Design of Sanitary Sewer System

Key components

Service connections, Manholes and pump stations

Design Flows

1. Infiltration and interflow (71 to 140 m^3/d/km)
2. Flow from the service connections

Type of Area	Density (persons/ha)
Large lots	5-7
Small lots, single family	75
Small lots, two family	125
Multistory apartments	2500

Design period: usually of the order of 50 years

Variation in flow

$$\frac{Q_{peak}}{Q_{ave}} = \frac{5.5}{(P/1000)^{0.18}}, \qquad \frac{Q_{min}}{Q_{ave}} = 0.2(P/1000)^{0.16}$$

P= population of the service area

Example: You are required to estimate the peak and minimum sewage flows for a town having an area of 2500 ha. The residential area is 60% of the total area, whereas commercial and industrial areas are 30% and 10% of the total area, respectively. Of the residential area, 40% are large lots, 55% small single-family lots and 5% multistory apartments. The wastewater from the residential area is estimated to be 800 Lpcd. The sewage from commercial and industrial areas is estimated to be 25000 L/ha/d and 40000 L/ha/d, respectively.

Type	Area(ha)	Density (persons/ha)	Population	Flow (m^3/s)
Large lots	0.4(1500)= 600	6	3,600	0.03
Small single family lots	0.55(1500) = 825	75	61,875	0.57
Multistory apartments	0.05(1500) = 75	2500	187,500	1.74
Total			**252,975**	**2.34**

Commercial sector = 30% of 2500 ha = 750 ha
Average flow from commercial sector = 750x25,000 L/d= 0.22 m^3/s

Industrial sector = 10 % of 2500 ha = 250 ha
Average flow from industrial sector = 250x40,000 L/d = 0.12 m^3/s
Thus,
Average wastewater flow (excluding I/I) = 2.34+0.22+0.12 = 2.68 m^3/s
Assuming total population is equal to residential population, i.e.

P= 252,975

Then,

$$\frac{Q_{peak}}{Q_{ave}} = \frac{5.5}{(P/1000)^{0.18}} = \frac{5.5}{(252.975)^{0.18}} = 2.0$$

$$\frac{Q_{\min}}{Q_{ave}} = 0.2(P/1000)^{0.16} = 0.2(252.975)^{0.16} = 0.48$$

Hence,

Peak flow = Peak factor x wastewater + I/I = 2.0(2.68)+0.03= 5.39 m^3/s

Minimum flow = 0.48(2.68) + 0.03 = 1.32 m^3/s

Hydraulics of Sewers

Minimum velocity (self-cleansing velocity) = 0.6 m/s

Maximum velocity = 3.5 m/s

Minimum pipe diameter = 150 mm.

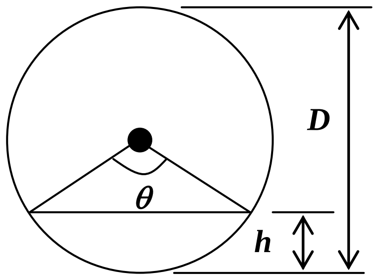
Sanitary sewers up to 375 mm diameter should be designed to run half full.

Larger pipes may run three-fourths full.

The design problem

Given:
1. Discharge, Q
2. Pipe Diameter, D
3. Pipe slope, S_0

Determine:
1. Depth of flow, h
2. Minimum velocity, V_{min}
3. Maximum velocity, V_{max}



$$h = \frac{D}{2}\left[1 - \cos\left(\frac{\theta}{2}\right)\right] \qquad A = D^2\left[\frac{\theta - \sin\theta}{8}\right] \qquad P = \frac{D\theta}{2}$$

$$Q = \frac{A}{n}\left[\frac{A}{P}\right]^{2/3} S_0^{1/2}$$

Combining these equations we get

$$\frac{(\theta - \sin\theta)^{5/3}}{\theta^{2/3}} - \frac{20.16nQ}{D^{8/3}S_0^{1/2}} = 0$$

After solving it by trials we can compute A and then, $V = \frac{Q}{A}$

If $V < V_{\min}$, reduce the diameter to achieve $V \geq V_{\min}$

If diameter is the minimum (150 mm), put $V = V_{\min}$ and find the slope of the pipe from the Manning's equation.

