is assumed which fixes the value of the remaining unknown terms. A good first approximation is $d_c=0.66(h_1-z)$. Successive approximations of d_c will quickly converge toward the solution.

To check the assumption of type 1 flow, the critical slope for the culvert is computed as $S_c=(Q/K_c)^2$. Here S_c is the critical slope and K_c is the conveyance of the section of flow at critical depth at the inlet. If $S_c<S_0$ and $h_4<h_c$, the assumption of type 1 flow has been proved and the correct discharge has been computed. If $h_4>h_c$, type 3 flow has been identified and the discharge may be computed as outlined on page 30. If $h_4<h_c$ and $S_c>S_0$, type 2 flow is assumed and the analysis is continued as outlined on pages 25–30.

For circular, pipe-arch, and rectangular sections, the identification of flow type is simplified by figures 9, 10, and 11. The procedure is outlined below.

Circular sections

1. Compute $(h_1-z)/D$ and $(S_0D^{1/3})/n^2$ and plot the point on figure 9. A point to the right of the curve indicates type 1 flow and a point to the left, type 2 flow.
2. Determine d_c from figure 10.
3. Compare (d_c+z) with h_4.

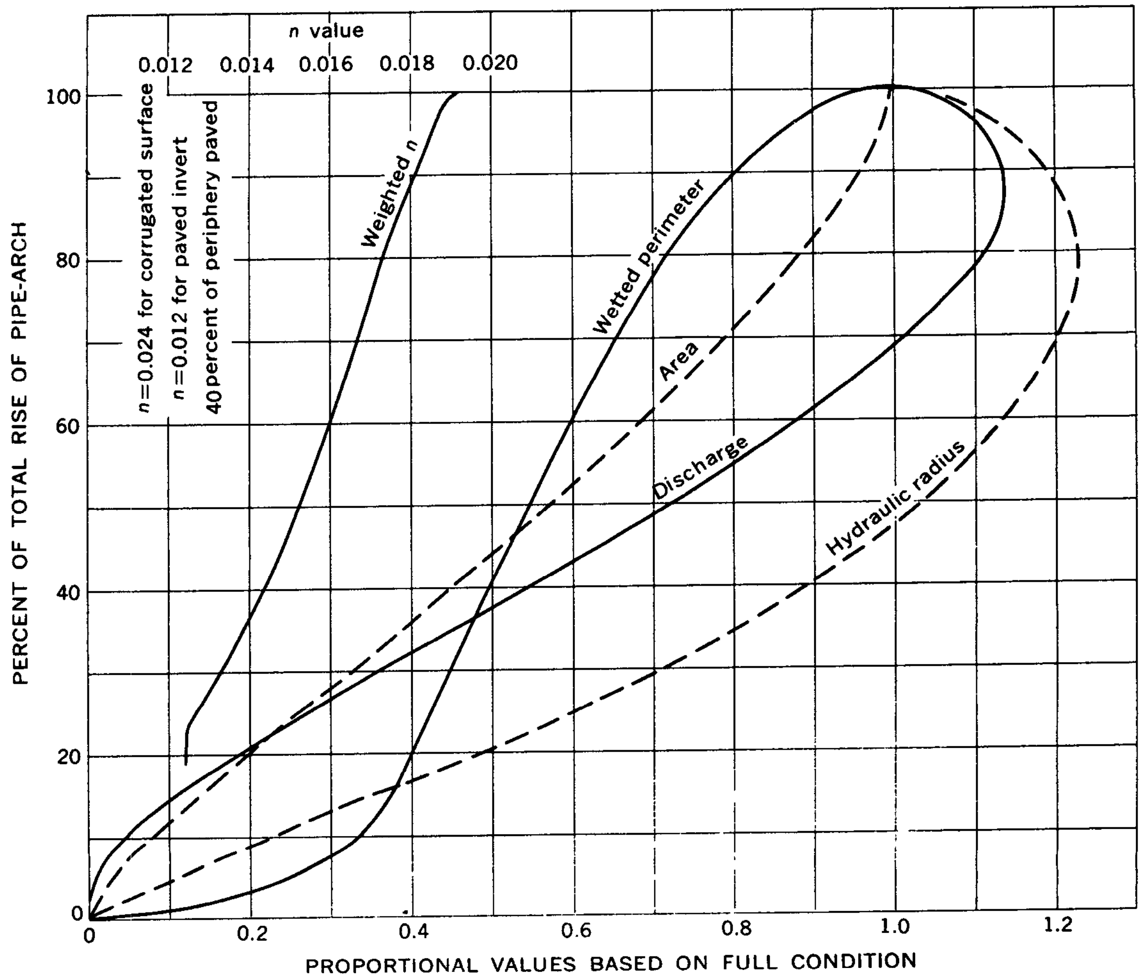

Figure 7.—Hydraulic properties of the paved-invert pipe-arch.

Pipe-arch data for full flow are as follows:

Span (in)	Rise (in)	Area (sq ft)	R (ft)
18	11	1.1	0.280
22	13	1.6	.340
25	16	2.2	.400
29	18	2.8	.446
36	22	4.4	.560
43	27	6.4	.679
50	31	8.7	.791
58	36	11.4	.891
65	40	14.3	1.01
72	44	17.6	1.12

4. Type 1 flow can occur only if the criterion of step 1 is met and $h_4<(d_c+z)$. If type 1 flow is identified, compute the discharge with equations 4 and 5 as outlined below. Type of flow must always be proved after final computations are made.

Computation steps:

1. Compute C, the discharge coefficient.
2. Enter figure 10 with $(h_1-z)/D$ and select value of d_c/D from the appropriate curve. Compute d_c.
3. With this value of d_c, enter equation 4 and compute Q.
4. Compute $\alpha_1 V_1^2/2g$, $h_{f_{1-2}}$, and A_c.

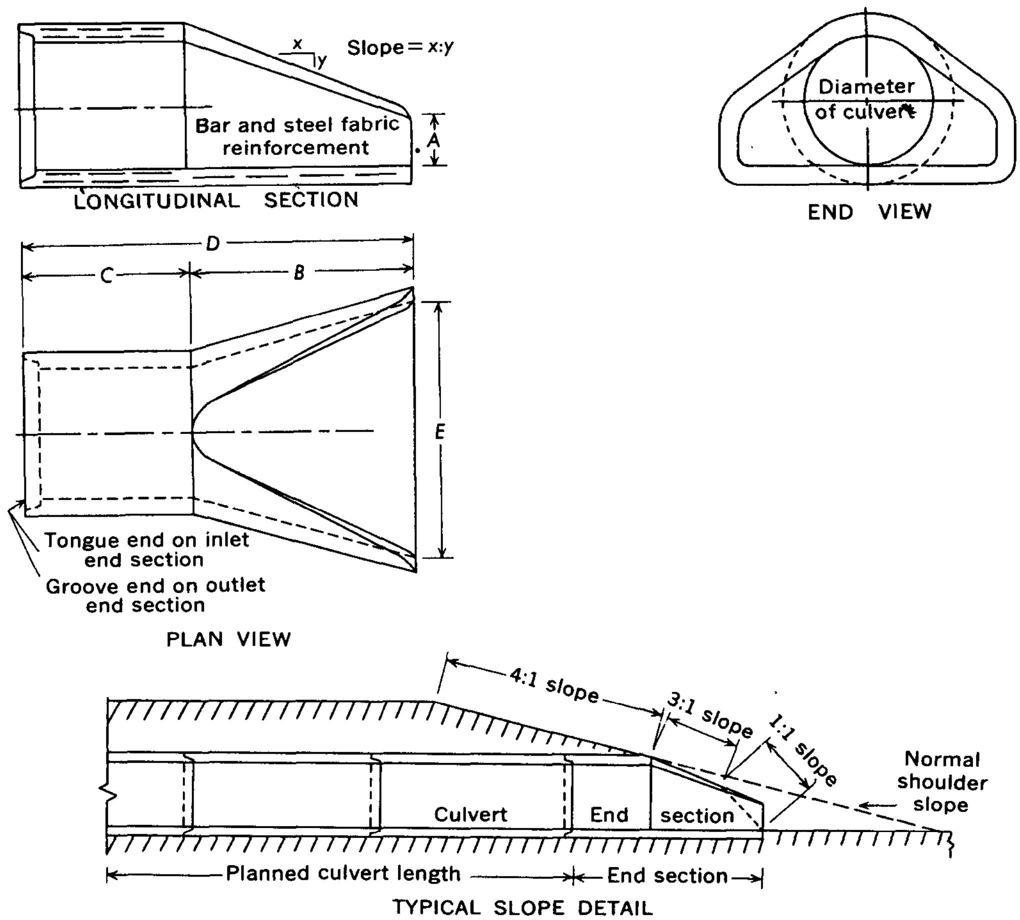

Figure 8.—Dimensions of flared end sections for reinforced concrete pipe.

