ENVE 204

Lecture -1

Review of pipe flow:
Friction & Minor Losses

Assist. Prof. Neslihan SEMERCİ
Marmara University
Department of Environmental Engineering

Important Definitions

Pressure Pipe Flow: Refers to full water flow in closed conduits of circular cross sections under a certain pressure gradient.

For a given discharge (Q), pipe flow at any location can be described by
- the pipe cross section
- the pipe elevation,
- the pressure, and
- the flow velocity in the pipe.

Elevation (h) of a particular section in the pipe is usually measured with respect to a horizontal reference datum such as mean sea level (MSL).

Pressure (P) in the pipe varies from one point to another, but a mean value is normally used at a given cross section.

Mean velocity (V) is defined as the discharge (Q) divided by the cross-sectional area (A)

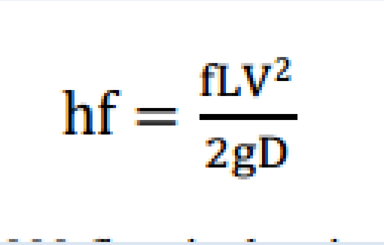
Head Loss From Pipe Friction

- Energy loss resulting from friction in a pipeline is commonly termed the friction head loss (hf)
- This is the head loss caused by pipe wall friction and the viscous dissipation in flowing water.
- It is also called **‘major loss’**.

FRICTION LOSS EQUATION

- The most popular pipe flow equation was derived by Henry Darcy (1803 to 1858), Julius Weiscbach (1806 to 1871), and the others about the middle of the nineteenth century.

- The equation takes the following form and is commonly known as the Darcy-Weisbach Equation.



$$hf = \frac{fLV^2}{2gD}$$

Turbulent flow or laminar flow

- Reynolds Number (NR) < 2000 → laminar flow

$$f = \frac{64}{Nr}$$

- Reynolds Number (NR) ≥ 4000 → turbulent flow;
  - the value of friction factor (f) then becomes less dependent on the Reynolds Number but more dependent on **the relative roughness (e/D)** of the pipe.