Table 4.25 Available Sizes of Concrete Pipe

Nonreinforced pipe Diameter (mm)	Nonreinforced pipe Diameter (in.)	Reinforced Pipe Diameter (mm)	Reinforced Pipe Diameter (in.)
100	4	—	—
150	6	—	—
205	8	—	—
255	10	—	—
305	12	305	12
380	15	380	15
455	18	455	18
535	21	535	21
610	24	610	24
685	27	685	27
760	30	760	30
840	33	840	33
915	36	915	36
—	—	1,065	42
—	—	1,220	48
—	—	1,370	54
—	—	1,525	60
—	—	1,675	66
—	—	1,830	72
—	—	1,980	78
—	—	2,135	84
—	—	2,285	90
—	—	2,440	96
—	—	2,590	102
—	—	2,745	108

Example: Determine the average velocity in a trunk sewer made of concrete (n=0.015) having 1500 mm diameter laid on a slope of 1%. The peak discharge through the pipe is estimated to be 4000L/s.

Given:

$$n = 0.015,\quad Q = 4m^3/s,\quad S_0 = 0.01,\quad D = 1.5m$$

$$\frac{(\theta - \sin\theta)^{5/3}}{\theta^{2/3}} - \frac{20.16(0.015)(4)}{(1.5)^{8/3}(0.01)^{1/2}} = 0$$

By trials,

$$\theta = 3.5 radian$$

Therefore,

$$h = \frac{D}{2}\left[1 - \cos\left(\frac{\theta}{2}\right)\right] = \frac{1.5}{2}\left[1 - \cos\left(\frac{3.5}{2}\right)\right] = 0.88m$$

$$A = D^2\left[\frac{\theta - \sin\theta}{8}\right] = 1.5^2\left[\frac{3.5 - \sin 3.5}{8}\right] = 1.08m^2$$

The average flow velocity in the sewer is given by

$$V = \frac{Q}{A} = \frac{4}{1.08} = 3.7m/s$$

Sewer Pipe Material

Rigid Pipes: Concrete, Cast iron, Vitrified clay

Flexible pipes: Ductile iron, Steel, PVC

Advantages and disadvantages of each category

Typical Manholes

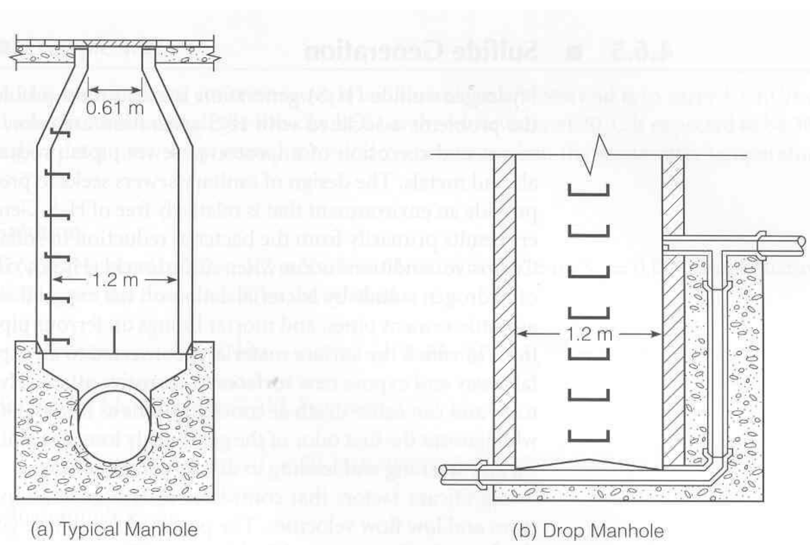


Figure 4.35 ■ Typical Manholes
ASCE. *Gravity Sewer Design and Construction*. Copyright © 1982 by ASCE. Reprinted by permission.

Sulfide Generation

$$Z = 0.308\frac{EBOD}{S_0^{0.5}Q^{0.33}} \times \frac{P}{B}$$

$$EBOD = BOD \times 1.07^{T-20}$$

$BOD =$ 5-day biochemical oxygen demand

$S_0 =$ Slope of the pipe

$Q =$ Discharge through the pipe

$P, B =$ Wetted perimeter and top width of the flow, respectively.