Selected dimensions for various diameters of pipe

Diam (in)	A (ft	in)	B (ft	in)	C (ft	in)	D (ft	in)	E (ft	in)
12	0	4	2	0	4	0⅞	6	0⅞	2	0
15	0	6	2	3	3	10	6	1	2	6
18	0	9	2	3	3	10	6	1	3	0
21	0	9	3	0	3	1½	6	1½	3	6
24*	0	9½	3	7½	2	6	6	1½	4	0
27	0	10½	4	1½	2	0	6	1½	4	6
30*	1	0	4	6	1	7¾	6	1¾	5	0
36	1	3	5	3	2	10¾	8	1¾	6	0
42	1	9	5	3	2	11	8	2	6	6
48	2	0	6	0	2	2	8	2	7	0
54	2	3	5	5	2	9¼	8	2¼	7	6

*Overall length (*D*) of Iowa design is 8 ft 1½ in for 24 in and 8 ft 1¾ in for 30 in.

NOTE.—Slope 3:1 for all sizes except 54 in. which is 2.4:1.

5. Compute Q from equation 5. Generally this computed Q will closely check the assumed Q from step 3. If it does not, repeat steps 2–5, using $[h_1+\alpha_1 V_1^2/2g-h_{f_{1-2}}]$ for $[h_1]$ in step 2.

When the two discharges check within 1 percent, the final result may be considered satisfactory.

Pipe-arch sections

Type 1 flow in a riveted pipe-arch is computed in exactly the same steps as for a circular section by using the pipe-arch data in figures 9 and 10. Not all multiplate pipe-arches are geometrically similar to riveted pipe-arches or to each other. Therefore the curves of figures 9 and 10 will provide less accurate values.

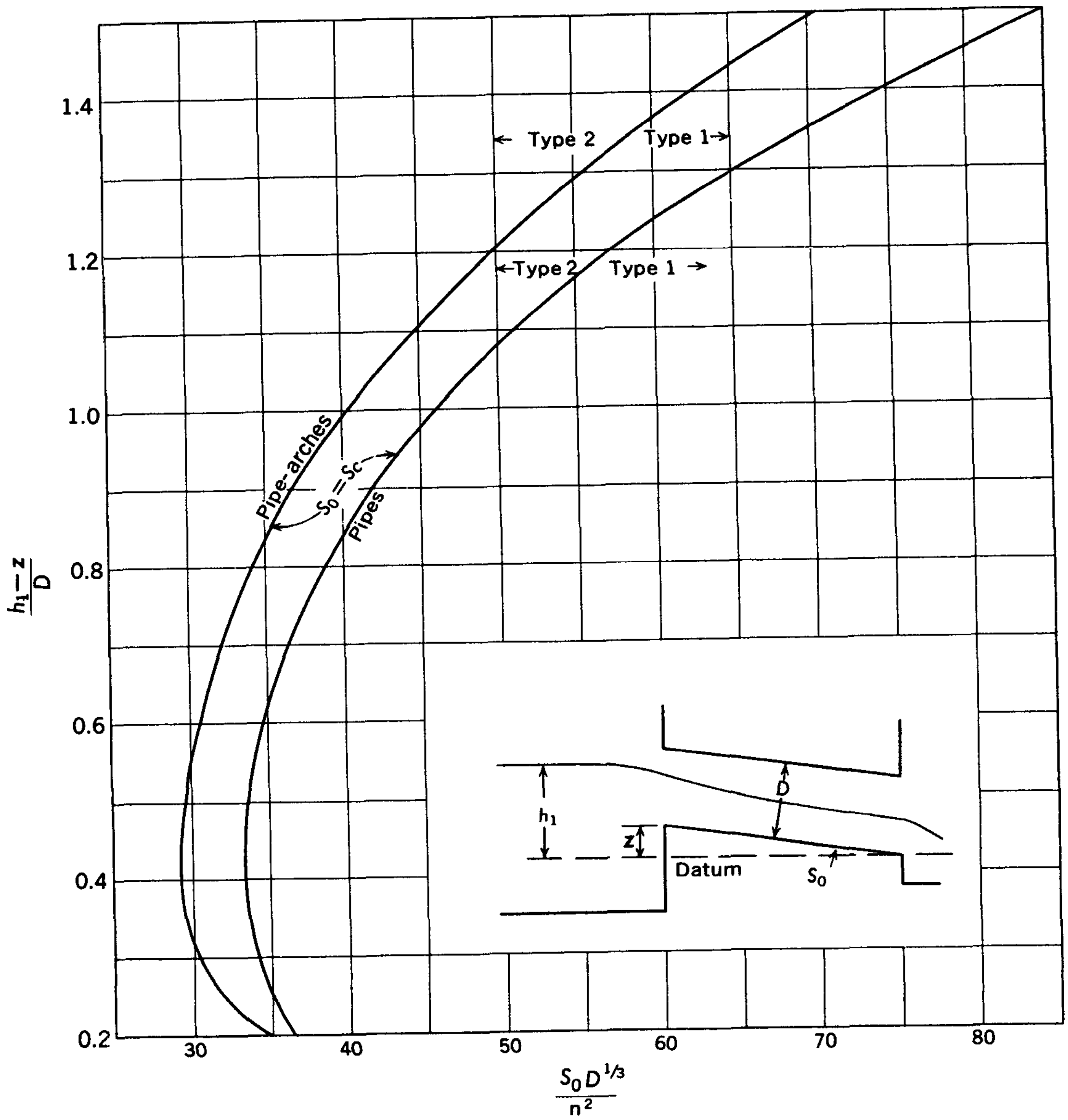

Figure 9.—Critical slope as a function of head for pipe and pipe-arch culverts, with free outfall.

However, because the values from figures 9 and 10 are only approximations, they are satisfactory to use for multiplate pipe-arch flow computation.

Rectangular sections

1. Compute the factors for the ordinate and abscissa of figure 11 for the culvert, assuming $d_c=0.66(h_1-z)$, and plot the point. A point to the right of the line indicates type 1 flow, and a point to the left indicates type 2 flow.
2. Compare (d_c+z) with h_4.
3. Type 1 flow can occur only if the criterion of step 1 is met and $h_4<(d_c+z)$. If type 1 flow is identified, compute the discharge with equations 3 and 5 as outlined below.

Computation steps:

1. Compute C.
2. Determine d_c factor from table on page 25.
3. Assume $d_c=d_c$ factor times (h_1-z).
4. With value of d_c from step 3, enter equation 3 and compute Q.
5. Compute $\alpha_1 V_1^2/2g$, $h_{f_{1-2}}$, and A_c.

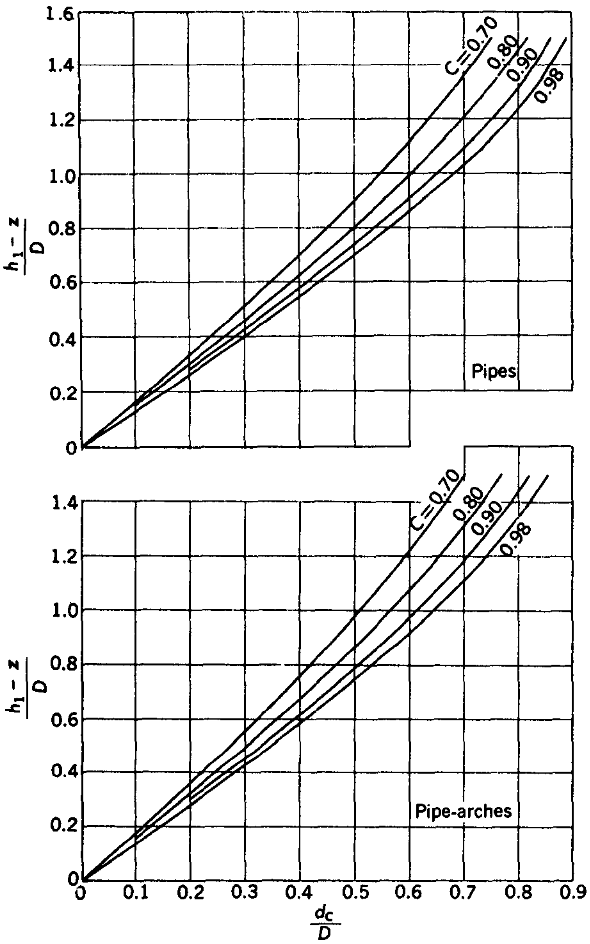

Figure 10.—Relation between head and critical depth in pipe and pipe-arch culverts.

