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design data 37

american concrete pipe association

PARTIAL FLOW CONDITIONS ELLIPTICAL CONCRETE PIPE

Sewers, both sanitary and storm, are designed to carry a peak flow based on anticipated land development. The hydraulic capacity of sewers or culverts constructed of precast elliptical concrete pipe flowing full under gravity conditions on a known slope is readily calculated from the Manning Formula. Most sewers, however, are designed to operate under partial flow conditions. Culverts operate under either inlet control or outlet control. The type of control under which a particular culvert operates is dependent upon all the hydraulic factors present. Culverts operating under inlet control will always flow partially full while those operating under outlet control can flow full or partially full.

Determination of the depth and velocity of flow in pipe flowing partially full is therefore frequently necessary. This design data presents a method for determining the values of the partial flow depth and velocity in elliptical concrete pipe through the use of a series of partial flow curves which eliminate tedious trial and error computations.

A complete discussion of the hydraulics of sewers is presented in Design Data 4, and the hydraulics of culverts is presented in Design Data 8.

HYDRAULICS OF CONCRETE PIPE

The most widely accepted formula for evaluating the hydraulic capacity of nonpressure pipe is the Manning Formula. This formula is:

$$Q = \frac{1.486}{n} \times A \times R^{2/3} \times S_o^{1/2} \qquad (1)$$

where

Q = flow quantity, cubic feet per second
n = Manning's roughness coefficient
A = cross sectional area of flow, square feet
R = hydraulic radius, feet
S_o = slope, feet of vertical drop per foot of horizontal distance

Table I provides values of $S_o^{1/2}$. *Table II* lists the full flow area, A_F, hydraulic radius, R, and a constant, C_1. For a specific pipe size under full flow conditions, the first three terms of the right hand side of Manning's Formula equal a constant [$C_1 = (1.486/n) \times A \times R^{2/3}$]. Values of C_1 are presented for the more commonly used values, 0.010, 0.011, 0.012, and 0.013, for the roughness coefficient, *n*, for precast concrete pipe. Utilizing the appropriate value of $S_o^{1/2}$ from *Table I* and C_1 from *Table II*, the full flow quantity, Q_F, may be determined from Manning's Formula conveniently expressed as:

$$Q_F = C_1 \times S_o^{1/2} \qquad (2)$$

Once the full flow quantity, Q_F, has been determined, the average velocity, V_F, for full flow conditions may be calculated from the basic hydraulic relationship:

$$V_F = \frac{Q_F}{A_F} \qquad (3)$$

where

Q_F = flow quantity, flowing full, cubic feet per second
V_F = the average velocity, flowing full, feet per second
A_F = cross sectional area, flowing full, square feet

PARTIAL FLOW HYDRAULIC ELEMENTS

For any size of pipe, curves showing the partial flow relationship of the hydraulic elements, flow quantity, area of flow, hydraulic radius, and velocity of flow in terms of the full flow conditions can be plotted. *Figure 1 and 2* provides such hydraulic element curves for horizontal and vertical elliptical concrete pipe and *Table II* provides full flow values for the hydraulic radius.

DESIGN METHOD

To determine the value of any one of the partial flow hydraulic elements for elliptical concrete pipe, the following three step design method is suggested:

1. Determine the full flow quantity, Q_F, and velocity, V_F, utilizing *Tables I* and *II* or other appropriate methods.
2. Determine the value of the ratio of partial flow to full flow of the known hydraulic elements.
3. Determine the values of the unknown hydraulic elements through the use of the partial flow curves.

TABLE I: Values of $S_o^{1/2}$ in Manning's Formula.

S	.___0	.___1	.___2	.___3	.___4	.___5	.___6	.___7	.___8	.___9
.000	.00000	.01000	.01414	.01732	.02000	.02236	.02449	.02646	.02828	.03000
.001	.03162	.03317	.03464	.03606	.03742	.03873	.04000	.04123	.04243	.04359
.002	.04472	.04583	.04690	.04796	.04899	.05000	.05099	.05196	.05292	.05385
.003	.05477	.05568	.05657	.05745	.05831	.05916	.06000	.06083	.06164	.06245
.004	.06325	.06403	.06481	.06557	.06633	.06708	.06782	.06856	.06928	.07000
.005	.07071	.07141	.07211	.07280	.07348	.07416	.07483	.07550	.07616	.07681
.006	.07746	.07810	.07874	.07937	.08000	.08062	.08124	.08185	.08246	.08307
.007	.08367	.08426	.08485	.08544	.08602	.08660	.08718	.08775	.08832	.08888
.008	.08944	.09000	.09055	.09110	.09165	.09220	.09274	.09327	.09381	.09434
.009	.09487	.09539	.09592	.09644	.09695	.09747	.09798	.09849	.09899	.09950
.010	.10000	.10050	.10100	.10149	.10198	.10247	.10296	.10344	.10392	.10440
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1304	.1342	.1378
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.2811
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146
.10	.3162	.3178	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302