Z values	Sulfide Condition
Z < 5,000	Sulfide rarely generated
5,000< Z < 10,000	Marginal condition for sulfide generation
Z > 10,000	Sulfide generation common

Example: Check the potential for sulfide generation in the trunk sewer of the previous example, if 5-day BOD of the sewage is measured as 1600 mg/L and the ambient temperature in the sewer is 30^{o}C.

Solution:

$$EBOD = BOD \times 1.07^{T-20} = 1600 \times 1.07^{10} = 3147.44$$

$$P = \frac{D\theta}{2} = \frac{1.5 \times 3.5}{2} = 2.625m$$

$$B = \frac{D}{2}\sin\left(\frac{\theta}{2}\right) = \frac{1.5}{2} \times \sin\left(\frac{3.5}{2}\right) = 0.738m$$

$$Z = 0.308\frac{EBOD}{S_0^{0.5}Q^{0.33}} \times \frac{P}{B} = 0.308\frac{3147.44}{0.01^{0.5}4^{0.33}} \times \frac{2.625}{0.738}$$

$$= 21822 > 10000$$

So, sulfide generation will be common in the sewer.

Design Computations

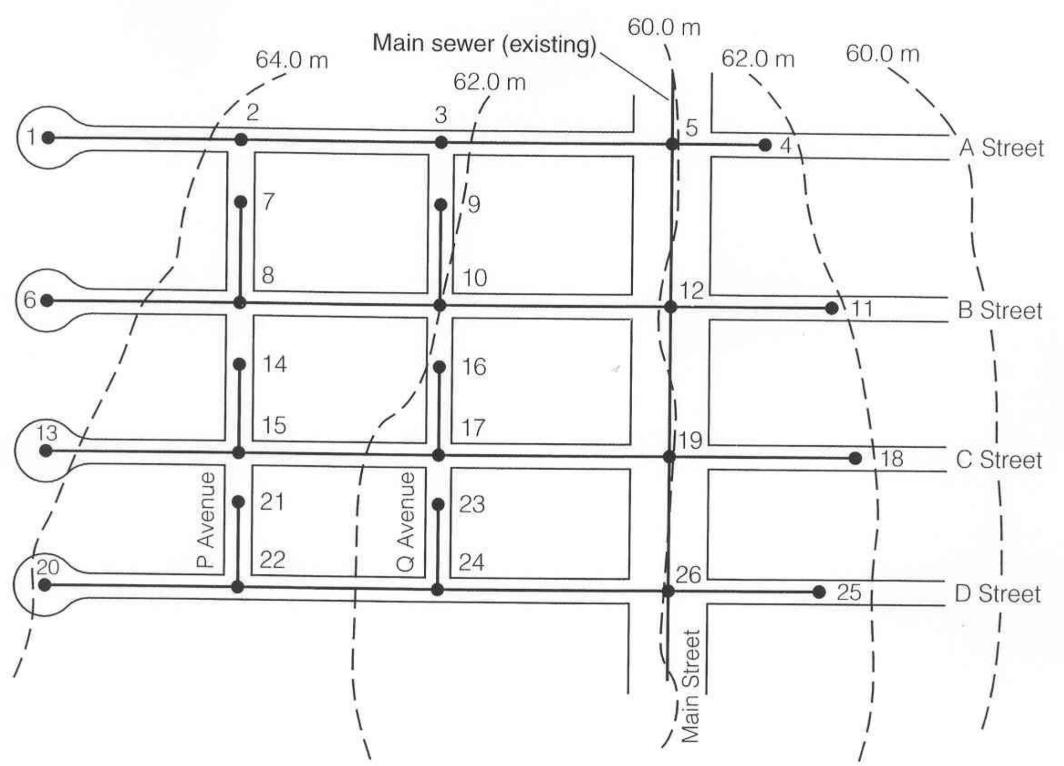
Line No.	Location	Manhole No.		Length (m)	Area		Maximum Flow			Minimum Flow			Slope of Sewer	Diam (mm)	Min Velocity (m/s)	Max Velocity (m/s)	Max Depth (mm)	Manhole Invert Drop (m)	Fall in Sewer (m)	Sewer Invert Elevation		Ground Surface Elevation	
		From	To		Increment (ha)	Total (ha)	I/I (m^3/s)	Sewage (m^3/s)	Total (m^3/s)	I/I (m^3/s)	Sewage (m^3/s)	Total (m^3/s)								Upper End (m)	Lower End (m)	Upper End (m)	Lower End (m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)