6. Compute Q from equation 5. Generally this computed Q will closely check the assumed Q from step 4. If it does not, repeat steps 2–6, using

   $[h_1+\alpha_1 V_1^2/2g-h_{f_{1-2}}]$ for $[h_1]$ in step 3.

Computation of type 1 flow with ponded headwater for rectangular box culverts set flush in a vertical headwall is simplified by the fact that C is limited to values from 0.95 to 0.98. The factor 0.66 in the formula $d_c=0.66(h_1-z)$ can be refined to give a final result with one computation. The following table gives factors for various values of C:

C	d_c *factor*
0.98	0.658
.97	.653
.96	.648
.95	.643

Irregular sections

Arches and all other culverts that have irregularly shaped bottoms or tops (including rectangular shapes with fillets but excluding pipe-arches) are considered in this category. The same general procedure is used in computing discharge for irregular shapes, except that equation 1 or 2 must be used with equation 5 to obtain the unique solution. For rectangular culverts with fillets, a variation of equation 3, in the form of $Q=5.67\,Td_m^{3/2}$, may be used.

If a number of discharge computations will be made for a given irregularly shaped culvert, prepare graphs of area, wetted perimeter, and conveyance.

Type 2 flow

If type 2 flow is correctly assumed, the critical depth should occur at the outlet. The flow equations used for the computation of type 1 flow are also applicable here, with the further provision that the barrel friction loss must be accounted for in the energy equation since the control section has shifted to the outlet.

The discharge and the critical depth must be computed by solution of equation 7 and the applicable critical-depth equation 1, 2, 3, or 4. The solution is tedious, because to compute the barrel friction loss, $h_{f_{2-3}}$, the height of the water surface at the inlet must be established.

The complete equation for determining the depth d_2 at the inlet is

$$h_1-z=d_2+\frac{V_2^2}{2g}+\left(\frac{1}{C^2}-1\right)\frac{V_3^2}{2g}+h_{f_{1-2}}-\frac{\alpha_1 V_1^2}{2g}. \tag{13}$$

Even though entrance losses actually are a function of the terminal velocity rather than of the entrance velocity, the above equation may be simplified for most computations by assuming $V_3=V_2$. Under average conditions this is a fair approximation. Also, as a general rule, where ponded conditions exist above the culvert, or the approach velocity head and the approach friction loss are compensating, these factors may be neglected. Thus, the equation is simplified to

$$h_1-z=d_2+\frac{V_2^2}{2gC^2}. \tag{14}$$

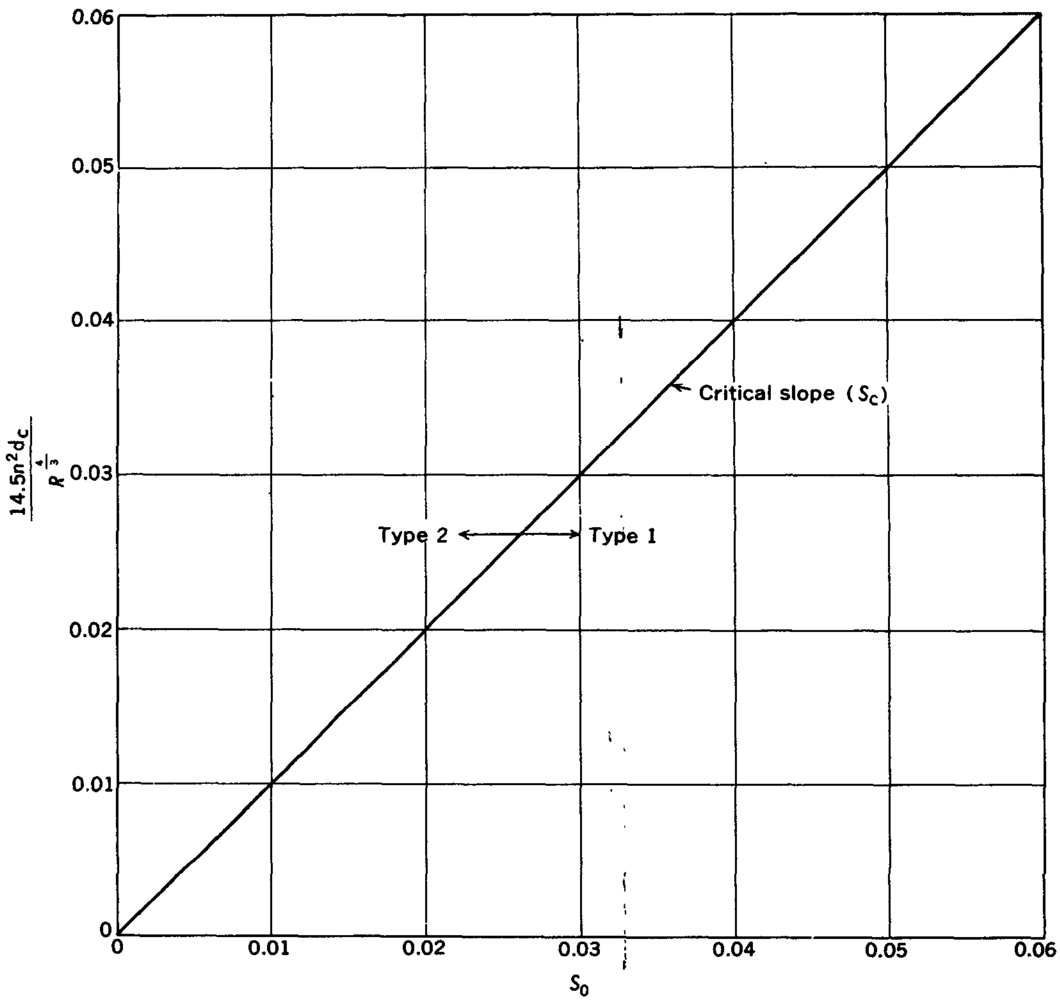

Figure 11.—Critical slope for culverts of rectangular section, with free outfall.

Figures 12 and 13 are graphical solutions of equation 14 for circular and riveted pipe-arch sections. Figure 14 is the solution for square or rectangular sections. These curves are based on ponded approach conditions and the assumption that $V_3=V_2$. Similar curves may be constructed for any given culvert shape, but the development is so tedious that it generally is not worthwhile.

In the event that approach velocity head and friction loss cannot be neglected, the (h_1-z) term should be increased by their algebraic sum.

In long rough culverts V_3 is much larger than V_2; therefore,

$$\frac{V_2^2}{2gC^2}<<\frac{V_2^2}{2g}+\left(\frac{1}{C^2}-1\right)\frac{V_3^2}{2g}. \qquad (15)$$

The smaller the discharge coefficient, the greater will be the difference in d_2. The d_2 computed from figures 12, 13, and 14 may be greatly in error when this condition exists. The proper way to determine d_2 in this situation is by routing. The routing method is described on page 31.

The procedure outlined below is recommended for computation of discharge.

