CHAPTER 3

HYDRAULICS OF SEWERS

FLUID FLOWS

When a fluid flows past a point or through a path different parameters associated with the flow of the fluid, certain parameters vary and others may remain constant [1].

The two basic parameters of any fluid flow are velocity of the fluid particle or element and the pressure of the fluid at the point under consideration. The flow of fluids can be classified in different patterns based on the variation of the flow parameters with time and distance. The benefit of characterizing the fluid flow as certain patterns helps in analyzing it under the appropriate solution paradigm [1].

Classification Based on Variation with Time

The classification of the fluid flow based on the variation of the fluid flow parameters with time characterizes the flow in two categories, steady and unsteady flow. If the flow parameters, such as velocity, pressure, density and discharge do not vary with time or are independent of time then the flow is *steady*. If the flow parameters vary with time then the flow is categorized as *unsteady* [1].

In real conditions it is very rare to have such flows with parameters exactly constant with time. The parameters usually vary with time but variation is within a small range such as the average of particular parameter is constant for certain duration of time [1].

Classification Based on Variation with Space

The other classification criterion for the fluid flow is based on the variation of the flow parameters with distance or space. It characterizes the flow as *uniform* or *non-uniform*. The fluid flow is a *uniform flow* if the flow parameters remain constant with distance along the flow path. And the fluid flow is *non-uniform* if the flow parameters vary and are different at different points on the flow path [1].

For a uniform flow, by its definition, the area of the cross section of the flow should remain constant. So a fitting example of the uniform flow is the flow of a liquid thorough a pipeline of constant diameter. And contrary to this the flow through a pipeline of variable diameter would be necessarily non-uniform [1].

Flow Types and Examples

A steady flow can be uniform or non-uniform and similarly an unsteady flow can also be uniform or non-uniform. For a steady flow discharge is constant with time and for a uniform flow the area of cross section of the fluid flow is constant through the flow path [1].

Examples of Different Flow Types [1]

Steady and Uniform Flow: Flow through a pipeline of constant diameter with a discharge constant with time.

Steady and Non-Uniform Flow: Fixed discharge flow through a tapering pipe. Water flow through a river with a constant discharge is also a good example of such flow as the span of river generally varies with distance and amount of water flow in river is constant.

Unsteady and Uniform Flow: A flow through pipeline of constant cross section with sudden changes in fluid discharge or pressure.

Unsteady and Non-Uniform Flow: Pressure surges in a flow through a pipe of variable cross section. A practical example can be the water flow in the network of canals during water release.

FORMULAE USED IN HYDRAULIC DESIGN OF SEWERS

In principle, all open channel flow formulae can be used in hydraulic design of sewer pipes tough Manning's formula is the most common today.

- <u>Chezy's formula</u>

$$V = C \sqrt{R.S}$$

where V (m/s), R (m) and S (m/m).

Coefficient C given by Kutter reads as following in metric units

$$C = \frac{(23 + 0.00155/s) + 1/n}{1 + \left(n/\sqrt{R}\right)(23 + 0.00155/s)}$$

n is same as Manning's equation.

or simplified form of this coefficient can be written as

$$C = \frac{100\sqrt{R}}{m + \sqrt{R}}$$

m = 0.35 for concrete pipes

m = 0.25 for vitrified clay pipes

- <u>Darcy-Weisbach Equation</u>

$$h_L = f \frac{L}{D} \frac{v^2}{2g}$$

- ### Manning's Equation

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

n is same as the n in Kutter's formula. In general n = 0.013 - 0.015 for sewer pipes.