Figure 4.36 ■ Typical Computation Form for Design of Sanitary Sewers

Example A sewer system is to be designed to service the area shown in the following Figure. The average per capita wastewater flow-rate is estimated to be 800 L/d/person, and the infiltration and inflow (I/I) is estimated to be 70 m^3/d/km. The sewer system is to join an existing main sewer at manhole MH 5, where the average wastewater flow is 0.37 m^3 /s, representing the contribution of approximately 100,000 people.

The I/I contribution to the flow in the main sewer at MH 5 is negligible, and the main sewer at MH 5 is 1,065 mm in diameter, has an invert elevation of 55.35 m, and is laid on a slope of 0.9%. The layout of the sewer system shown in the figure is based on the topography of the area, and the pipe lengths, contributing areas, and ground-surface elevations are shown in the table.

Design the sewer system between A Street and C Street for a saturation density of 130 persons/ha. Municipal guidelines require that the sewer pipes have a minimum cover of 2 m, a minimum slope of 0.08%, a peak flow factor of 3.0, a minimum flow factor of 0.5, and a minimum allowable pipe diameter of 150 mm.



Line no. (1)	Location (2)	Manhole no. From (3)	Manhole no. To (4)	Length (m) (5)	Contributing area (ha) (6)	Ground surface elevation Upper end (m) (28)	Ground surface elevation Lower end (m) (29)
0	Main Street	—	5	—	—	—	60.04
1	A Street	1	2	53	0.47	65.00	63.80
2	A Street	2	3	91	0.50	63.80	62.40
3	A Street	3	5	100	0.44	62.40	60.04
4	A Street	4	5	89	0.90	61.88	60.04
5	Main Street	5	12	69	0.17	60.04	60.04
6	B Street	6	8	58	0.43	65.08	63.20
7	P Avenue	7	8	50	0.48	63.60	63.20
8	B Street	8	10	91	0.39	63.20	62.04
9	Q Avenue	9	10	56	0.88	62.72	62.04
10	B Street	10	12	97	0.45	62.04	60.04
11	B Street	11	12	125	0.90	61.88	60.04
12	Main Street	12	19	75	0.28	60.04	60.20
13	C Street	13	15	57	0.60	64.40	62.84
14	P Avenue	14	15	53	0.76	63.24	62.84
15	C Street	15	17	97	0.51	62.84	61.60
16	Q Avenue	16	17	63	0.94	62.12	61.60
17	C Street	17	19	100	0.46	61.60	60.20
18	C Street	18	19	138	1.41	61.92	60.20
19	Main Street	19	26	78	0.30	60.20	60.08