Circular sections

Computation steps:

1. Compute C and enter figure 10 with $(h_1-z)/D$. Select the value of d_c/D from the appropriate curve.
2. Use 95 percent of d_c/D as a first approximation to compute d_c. The 95 percent is

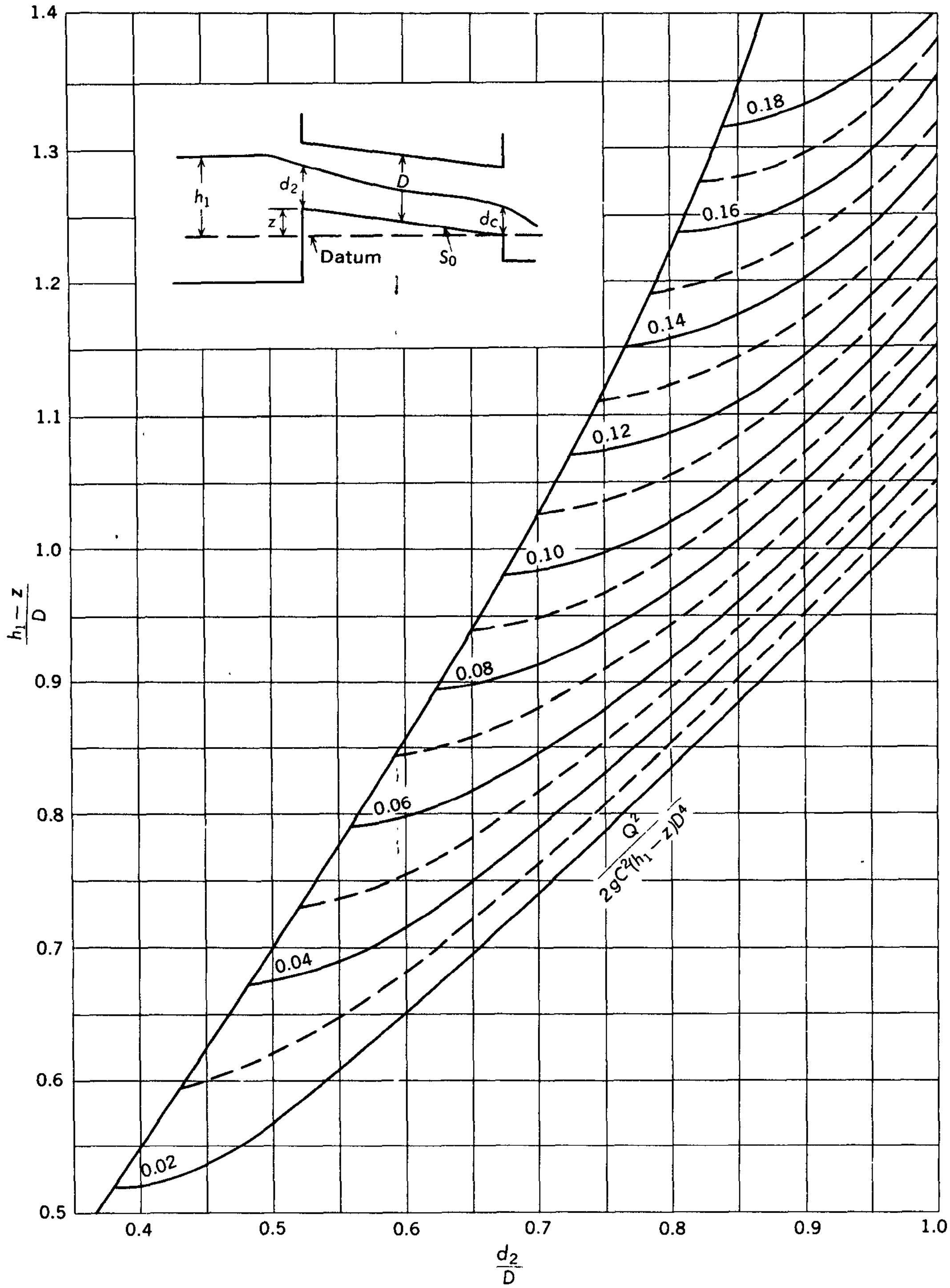

Figure 12.—Relation between head and depth of water at inlet with critical depth at outlet for culverts of circular section.

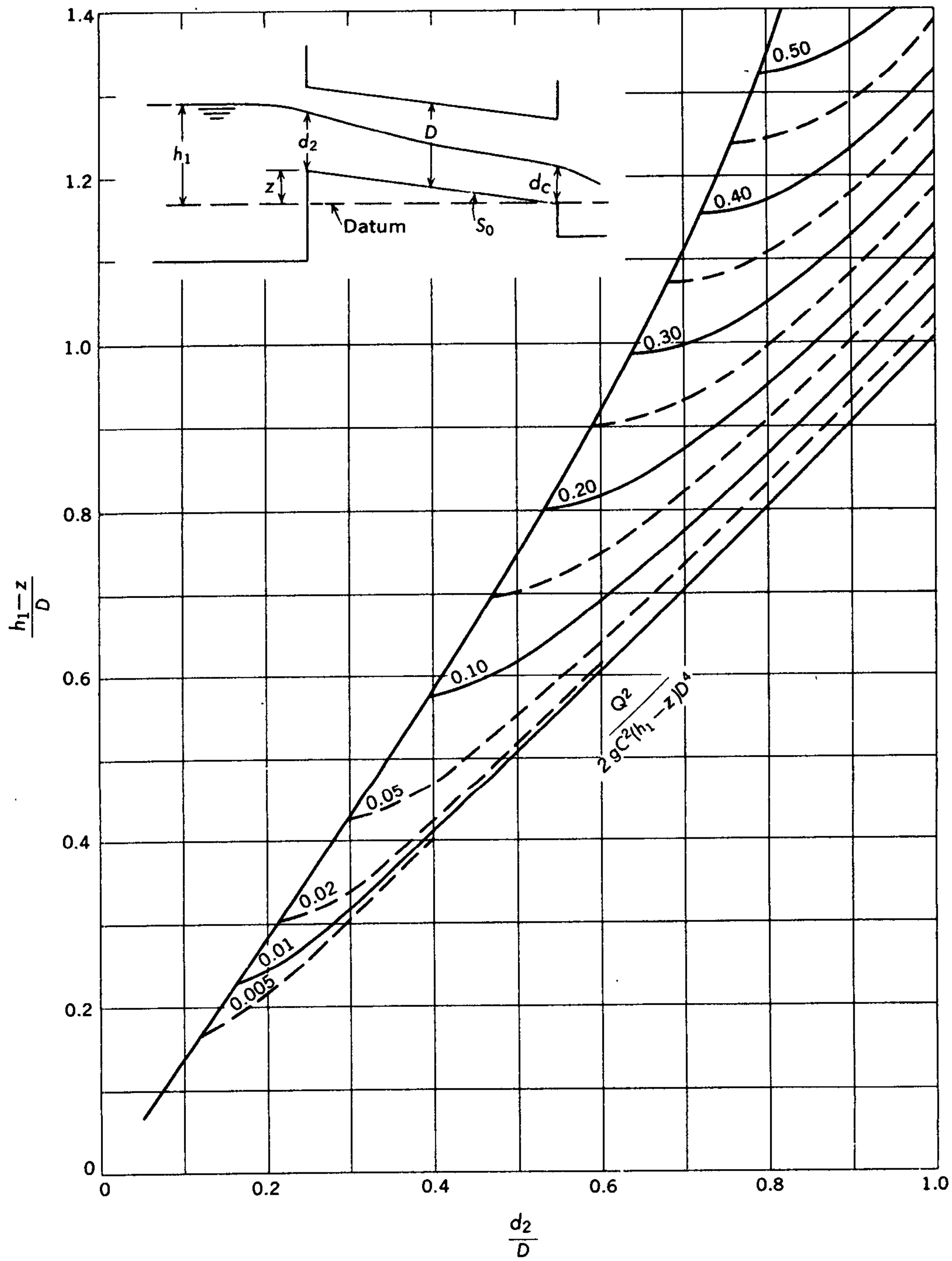

Figure 13.—Relation between head and depth of water at inlet with critical depth at outlet for pipe-arch culverts.

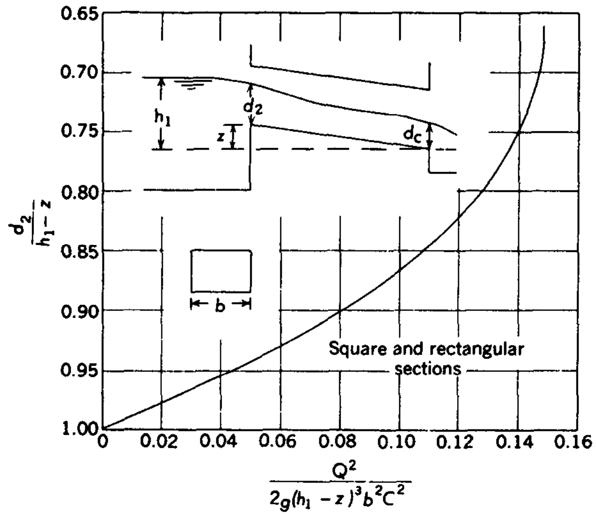

Figure 14.—Relation between head and depth of water at inlet with critical depth at outlet for culverts of rectangular section.

used to compensate for the friction loss in the culvert.