There are nomograms for the solution of Manning formula as shown in Figure 1.
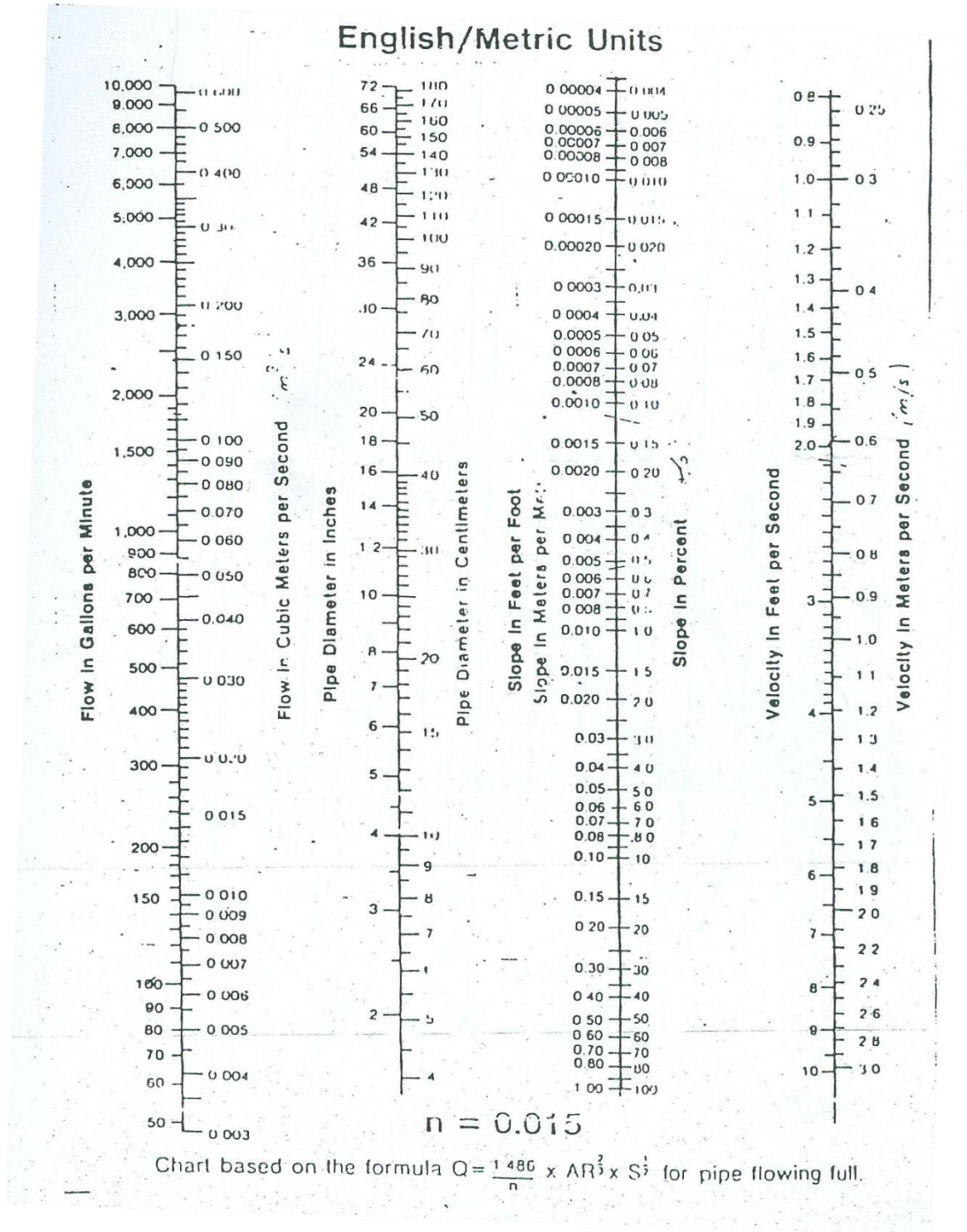

Figure 1. Nomogram for solution of Manning's equation for circular pipes flowing full (n = 0.015)

HYDRAULICS OF PARTIALLY FILLED SECTIONS

Sanitary sewers are not to be designed to flow full. Thus "hydraulics of partially filled section" is important.

