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PARTIAL FLOW CONDITIONS CIRCULAR 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 circular 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 circular 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:

$$Q = \frac{1.486}{n} \times A \times R^{2/3} \times S_0^{1/2} \quad (1)$$

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
- S₀ = slope, feet of vertical drop per foot of horizontal distance

Table I provides values of S₀^{1/2}. Table II lists the full flow area, A_F, hydraulic radius, R, and a constant, C₁. 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 [C₁ = (1.486/n) × A × R^{2/3}]. Values of C₁ 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 S₀^{1/2} from Table I and C₁ from Table II, the full flow quantity, Q_F, may be determined from Manning's Formula conveniently expressed as:

$$Q_F = C_1 \times S_0^{1/2} \quad (2)$$

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:

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

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 provides such hydraulic element curves for circular concrete pipe.

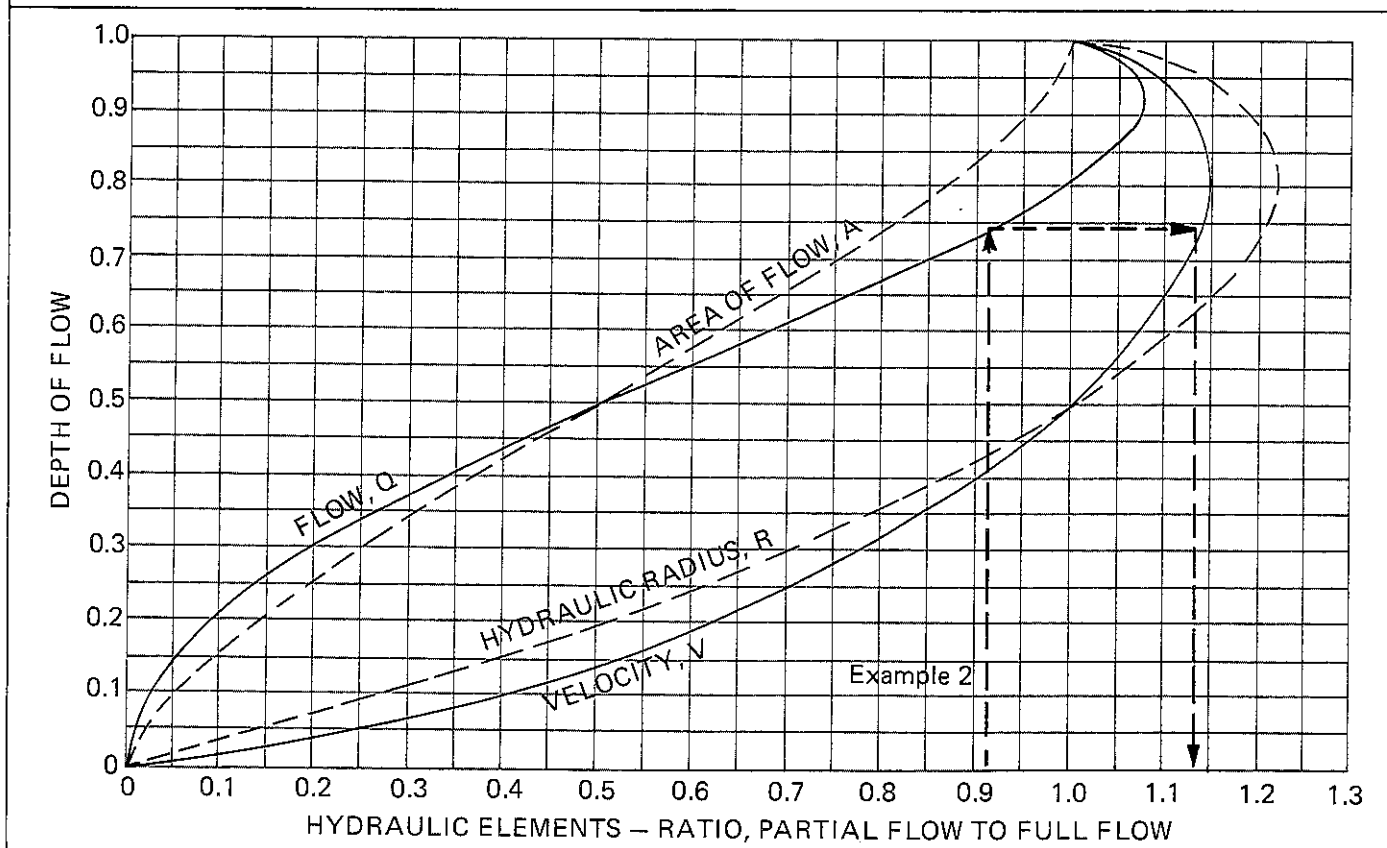
DESIGN METHOD

To determine the value of any one of the partial flow hydraulic elements for circular 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 use of the partial flow curves.