3. With this first approximation of d_c, use equation 4 to obtain a trial value of Q.
4. Compute $Q^2/2gC^2(h_1-z)(D^4)$ and enter figure 12 with $(h_1-z)/D$ to obtain d_2/D. Compute d_2.
5. Having trial values of Q, d_2, and d_3 (which is d_c), compute

   (a) $\alpha_1 V_1^2/2g$

   (b) $h_{f_{1-2}}$

   (c) $h_{f_{2-3}}$.
6. Compute $H=h_1+\alpha_1 V_1^2/2g-h_{f_{1-2}}-h_{f_{2-3}}$.
7. Use value from step 6 as numerator in ratio H/D. Use this ratio as ordinate in figure 10 to read d_c/D.
8. From step 7, compute d_c.
9. Using value of d_c from step 8 in equation 4, compute Q.
10. Compute $Q^2/2gC^2(h_1-z)(D^4)$, using Q from step 9.
11. Use the value from step 10 in figure 12 to obtain d_2/D and compute d_2.
12. Compute the velocity head and friction with latest values of Q, d_c, and d_2. Also compute A_c and K_c.
13. Compute Q from equation 7. The computed Q should closely check the assumed Q of step 9.
14. If the discharge computed with equation 7 is not within 1 percent of the discharge computed in step 9, the assumed value of d_c is incorrect. The correct value of d_c must be determined by successive approximation, repeating the procedure outlined above.
15. After the discharge and the elevation of the water surface at critical depth are established, the assumption of type 2 flow is checked by comparing the elevation of critical depth with the tailwater elevation.

If $h_c > h_4$, type 2 flow occurred. If $h_c < h_4$, type 3 flow occurred, and the discharge may be computed as outlined in the next section.

Pipe-arch sections

Type 2 flow in a riveted pipe-arch is computed in exactly the same manner as for a circular section by using the pipe-arch data in figures 10 and 13. These curves will give approximate values applicable to multiplate pipe-arch computations.

Rectangular sections

Computation steps:

1. Compute C.
2. Determine d_c factor from the table on page 25.
3. Assume d_c (which is d_3)$=d_c$ factor times (h_1-z). Note.—The d_c factor from page 25 may be reduced 0.03 to approximate the friction loss in the culvert.
4. Compute Q from equation 3.
5. Compute $Q^2/2g(h_1-z)^3 b^2 C^2$ and enter figure 14. Obtain a value of $d_2/(h_1-z)$ and compute d_2.
6. Having trial values of Q, d_2, and d_3 (which is d_c) compute

   (a) $\alpha_1 V_1^2/2g$

   (b) $h_{f_{1-2}}$

   (c) $h_{f_{2-3}}$.
7. Compute $H=h_1+\alpha_1 V_1^2/2g-h_{f_{1-2}}-h_{f_{2-3}}$.
8. Assume $d_c=d_c$ factor times value from step 7.
9. Using value of d_c from step 8 in equation 3, compute Q.

10. Compute $Q^2/2g(h_1-z)^3b^2C^2$ and enter figure 14. Obtain a value of $d_2/(h_1-z)$ and compute d_2.
11. Compute $\alpha_1V_1^2/2g$, $h_{f_{1-2}}$, $h_{f_{2-3}}$ from latest values of Q, d_2 and d_c.
12. Compute Q from equation 7. The computed Q should closely check the assumed Q of step 9.
13. If the discharge computed with equation 7 is not equal to the discharge computed in step 9, the procedure given above must be repeated until agreement within 1 percent is reached.
14. The assumption of type 2 flow is checked as for circular sections.

Irregular sections

The same general rules apply to type 2 flow through irregular sections as apply to type 1 flow. Special consideration should be given to roughness coefficients, slope of culvert, and change in shape of culvert cross section. However, the general equations 1 and 2 for critical-depth flow may be used with equation 7 for computing discharge.

Equation 13 should be used to determine depth of water d_2 at the inlet because many irregularly shaped culverts have rough barrels. In these computations, d_2 must be measured in a manner similar to the measurement of d_c, either as the depth to the average bottom or the depth to the lowest point in the section. The same criteria must be used in measuring h_1 and z.

For certain conditions it may be necessary to use the routing method to compute discharge.

Flow with backwater

In flow with backwater, types 3 and 4, critical depth does not occur in the culvert, and the upstream elevation of the water surface for a given discharge is a function of the surface elevation of the tailwater.

Type 3 flow

Water-surface elevations h_1 and h_4 can normally be established from highwater marks, and it is assumed that h_3 equals h_4. The following procedure is recommended in computing discharge:

1. Assume a discharge. A fair approximation is $0.95A_3\sqrt{2g(h_1-h_4)}$.
2. Determine the depth at the inlet d_2 by trial solution of equation 13 or directly from figures 12, 13, or 14 if the culvert has a circular, pipe-arch, or rectangular section.
3. Compute the conveyance of the sections at the approach, the inlet, and the outlet.
4. Compute the friction loss between the approach and the inlet,

$$h_{f_{1-2}}=L_w(Q^2/K_1K_2),$$

and between the inlet and the outlet

$$h_{f_{2-3}}=L(Q^2/K_2K_3).$$

5. Compute the approach velocity head, $\alpha_1V_1^2/2g$.
6. Compute the discharge with equation 8.
7. If the discharge computed with equation 8 is not equal to the assumed discharge, then another discharge should be assumed and the procedure outlined above repeated.

Type 4 flow

Generally for type 4 flow, ponded conditions exist. If water is not ponded, h_1 should be adjusted for velocity head in the approach section and friction loss between the approach section and the inlet.

Discharge is computed directly from equation 9, where A_0 and R_0 are the area and hydraulic radius, respectively, for a full culvert.

A constant can be determined for any given culvert, so the discharge can be computed simply by multiplying the constant, which equals

$$CA_0\sqrt{\frac{2g}{1+\frac{29C^2n^2L}{R_0^{4/3}}}}$$

by the square root of the difference between headwater and tailwater elevations, $\sqrt{h_1-h_4}$. Note that type 4 flow is independent of the culvert slope.

Flow under high head

Type 5 or 6 flow will occur if the tailwater is below the crown at the outlet, and $(h_1-z)/D$ is equal to or greater than 1.5. Approach velocity head and friction loss are included in the computations when appropriate.

The type of flow is dependent largely on the amount of beveling or rounding of the culvert entrance. For this and other reasons previously mentioned, the criteria for identifying type 5 or type 6 flow must be considered approximate. Generally there is a transition from low-head to high-head flow that must be considered. This item is discussed under "Ratings with Transition between Flow Types," on page 47.

Concrete culverts

Figure 15 may be used to classify type 5 or 6 flow in concrete culvert barrels by the procedure outlined below.

1. Compute the ratios L/D, r/D, or w/D, and S_0.
2. Select the curve of figure 15 corresponding to r/D or w/D for the culvert. Sketch in an interpolated curve for the given r/D or w/D, if necessary.
3. Plot the point defined by S_0 and L/D for the culvert.
4. If the point lies to the right of the curve selected in step 2, the flow was type 6; if the point lies to the left, the flow was type 5.

The use of the figure 15 is restricted to square, rounded, or beveled entrances, either with or without wingwalls. Wingwalls do not affect the flow classification, as the rounding effect they provide is offset by a tendency to produce vortexes that supply air to the culvert entrance. For culverts with wingwalls, use the geometry of only the top side of the entrance in computing the effective radius of rounding, r, or the effective bevel, w, in using figure 15.

Corrugated-pipe culverts

Figure 16 may be used to classify type 5 or 6 flow in rough pipes, both circular and pipe-arch sections, mounted flush with a vertical headwall, either with or without wingwalls, as outlined below. Figure 16*A* should be used in classifying the flow if the pipe projects from a headwall or embankment.

1. Determine the ratio r/D for the pipe.
2. From figure 16, select the graph corresponding to the value of r/D for the culvert.
3. Compute the ratio $29n^2(h_1-z)/R_0^{4/3}$ and select the corresponding curve on the graph selected in step 2. Sketch in an interpolated curve for the computed ratio, if necessary.
4. Plot the point defined by S_0 and L/D for the culvert.
5. If the point plots to the right of the curve selected in step 3, the flow was type 6; if the point plots to the left of the curve, the flow was type 5.