TABLE II: Full Flow Coefficient Values Elliptical Concrete Pipe.

Pipe Size R x S (HE) S x R (VE) (Inches)	Approximate Equivalent Circular Diameter (Inches)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Value of $C_1 = \frac{1.486}{n} \times A \times R^{2/3}$			
				n = 0.010	n = 0.011	n = 0.012	n = 0.013
14 x 23	18	1.8	0.367	138	125	116	108
19 x 30	24	3.3	0.490	301	274	252	232
22 x 34	27	4.1	0.546	405	368	339	313
24 x 38	30	5.1	0.613	547	497	456	421
27 x 42	33	6.3	0.686	728	662	607	560
29 x 45	36	7.4	0.736	891	810	746	686
32 x 49	39	8.8	0.812	1140	1036	948	875
34 x 53	42	10.2	0.875	1386	1260	1156	1067
38 x 60	48	12.9	0.969	1878	1707	1565	1445
43 x 68	54	16.6	1.106	2635	2395	2196	2027
48 x 76	60	20.5	1.229	3491	3174	2910	2686
53 x 83	66	24.8	1.352	4503	4094	3753	3464
58 x 91	72	29.5	1.475	5680	5164	4734	4370
63 x 98	78	34.6	1.598	7027	6388	5856	5406
68 x 106	84	40.1	1.721	8560	7790	7140	6590
72 x 113	90	46.1	1.845	10300	9365	8584	7925
77 x 121	96	52.4	1.967	12220	11110	10190	9403
82 x 128	102	59.2	2.091	14380	13070	11980	11060
87 x 136	108	66.4	2.215	16770	15240	13970	12900
92 x 143	114	74.0	2.340	19380	17620	16150	14910
97 x 151	120	82.0	2.461	22190	20180	18490	17070
106 x 166	132	99.2	2.707	28630	26020	23860	22020
116 x 180	144	118.6	2.968	36400	33100	30340	28000

FIGURE 1: Relative Velocity and Flow in Horizontal Elliptical Pipe for Any Depth of Flow.