Figure 2 shows the illustration of a partially filled section of a circular pipe.
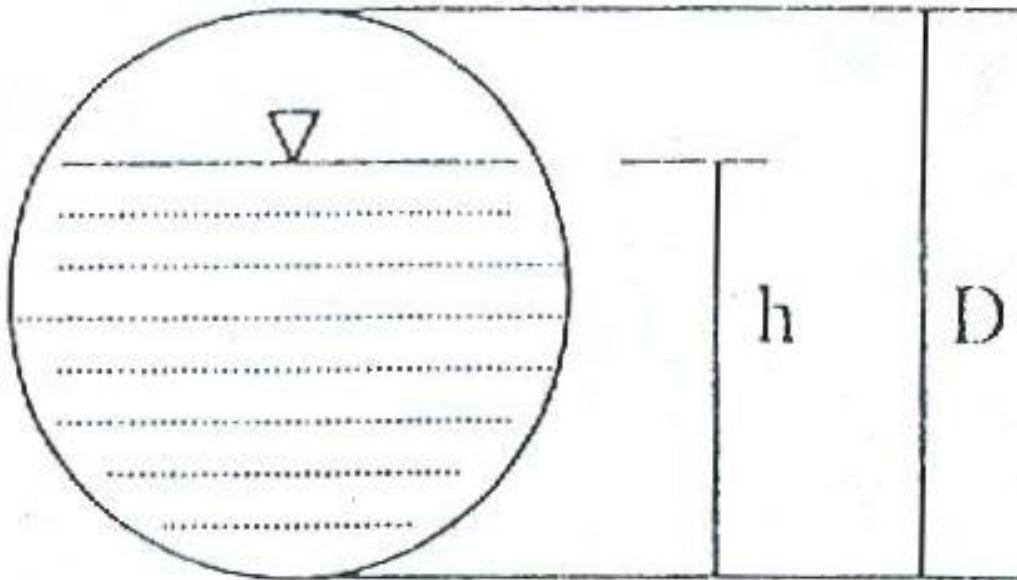

Figure 2: Partially filled section of a circular pipe.

Relationship between (Q, V, R, A), and (Q_f, V_f, R_f, A_f) are given in the form of diagram depending on h/D (d/D) ratio in the Figure 3 where:

Q, V, R, A: Flow rate, flow velocity, hydraulic radius and area for partly filled flow.

Q_f, V_f, R_f, A_f: Flow rate, flow velocity, hydraulic radius and area for full flow condition.

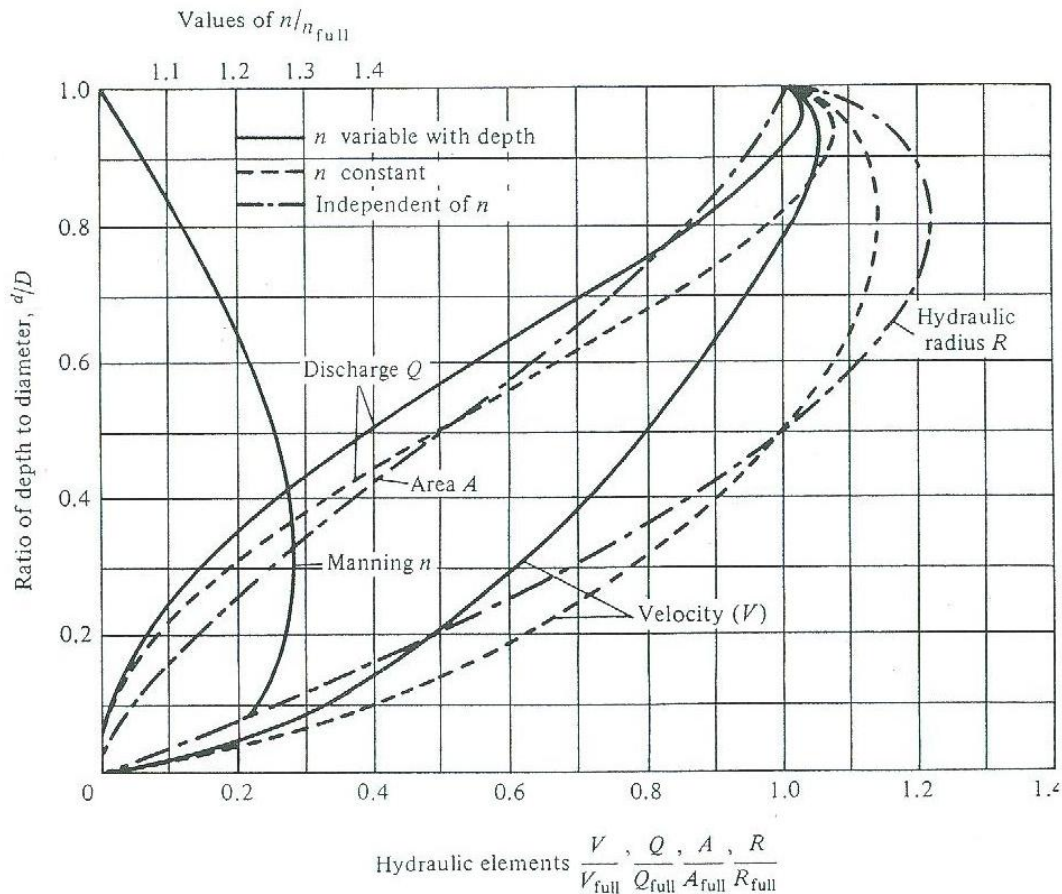Remember that in the Figure 3, coefficient n varies with diameter and h/D ratio.