Type 5 flow

In type 5 flow the culvert entrance is submerged, and the tailwater is below the crown at the outlet. The flow is rapid near the entrance to the culvert. The discharge may be computed directly from equation 10.

Type 6 flow

In type 6 flow the water surface is assumed to be at the top of the culvert at the outlet, but the culvert is not submerged and free outfall prevails. The following procedure may be used to compute discharge:

1. Compute the ratio h_1/D. Select the discharge coefficient, C, applicable to the culvert geometry.
2. From figure 17, determine the value of $Q/A_0\sqrt{D}$ corresponding to $29n^2L/R_0^{4/3}=1$.
3. Compute the ratio $29n^2L/R_0^{4/3}$ for the culvert under study.
4. From figure 17, using the computed ratio $29n^2L/R_0^{4/3}$ and the coefficient C, find the correction factor, k_f.
5. Multiply the value of $Q/A_0\sqrt{D}$ from step 2 by the value of k_f from step 4, thus determining an adjusted ratio $Q/A_0\sqrt{D}$.
6. Determine the value of Q from the adjusted ratio.

Routing method

The previously described computation procedures cover the standard conditions found in a great majority of culvert installations. The methods for computation of types 1–4 flow are inappropriate for some nonstandard conditions. Some examples of such conditions are:

1. Approach velocity head or friction loss of appreciable amount.

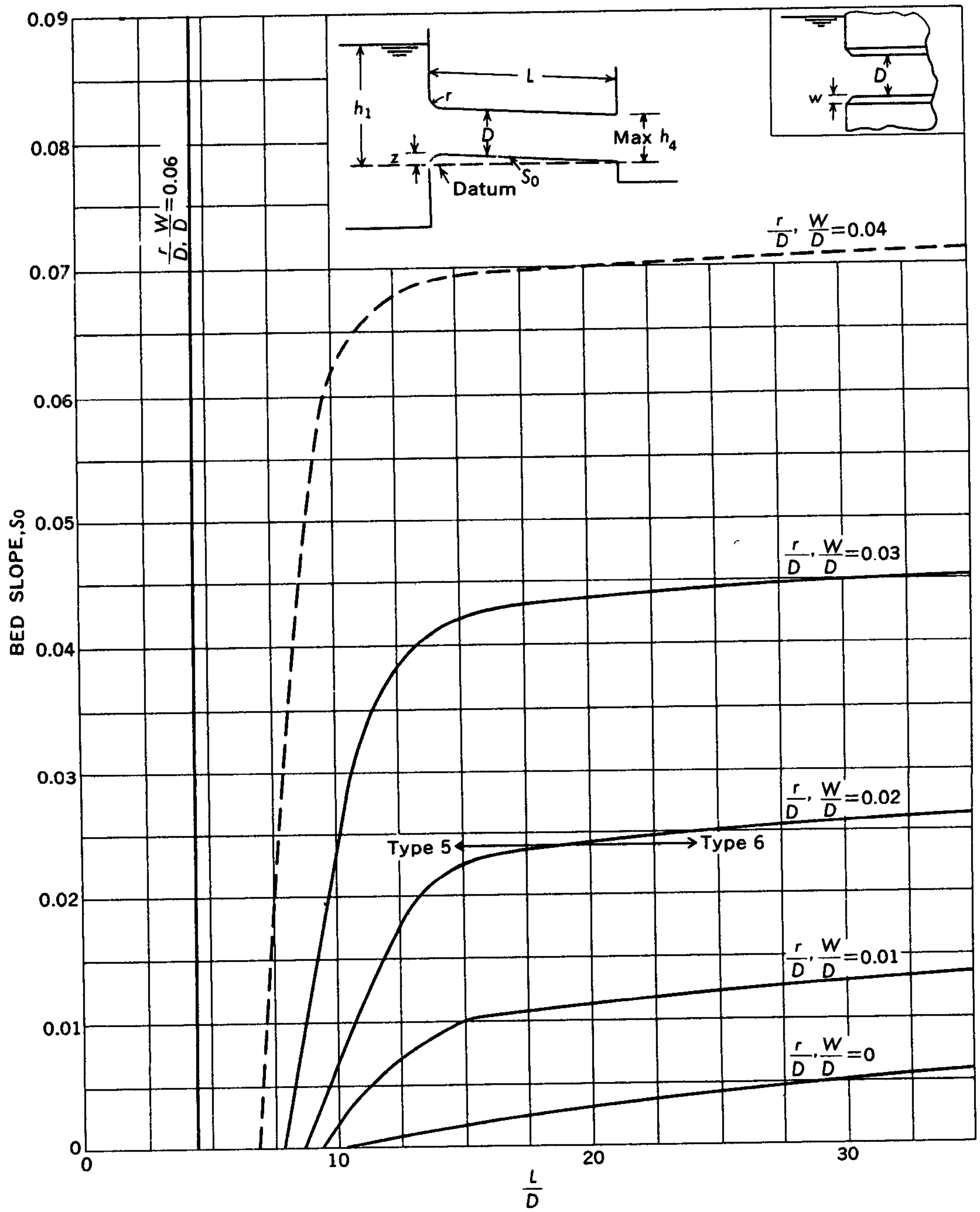

Figure 15.—Criterion for classifying types 5 and 6 flow in box or pipe culverts with concrete barrels and square, rounded, or beveled entrances, either with or without wingwalls.

2. Variation in cross-sectional dimensions through the culvert barrel.
3. Nonuniform slope, break in slope along the culvert barrel, or severe adverse slope.

The standard equations, 5, 7–11, may all be derived by writing the Bernoulli (energy) equation between the control section and the approach section. The routing procedure is a method whereby the energy equation is solved by the following procedures:

1. For flow types 1 and 2 (flow at critical depth), assume a critical depth of flow at the control section, compute the corresponding discharge, then route the energy