Roughness Heigths, e, for certain common materials

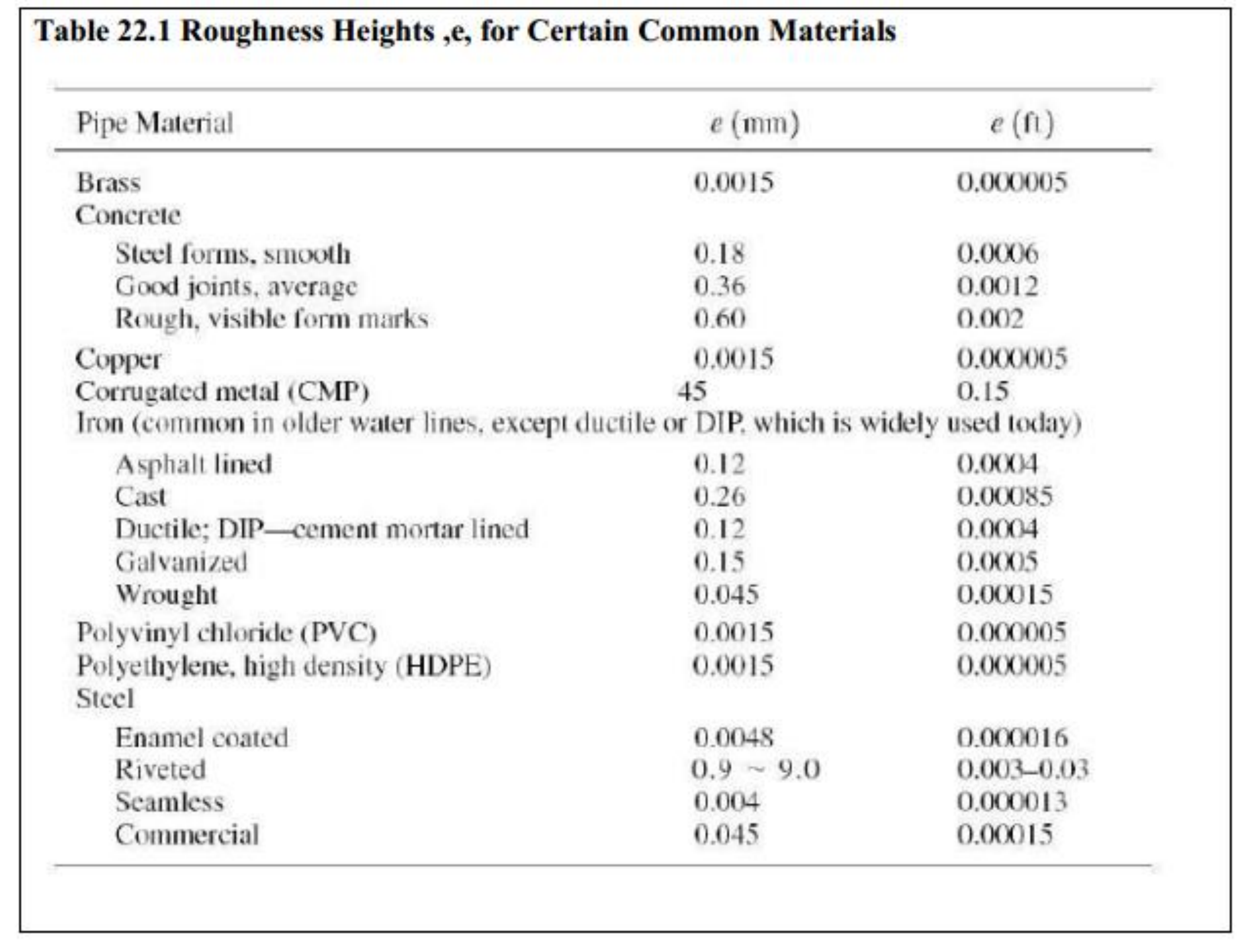


Table 22.1 Roughness Heights ,e, for Certain Common Materials

Pipe Material	*e* (mm)	*e* (ft)
Brass	0.0015	0.000005
Concrete		
Steel forms, smooth	0.18	0.0006
Good joints, average	0.36	0.0012
Rough, visible form marks	0.60	0.002
Copper	0.0015	0.000005
Corrugated metal (CMP)	45	0.15
Iron (common in older water lines, except ductile or DIP, which is widely used today)		
Asphalt lined	0.12	0.0004
Cast	0.26	0.00085
Ductile; DIP—cement mortar lined	0.12	0.0004
Galvanized	0.15	0.0005
Wrought	0.045	0.00015
Polyvinyl chloride (PVC)	0.0015	0.000005
Polyethylene, high density (HDPE)	0.0015	0.000005
Steel		
Enamel coated	0.0048	0.000016
Riveted	0.9 ~ 9.0	0.003–0.03
Seamless	0.004	0.000013
Commercial	0.045	0.00015