TABLE I: Values of $S_o^{1/2}$ in Manning's Formula.											TABLE II: Full Flow Coefficient Values Circular Concrete Pipe.						
S	Value of $S_o^{1/2}$										D Pipe Diameter (inches)	A Area (Square Feet)	R Hydraulic Radius (Feet)	Value of $C_1 = \frac{1.486}{n} \times A \times R^{3/2}$			
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9				n=0.010	n=0.011	n=0.012	n=0.013
.000	.0000	.0100	.0141	.0173	.0200	.0223	.0244	.0264	.0282	.0300	8	0.349	0.167	15.8	14.3	13.1	12.1
.001	.0316	.0331	.0346	.0360	.0374	.0387	.0400	.0412	.0424	.0435	10	0.545	0.208	28.4	25.8	23.6	21.8
.002	.0447	.0458	.0469	.0479	.0489	.0500	.0509	.0519	.0529	.0538	12	0.785	0.250	46.4	42.1	38.6	35.7
.003	.0547	.0558	.0567	.0575	.0583	.0591	.0600	.0608	.0616	.0624	15	1.227	0.312	84.1	76.5	70.1	64.7
.004	.0632	.0640	.0648	.0655	.0663	.0670	.0678	.0685	.0692	.0700	18	1.767	0.375	137	124	114	105
.005	.0707	.0714	.0721	.0728	.0734	.0741	.0748	.0755	.0761	.0768	21	2.405	0.437	206	187	172	158
.006	.0774	.0781	.0787	.0793	.0800	.0806	.0812	.0818	.0824	.0830	24	3.142	0.500	294	267	245	226
.007	.0836	.0842	.0848	.0854	.0860	.0866	.0871	.0877	.0883	.0888	27	3.976	0.562	402	366	335	310
.008	.0894	.0900	.0905	.0910	.0916	.0922	.0927	.0932	.0938	.0943	30	4.909	0.625	533	485	444	410
.009	.0948	.0953	.0959	.0964	.0969	.0974	.0979	.0984	.0989	.0995	33	5.940	0.688	686	624	574	530
.010	.1000	.1005	.1010	.1014	.1019	.1024	.1029	.1034	.1039	.1044	36	7.069	0.750	867	788	722	666
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1304	.1342	.1378	42	9.621	0.875	1308	1189	1090	1005
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703	48	12.566	1.000	1867	1698	1556	1436
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975	54	15.904	1.125	2557	2325	2131	1967
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214	60	19.635	1.250	3385	3077	2821	2604
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429	66	23.758	1.375	4364	3967	3636	3357
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627	72	28.274	1.500	5504	5004	4587	4234
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.2811	78	33.183	1.625	6815	6195	5679	5242
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983	84	38.485	1.750	8304	7549	6920	6388
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146	90	44.170	1.875	9985	9078	8321	7681
.10	.3162	.3178	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302	96	50.266	2.000	11850	10780	9878	9119
											102	56.745	2.125	13940	12670	11620	10720
											108	63.617	2.250	16230	14760	13530	12490
											114	70.882	2.375	18750	17040	15620	14420
											120	78.540	2.500	21500	19540	17920	16540
											126	86.590	2.625	24480	22260	20400	18830
											132	95.033	2.750	27720	25200	23100	21330
											138	103.870	2.875	31210	28370	26010	24010
											144	113.100	3.000	34960	31780	29130	26890

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



EXAMPLE 1

Given: A 48-inch diameter circular concrete pipe storm sewer, with n equal to 0.012 and flowing one-third full.

Find: Slope required to maintain a minimum velocity of 3 feet per second.

Solution: Enter *Figure 1* on the vertical scale at Depth of Flow = 0.33 and project a horizontal line to the curved line representing velocity. On the horizontal scale directly beneath the point of intersection read a value of 0.81 which represents the proportional value for full flow:

$$\frac{V}{V_F} = 0.81$$

Since the actual velocity required is 3 feet per second:

$$V_F = \frac{3}{0.81}$$

$$V_F = 3.7$$

Entering *Table II* at a pipe diameter of 48 inches and an n value of 0.012, the C_1 value is 1556 and A_F is 12.566 square feet.

Combining Equations 2 and 3 and solving for S_o :

$$S_o = \left[\frac{V_F A_F}{C_1} \right]^2$$

$$S_o = \left[\frac{(3.7)(12.566)}{1556} \right]^2$$

$$S_o = 0.00089 \text{ feet per foot}$$

Answer: The slope required to maintain a minimum velocity of 3 feet per second at one-third full is 0.00089 feet per foot.

EXAMPLE 2

Given: A 42-inch circular concrete culvert with a slope, S_o , equal to 0.01 and n equal to 0.012. The design discharge, Q , is 100 cubic feet per second and the culvert is under inlet control.

Find: The outlet velocity.

Solution: Entering *Table II* at a pipe diameter of 42 inches and an n value of 0.012, the C_1 value is 1090 and A_F is 9.621 square feet. From *Table I*, the value of $S_o^{1/2}$ is 0.1. From *Equation 2*:

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

$$Q_F = 1090 \times 0.1$$

$$Q_F = 109 \text{ cubic feet per second}$$

From *Equation 3*:

$$V_F = Q_F / A_F$$

$$V_F = 109 / 9.621$$

$$V_F = 11.3 \text{ feet per second}$$

Calculating the ratio of partial flow Q to full flow Q_F :

$$Q/Q_F = 100/109 = 0.92$$

Enter *Figure 1* at 0.92 on the horizontal scale and project a vertical line to the flow, Q , curve. From the intersection project a horizontal line to the velocity curve, V , and from this intersection project a vertical line to the horizontal scale. The ratio of partial flow V to full flow V_F is 1.13:

$$\frac{V}{V_F} = 1.13$$

$$V = 11.3 \times 1.13$$

$$V = 12.8 \text{ feet per second}$$

Answer: The outlet velocity is 12.8 feet per second.