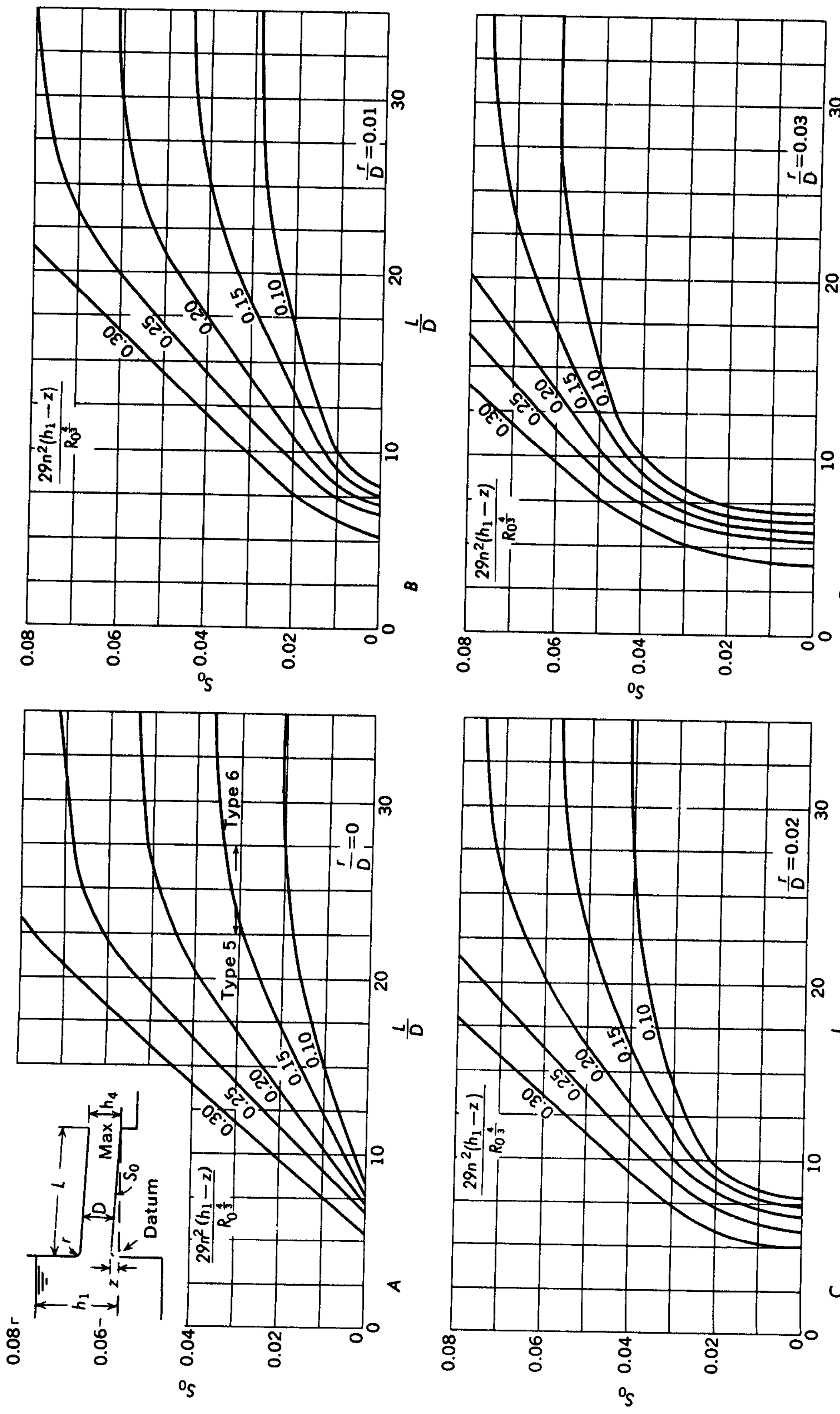

Figure 16.—Criterion for classifying types 5 and 6 flow in pipe culverts with rough barrels.

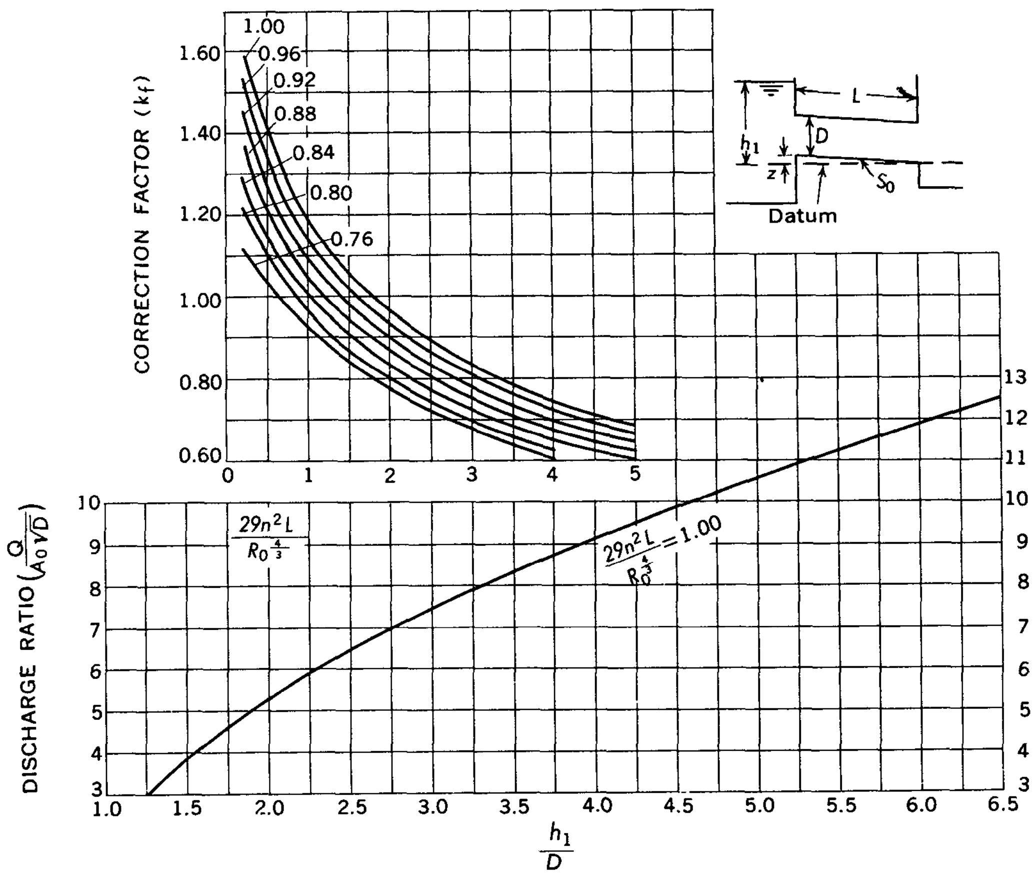

Figure 17.—Relation between head and discharge for type 6 flow.

gradient upstream to the headwater elevation using the computed discharge. If the computed and known elevation there do not agree, assume another critical depth and repeat the procedure.

2. For types 3 and 4 flow (flow with backwater), the discharge is assumed. Then starting with the known tailwater elevation, the energy gradient is routed upstream to the headwater elevation. If the computed headwater elevation differs from that known, repeat the computations using other assumed discharges until agreement is reached.
3. For type 5 flow (flow under high head), the controlling feature is the entrance geometry. The routing procedure cannot be applied here.
4. For type 6 flow (flow under high head), the same procedure is followed as for type 3, except that the starting point for the piezometric head (h_3) must be estimated in some manner. In type 6 flow, h_3 is not measured to the water surface.

(1) For box culverts the line of piezometric head at the outlet may be considered to lie slightly below the centerline for high Froude numbers, gradually increasing to a level about halfway between centerline and top of barrel for a Froude number approaching unity. An average h_3 of $0.65D$ may be used for the range of Froude numbers ordinarily encountered in culvert flow in the field.

(2) For pipe culverts of circular section it is known that the piezometric head usually lies between $0.5D$ and $1.0D$. An average h_3 of $0.75D$ may be used for the range of Froude numbers ordinarily encountered under field conditions. A more exact value, based

on recent experiments with prototype size pipes, may be obtained by use of figure 18.

The routing method can be applied to both standard and nonstandard conditions. Determine type of flow and discharge coefficients from the curves and tables in this manual. Consider the velocity heads at starting and ending points. Compute friction losses separately between points where the bottom slope changes or where contraction occurs. Between any two points 1 and 2, the friction loss is equal to LQ^2/K_1K_2.

Compute entrance loss as $(1/C^2-1)V_3^2/2g$ where C is the discharge coefficient as determined in this chapter and $V_3^2/2g$ is the velocity head at the control or terminal section. Actually the entrance loss occurs through the contracting and expanding portion of the live stream, but it is related to the velocity head at the control or terminal section because of the methods used in determining the discharge coefficients listed in this chapter.

The routing method is performed as follows:

1. Elevation of water surface at the control section.
2. *Plus* velocity head at control section.
3. *Plus* friction loss between control section and entrance.
4. *Plus* entrance loss.
5. *Plus* friction loss between entrance and approach section.
6. *Minus* velocity head at approach section.
7. *Equals* computed headwater elevation.

Compare this computed headwater elevation with the known water-surface elevation and, if different, make successive trials until they reach agreement within 0.02 foot.

For types 2 and 3 flow an intermediate assumption of depth at the culvert entrance is made. Test the assumption by routing to the energy gradient at the entrance (steps 1–3 above), then deducting the velocity head at the entrance. Always verify the type of flow. Remember that it is impossible to route through critical depth.