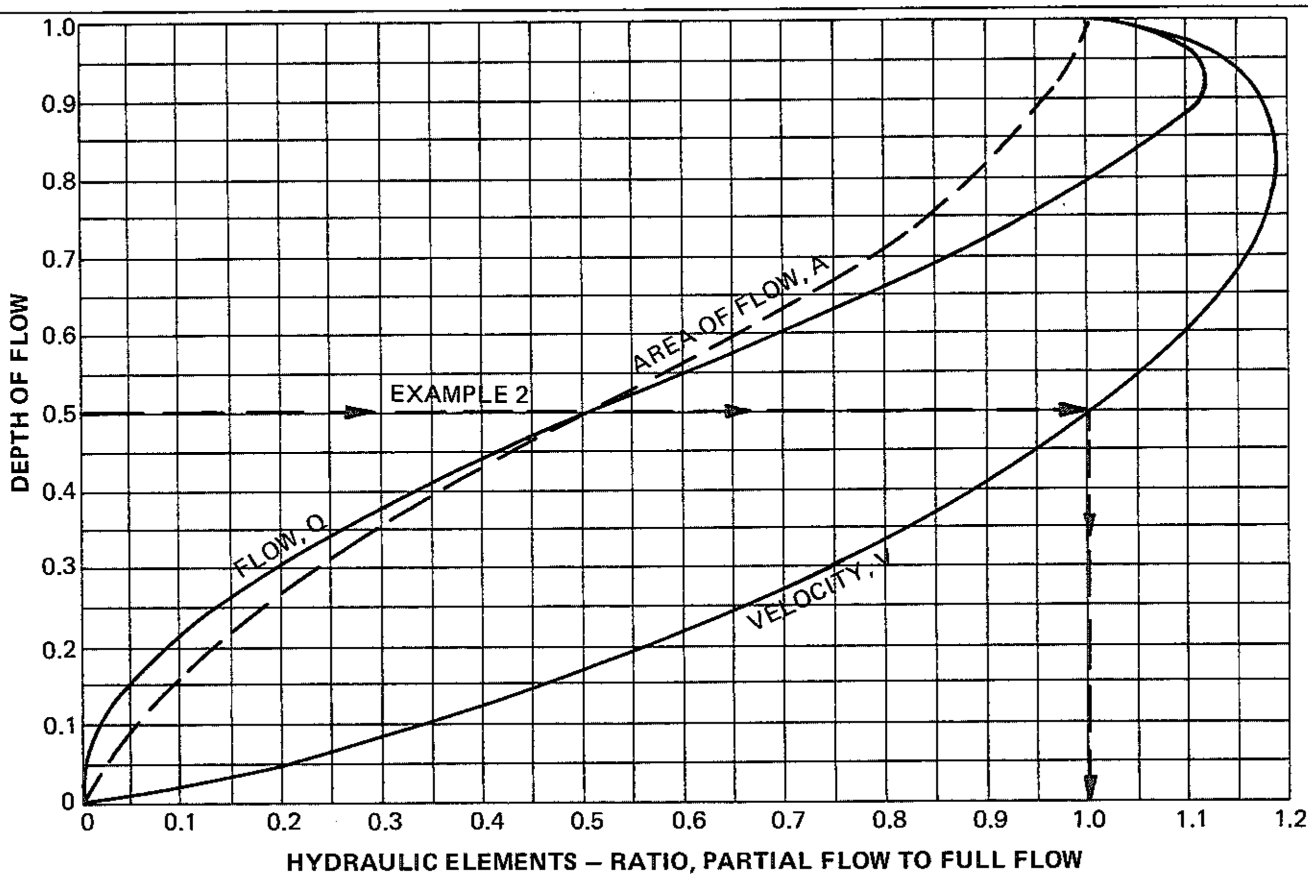
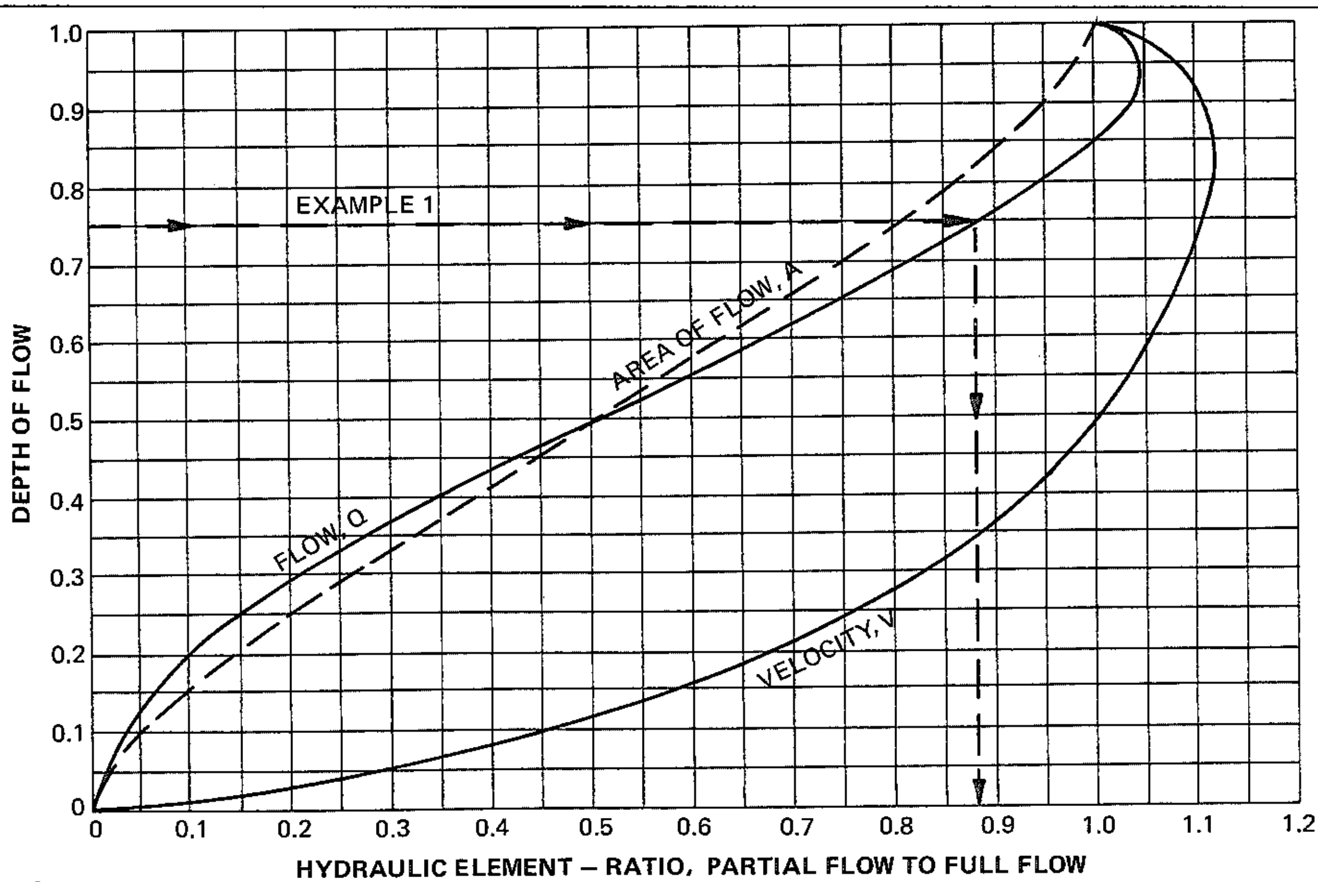