Figure 3. Hydraulic elements for circular pipes [2].

If the variation of coefficient n with depth is to be neglected, calculations involving flow in partly filled sewers can easily be handled using the data in Tables 1 and 2.

Table 1. Values of K for circular channels in terms of depth of flow in the equation $Q = (\frac{K}{n})d^{8/3}S^{1/2}$ [2].

$\frac{d^b}{D}$	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	. . . .	10.11	7.11	5.77	4.96	4.41	4.00	3.68	3.42	3.20
0.1	3.02	2.85	2.72	2.60	2.49	2.39	2.29	2.21	2.13	2.06
0.2	2.00	1.93	1.88	1.82	1.77	1.72	1.68	1.63	1.59	1.55
0.3	1.51	1.48	1.44	1.41	1.38	1.35	1.32	1.29	1.26	1.23
0.4	1.21	1.18	1.16	1.14	1.11	1.09	1.07	1.05	1.03	1.01
0.5	0.990	0.971	0.952	0.934	0.916	0.899	0.882	0.805	0.849	0.833
0.6	0.818	0.802	0.787	0.772	0.758	0.744	0.730	0.716	0.702	0.690
0.7	0.676	0.662	0.650	0.637	0.624	0.612	0.600	0.588	0.576	0.564
0.8	0.552	0.541	0.529	0.518	0.507	0.495	0.484	0.473	0.462	0.451
0.9	0.440	0.429	0.418	0.407	0.395	0.384	0.372	0.360	0.348	0.334
1.0	0.312									

where Q = flowrate, m³/s
n = Manning coefficient of friction
d = depth of flow, m
S = slope of energy grade line, m/m.
^bD = diameter of conduit, m.

Table 2. Values of K' for circular channels in terms of depth of flow in the equation $Q = (\frac{K'}{n})D^{8/3}S^{1/2}$ [2].

$\frac{d^b}{D}$	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	....	0.000047	0.00021	0.00050	0.00093	0.00150	0.00221	0.00306	0.00407	0.00521
0.1	0.00651	0.00795	0.00953	0.0113	0.0131	0.0152	0.0173	0.0196	0.0220	0.0246
0.2	0.0273	0.0301	0.0331	0.0362	0.0394	0.0427	0.0461	0.0497	0.0534	0.0572
0.3	0.0610	0.0650	0.0691	0.0733	0.0776	0.0820	0.0864	0.0910	0.0956	0.1003
0.4	0.1050	0.1099	0.1148	0.1197	0.1248	0.1298	0.1349	0.1401	0.1453	0.1506
0.5	0.156	0.161	0.166	0.172	0.177	0.183	0.188	0.193	0.199	0.204
0.6	0.209	0.215	0.220	0.225	0.231	0.236	0.241	0.246	0.251	0.256
0.7	0.261	0.266	0.271	0.275	0.280	0.284	0.289	0.293	0.297	0.301
0.8	0.305	0.308	0.312	0.315	0.318	0.321	0.324	0.326	0.329	0.331
0.9	0.332	0.334	0.335	0.335	0.335	0.335	0.334	0.332	0.329	0.325
1.0	0.312									

where Q = flowrate, m³/s
n = Manning coefficient of friction
D = diameter of conduit
S = slope of energy grade line, m/m.
$^b d$ = depth of flow

CALCULATION OF HYDRAULIC ELEMENTS BY TRIGONOMETRY

The derivation of hydraulic elements can be done also by trigonometry and Figure 4 will help to formulate the hydraulic elements formulae. In Figure 4, θ is wetted angle, h is water depth in the sewer and D is the diameter of the sewer.