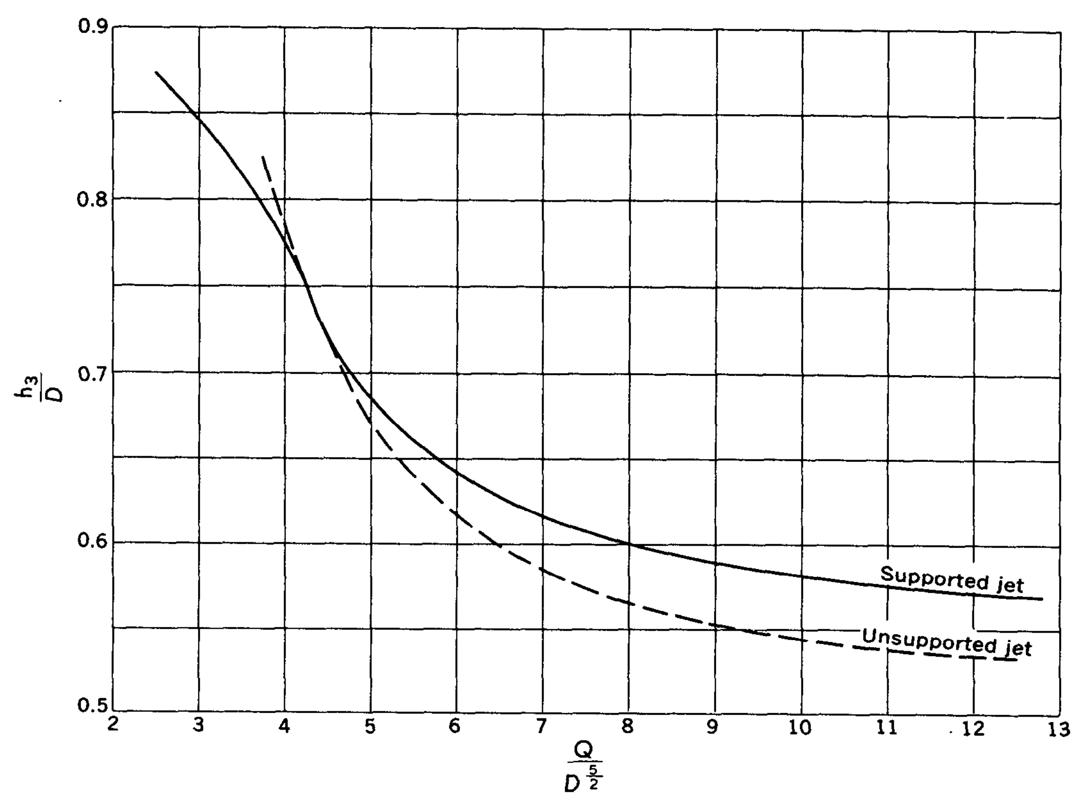

Figure 18.—Relation between outlet pressure lines and discharge for type 6 flow through culverts of circular section. Taken from report by J. L. French, 1956.

Calculations showing the standard and routing methods for various types of flow conditions are given under "Examples."

Unusual conditions

There will be, of course, occasional culvert-flow problems of unusual complexity, examples of which have not been covered in detail in this chapter. In most of the problems, results may be computed by reverting to the basic fundamentals of the subject or to literature covering the special conditions. Undoubtedly there will be occasional problems where no reliable solution is possible.

One exception to the general flow classification is that type 1 flow can occur with h_4 slightly greater than h_c, or with h_4 greater than D. In this case, type 1 flow is proved by trial computation of a backwater curve that extends from the known tailwater surface to the upstream end of the culvert. If the computed water-surface elevation is found to be below d_c, the type 1 flow existed.

Another rare type of part-full flow may sometimes occur where the headwater is below $1.5D$ at the entrance, but the tailwater is above the crown at the outlet.

Type 3 flow can occur with any bottom slope. In a culvert with a steep slope it might occur with $h_4/D>1.0$.

The fact that both $(h_1-z)/D$ and h_4/D are greater than 1.0 does not positively indicate type 4 flow. (h_1-z) must exceed D by an amount equal to $V_0^2/2gC^2$, where V_0 is full culvert velocity, or the pipe will not be full at the upstream end.

A culvert has to be short (L=about 10 diameters) to allow type 5 flow on a mild slope.

In order for type 6 flow to occur on a steep slope, the culvert must have a large r/D ratio, perhaps as great as 0.06.

Examples of unusual conditions that might be experienced are (1) culverts of nonuniform barrel geometry, (2) submerged culverts with flared outlets, (3) culverts with drop inlets, (4) cases where flow is rapid in the approach section, and (5) culverts flowing full part way. Examples 2–4 cannot be satisfactorily computed.

Other conditions which are not so unusual, but which must be given special consideration, are (1) partly buried culverts, (2) culverts in an aggraded section of a stream, (3) culverts partly plugged with debris, and (4) culverts partly plugged with ice.

For a culvert flowing full part way, the length of part-full flow at the downstream end may be determined by writing two equations, each of which will determine the point at which full flow ceases, and solving them simultaneously. Elevation of the culvert crown at the outlet plus the rise in the culvert crown (usually the same as the bottom) in the unknown length must equal the water-surface elevation at the outlet plus the friction loss in the unknown length plus the change in velocity head in the unknown length. The equation is

$$D+S_0x=d_3+Q^2x/K_0K_3+V_3^2/2g-V_0^2/2g, \quad (16)$$

in which x is the length of part-full flow.

Multiple culverts

A multiple-culvert installation is one in which the culvert barrels are separated by more than 0.1 the width or diameter of either barrel. This should not be confused with a multibarrel culvert which generally consists of two or more barrels, separated by thin webs, in a single structure.

Two or more culverts may be used as the drainage structure. In many places the culverts will be (1) made of different materials, (2) laid at different slopes, and (3) installed with different invert elevations. A common occurrence is for different flow types to occur. For example, a small culvert may be flowing under high head while a larger one is flowing as type 3.

At multiple culverts special consideration must be given to the computation of approach friction loss and velocity head. Assume the total discharge and estimate the total culvert area occupied by flow in order to compute these factors. If the assumed values are greatly different from the final result, recompute.

Compute the velocity head for the entire approach section and add to the water-surface elevation to determine the energy head at section 1 applicable to each culvert.

Add the conveyances of the flow sections of all culverts to determine the total conveyance at section 2. Then use this with the total conveyance at section 1 to compute the approach friction loss. Subtract this friction loss from the energy head at section 1 to obtain the energy head at section 2. This energy head is applicable to each of the culverts.

The percent of channel contraction is another factor in which the entire approach area and the combined total of culvert flow areas are used together. Because the total area of flow at the terminal sections of multiple culverts is used, it is possible that one or more of the areas used are located at section 2, and the others are at section 3.

Coefficients of Discharge

Coefficients of discharge, C, for flow types 1–6 were defined by laboratory study and are applicable to both the standard formula and routing methods of computation of discharge. The coefficients vary from 0.39 to 0.98, and they have been found to be a function of the degree of channel contraction and the geometry of the culvert entrance.

For certain entrance geometries the discharge coefficient is obtained by multiplying a base coefficient by an adjustment factor such as k_r or k_w. If this procedure results in a discharge coefficient greater than 0.98, a coefficient of 0.98 should be used as a limiting value in computing the discharge through the culvert.

The coefficients are applicable to both single-barrel and multibarrel culvert installations. If the width of the web between barrels in a multibarrel installation is less than 0.1 of the width of a single barrel, the web should be disregarded in determining the effect of the entrance geometry. Bevels are considered as such only within a range of 0.1 of the diameter, depth, or width of a culvert barrel. Larger sizes are not considered as bevels but as wingwalls.

Laboratory tests also indicate that the discharge coefficient does not vary with the proximity of the culvert floor to the ground level at the entrance. Thus in types 1, 2, and 3 flow, the geometry of the sides determines the value of C; similarly, in types 4, 5, and 6 flow the value of C varies with the geometry of the top and sides. If the degree of rounding or beveling is not the same on both sides, or on the sides and the top, the effect of r or w must be obtained by averaging the coefficients determined for the sides, or for the sides and top, according to the type of flow. One exception is noted: if the vertical sides of the culvert are rounded or beveled and the top entrance is square, multiply the average coefficient (determined by the procedure just described) by 0.90 for type 5 flow and by 0.95 for types 4 and 6 flow, using the coefficient for the square entrance as the lower limiting value.

The discharge coefficient does not vary with culvert skew.

The radius of rounding or degree of bevel of corrugated pipes should be measured in the field. These are critical dimensions that should not be chosen from a handbook and accepted blindly.

The ratio of channel contraction, m, is associated with horizontal contraction typical of flow types 1, 2, and 3. The effect of side contraction becomes negligible for flow types 4, 5, and 6 in which vertical contraction is more important. Therefore, no adjustment for contraction ratios less than 0.80 is warranted for flow types 4, 5, or 6.

In listing the discharge coefficients, it is convenient to divide the six flow types into three groups, each group having a discharge equation of the same general form. Thus, flow types 1, 2, and 3 form one group; types 4 and 6 another; and type 5 a third. The coefficient C is descriptive of the live-stream contraction at the inlet and its subsequent expansion in the barrel of the culvert. Hence, base coefficients for types 1, 2, and 3 flow should be identical for identical geometries, as should coefficients for types 4 and 6.

In a systematic presentation of the coefficients, the entrance geometries have been classified in four general categories: (1) flush setting in vertical headwall, (2) wingwall entrance, (3) projecting entrance, and (4) mitered pipe set flush with sloping embankment. The four classes have been subdivided as necessary, but they all are common to the three flow-type groups.