Table 4.27 Sewer Design Calculations

Line No. (1)	Location (2)	Manhole No. From (3)	Manhole No. To (4)	Length (m) (5)	Area Increment (ha) (6)	Area Total (ha) (7)	Maximum Flow I/I (m^3/min) (8)	Maximum Flow Sewage (m^3/min) (9)	Maximum Flow Total (m^3/min) (10)	Minimum Flow I/I (m^3/min) (11)	Minimum Flow Sewage (m^3/min) (12)	Minimum Flow Total (m^3/min) (13)	Slope of Sewer (14)	Diam (mm) (15)	Min Velocity (m/s) (16)	Max Velocity (m/s) (17)	Max Depth (mm) (18)	Invert Drop (m) (19)	Fall in Sewer (m) (20)	Sewer Invert Elevation Upper End (m) (21)	Sewer Invert Elevation Lower End (m) (22)	Ground Surface Elevation Upper End (m) (23)	Ground Surface Elevation Lower End (m) (24)
0	Main Street	–	5	–	–	–	–	–	66.6	–	–	11.1	0.009	1065	1.75	2.88	476	–	–	–	55.35	–	60.04
1	A Street	1	2	53	0.47	0.47	0.0026	0.102	0.105	0.0026	0.0170	0.0196	0.047	150	0.60	0.99	23	–	2.49	62.74	60.25	65.00	63.80
2	A Street	2	3	91	0.50	0.97	0.0070	0.210	0.217	0.0070	0.0350	0.0420	0.024	150	0.60	0.97	40	–	2.18	60.25	58.07	63.80	62.40
3	A Street	3	5	100	0.44	1.41	0.0120	0.305	0.317	0.0120	0.0509	0.0629	0.018	150	0.61	0.97	52	–	1.80	58.07	56.27	62.40	60.04
4	A Street	4	5	89	0.90	0.90	0.0043	0.195	0.199	0.0043	0.0325	0.0368	0.027	150	0.60	0.98	37	–	2.40	58.67	56.27	61.88	60.04
5	Main Street	5	12	69	0.17	309.96	0.0197	67.14	67.16	0.0197	11.19	11.21	0.001	1220	0.78	1.24	879	0.155	0.07	55.20	55.13	60.04	60.04
6	B Street	6	8	58	0.43	0.43	0.0028	0.0932	0.0960	0.0028	0.0155	0.0183	0.050	150	0.60	0.99	22	–	2.90	62.90	60.00	65.08	63.20
7	P Avenue	7	8	50	0.48	0.48	0.0024	0.104	0.106	0.0024	0.0173	0.0197	0.048	150	0.60	1.00	23	–	2.40	61.34	58.99	63.60	63.20
8	B Street	8	10	91	0.39	1.30	0.0097	0.282	0.292	0.0097	0.0469	0.0566	0.019	150	0.60	0.97	49	–	1.73	58.99	57.26	63.20	62.04
9	Q Avenue	9	10	56	0.88	0.88	0.0027	0.191	0.194	0.0027	0.0318	0.0345	0.029	150	0.60	1.00	36	–	1.62	60.44	58.82	62.72	62.04
10	B Street	10	12	97	0.45	2.67	0.0171	0.578	0.595	0.0171	0.0964	0.114	0.011	205	0.61	0.95	86	0.055	1.07	57.21	56.14	62.04	60.04
11	B Street	11	12	125	0.90	0.90	0.0061	0.195	0.201	0.0061	0.0325	0.0386	0.026	150	0.60	0.97	37	–	3.25	59.45	56.20	61.88	60.04
12	Main Street	12	19	75	0.28	313.81	0.0465	67.97	68.02	0.0465	11.33	11.38	0.001	1220	0.79	1.24	887	–	0.08	55.13	55.06	60.04	60.20
13	C Street	13	15	57	0.60	0.60	0.0028	0.130	0.133	0.0028	0.0217	0.0245	0.040	150	0.60	1.00	27	–	2.28	62.20	59.92	64.40	62.84
14	P Avenue	14	15	53	0.76	0.76	0.0026	0.165	0.168	0.0026	0.0274	0.0300	0.034	150	0.61	1.02	32	–	1.80	60.38	58.58	63.24	62.84
15	C Street	15	17	97	0.51	1.87	0.0101	0.405	0.415	0.0101	0.0675	0.0776	0.015	150	0.61	0.98	63	–	1.46	58.58	57.12	62.84	61.60
16	Q Avenue	16	17	63	0.94	0.94	0.0031	0.204	0.207	0.0031	0.0339	0.0370	0.028	150	0.60	1.01	37	–	1.76	59.90	58.21	62.12	61.60
17	C Street	17	19	100	0.48	3.27	0.0180	0.708	0.726	0.0180	0.1180	0.1360	0.010	205	0.60	0.96	83	0.055	1.00	57.07	56.07	61.60	60.20
18	C Street	18	19	138	1.41	1.41	0.0067	0.305	0.312	0.0067	0.0509	0.0576	0.019	150	0.60	0.99	51	–	2.62	58.75	56.13	61.92	60.20
19	Main Street	19	26	78	0.30	318.79	0.0750	69.05	69.13	0.0750	11.51	11.59	0.001	1220	0.79	1.25	900	–	0.08	55.06	54.98	60.20	60.08

Tutorial Problem

(a) Use MS-Excel to design the sewerage system for Streets A and B shown in the previous example.
(b) Use SewerCAD to design the sewerage system for Streets A and B shown in the previous example.

Reference: Water Resources Engineering by Chin, 2000.