FIGURE 2: Relative Velocity and Flow in Vertical Elliptical Pipe for Any Depth of Flow.



EXAMPLE 1

Given: A vertical elliptical concrete sewer is designed to flow ¾ full with a design flow, Q, of 200 cubic feet per second. The slope is 0.01 and *n* is equal to 0.013.

Find: The required pipe size.

Solution: Enter *Figure 2* at a depth of flow of 0.75 on the vertical scale. Project a line to the flow curve, Q, and from the intersection, project a vertical line to the horizontal scale and read a value of 0.87 which represents the proportional value for full flow:

$$\frac{Q}{Q_F} = 0.87$$

Since the actual flow required is 200 cubic feet per second:

$$Q_F = \frac{200}{0.87}$$

Q_F = 230 cubic feet per second

From *Table I*, the value of $S_o^{1/2}$ is 0.1, and using Equation 2, to calculate C_1:

$$C_1 = \frac{Q_F}{S_o^{1/2}}$$

$$C_1 = \frac{230}{0.1}$$

$$C_1 = 2300$$

Entering *Table II* with C_1 equal to 2300, and *n* equal to 0.013; the vertical elliptical pipe with a C_1 value equal to, or greater than 2300 is 76 × 48-inch.

Answer: Select a 76 × 48-inch vertical elliptical pipe.

EXAMPLE 2

Given: A 34 × 53-inch horizontal elliptical concrete pipe storm sewer outfall has an *n* value assumed to be 0.012 and is to be installed on a 10 percent slope. To meet future expansion conditions, the pipe will be designed to flow ½ full.

Find: The outlet velocity.

Solution: Entering *Table II* at a horizontal elliptical size of 34 × 53 inches and an *n* value of 0.012, the C_1 value is 1156 and A_F is 10.2 square feet. From *Table I*, $S_o^{1/2}$ is 0.3162. From Equation 2:

$$Q_F = C_1 S_o^{1/2}$$

$$Q_F = 1156 \times 0.3162$$

Q_F = 366 cubic feet per second

The full flow velocity can be calculated from Equation 3:

$$V_F = Q_F/A_F$$

$$V_F = 366/10.2$$

V_F = 36 feet per second

Enter *Figure 1* at 0.5 on the vertical scale and project a horizontal line to the velocity curves. From this intersection, project a vertical line to the horizontal scale. The ratio of partial flow V to full flow V_F is 1.0:

$$\frac{V}{V_F} = 1.0$$

$$V = V_F \times 1.0$$

$$V = 36 \times 1.0$$

V = 36 feet per second

Answer: The outlet velocity is 36 feet per second.