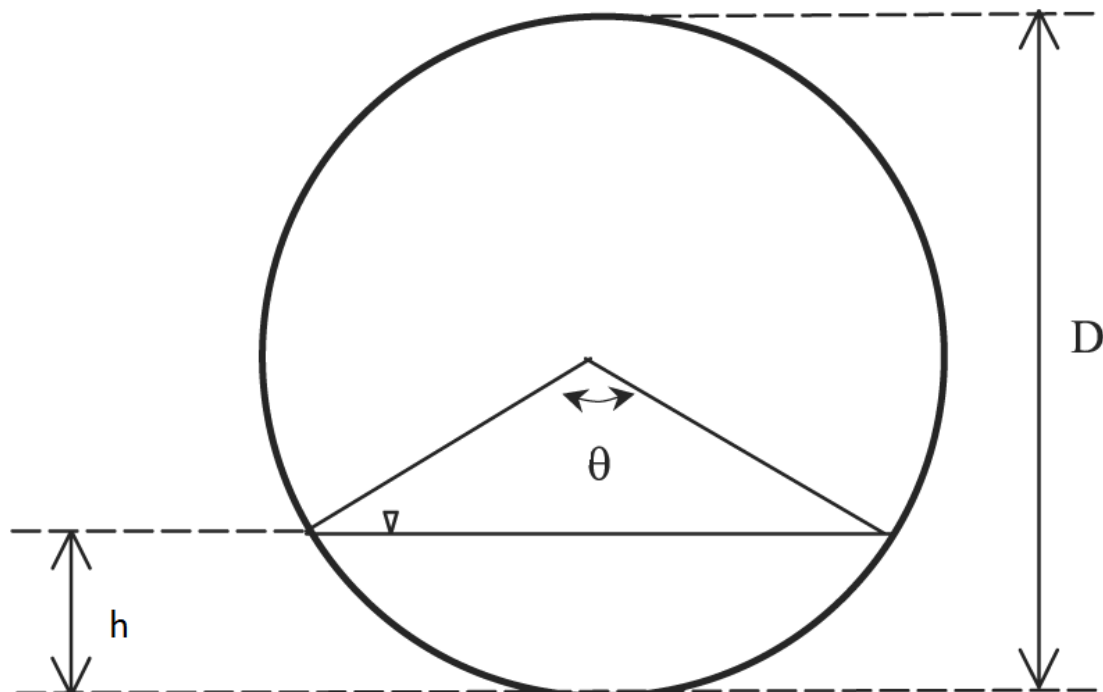Figure 4. Hydraulic elements derivation

(Q, V, R, A) and (Q_f, V_f, R_f, A_f) can be expressed in terms of wetted angle (θ).

$$\frac{h}{D} = \frac{1}{2}\left(1 - \cos\frac{\theta}{2}\right)$$

$$\cos\frac{\theta}{2} = 1 - 2\left(\frac{h}{D}\right) = \emptyset$$

$$\theta = 2\cos^{-1}\emptyset$$

$$\frac{A}{A_{full}} = \frac{1}{2\pi}(\theta - \sin\theta) = \frac{1}{\pi}\cos^{-1}\emptyset - \frac{1}{\pi}\emptyset\sqrt{1 - \emptyset^2}$$

$$\frac{R}{R_{full}} = \frac{\theta - \sin\theta}{\theta} = 1 - \frac{\emptyset\sqrt{1 - \emptyset^2}}{\cos^{-1}\emptyset}$$

$$\frac{V}{V_{full}} = \left(\frac{R}{R_{full}}\right)^{2/3}$$

$$\frac{V}{V_{full}} = \left(\frac{\theta - \sin\theta}{\theta}\right)^{2/3}$$

$$\frac{Q}{Q_{full}} = \frac{1}{2\pi}\frac{(\theta - \sin\theta)^{5/3}}{\theta^{2/3}}$$

$$\frac{Q}{Q_{full}} = 0.159\theta^{-\frac{2}{3}}(\theta - \sin\theta)^{5/3}$$

IMPORTANT
Take θ as radian
When cos θ or sin θ, take θ as degree.
To convert radian to degree, multiply radian with $180/\Pi$

References:

[1] http://www.brighthub.com/engineering/civil/articles/47261.aspx#ixzz1FdHZt1Rt

[2] Metcalf and Eddy, 1981. Wastewater Engineering: Collection and pumping of Wastewater. McGraw Hill Inc., New York.