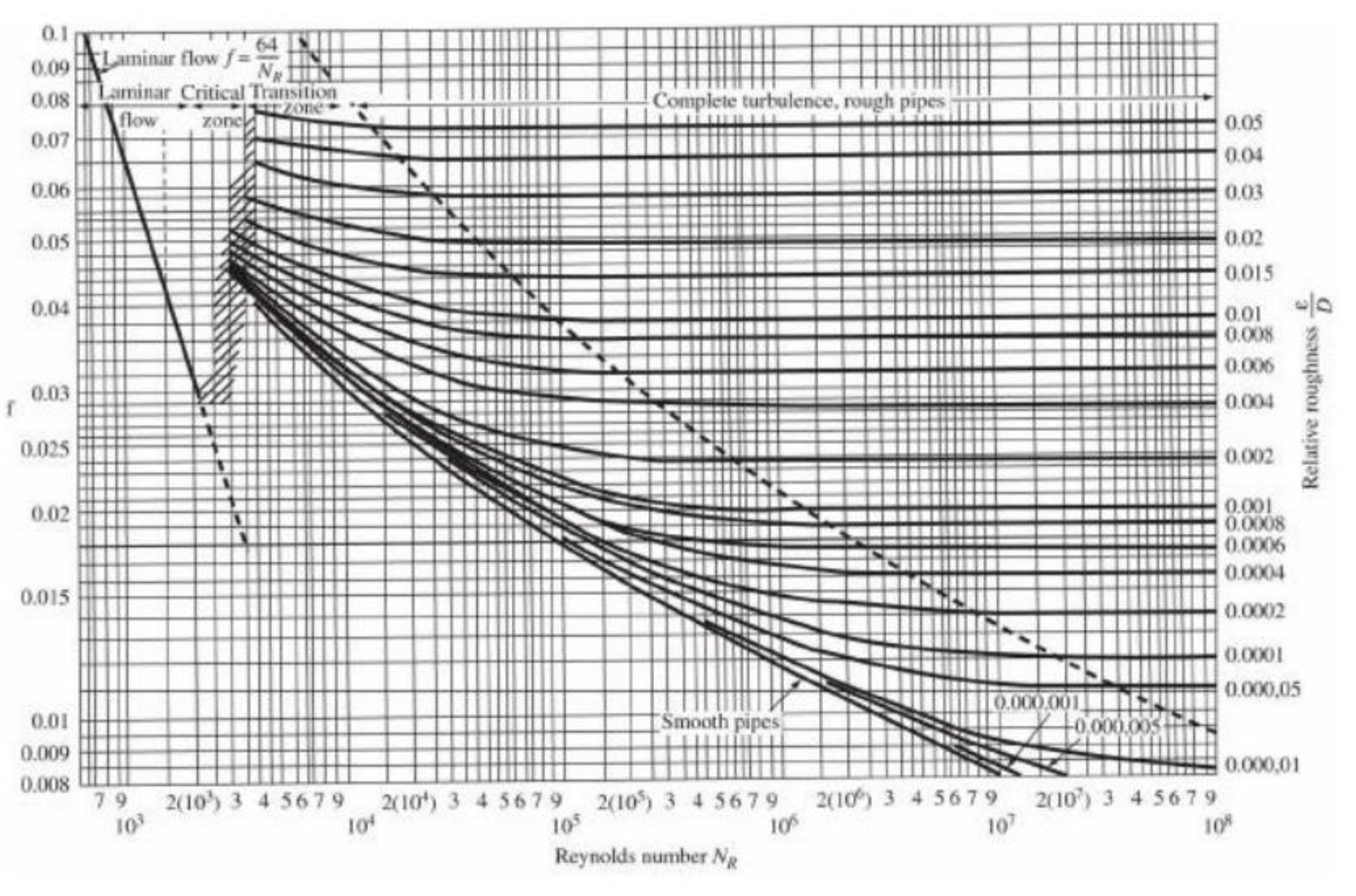
Friction factor can be found in three ways:

1. Graphical solution: Moody Diagram

2. Implicit equations : Colebrook-White Equation

3. Explicit equations: : Swamee-Jain Equation

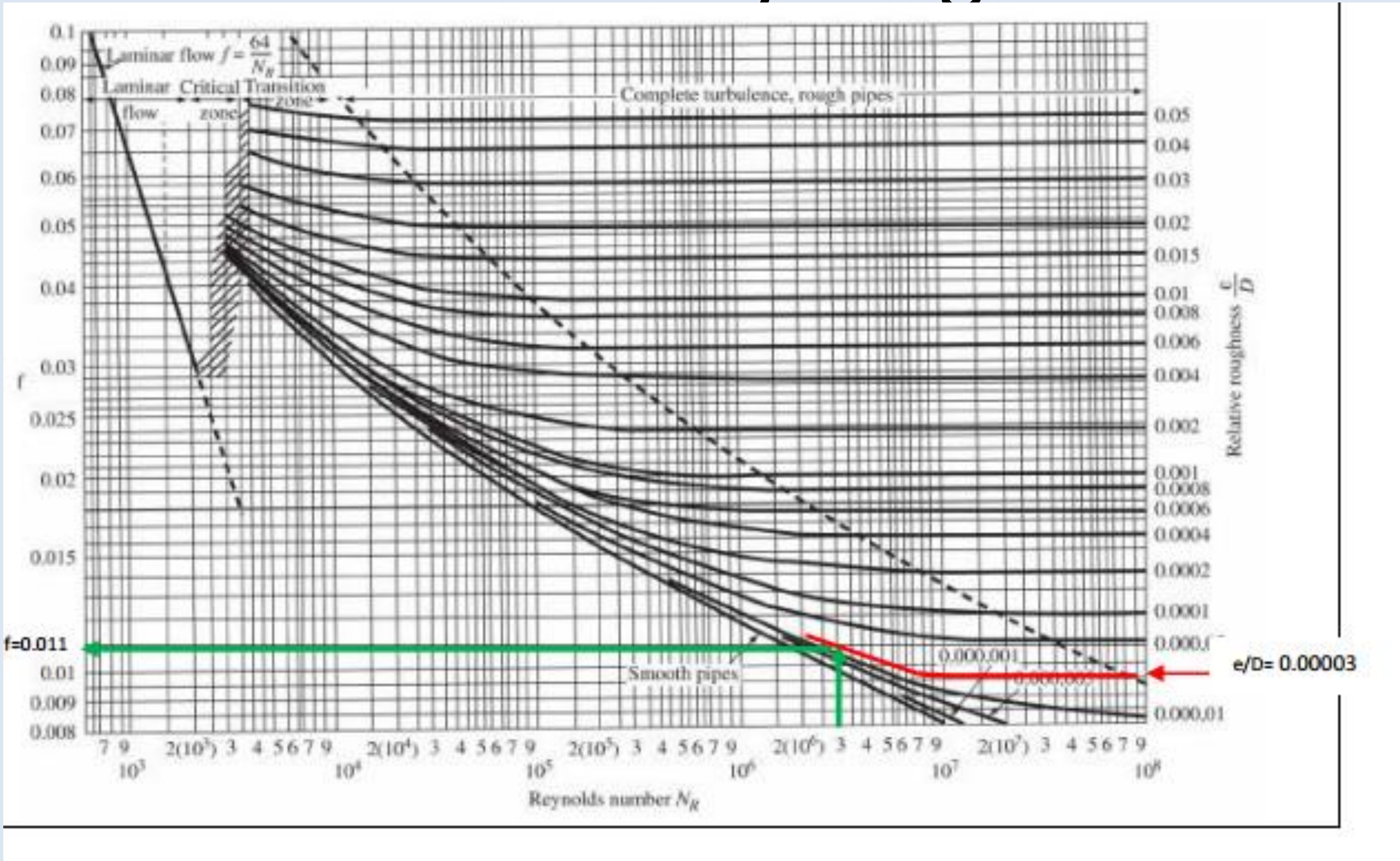
Moody Diagram



Determination of Friction Factor by using Moody Diagram

- **Example 22.1(Use of Moody Diagram to find friction factor):** A commercial steel pipe, 1.5 m in diameter, carries a 3.5 m^3/s of water at 20^0C. Determine the friction factor and the flow regime (i.e. laminar-critical; turbulent-transitional zone; turbulent-smooth pipe; or turbulent-rough pipe)

Use of Moody Diagram



Implicit and explicit equations for friction factor

Colebrook-White Equation:

$$\frac{1}{\sqrt{f}} = -\log\left(\frac{\frac{e}{D}}{3.7} + \frac{2.51}{N_R\sqrt{f}}\right)$$

Swamee-Jain Equation :

$$f = \frac{0.25}{\left[\log\left(\frac{\frac{e}{D}}{3.7}+\frac{5.74}{{N_R}^{0.9}}\right)\right]^2}$$

Emprical Equations for Friction Head Loss

Hazen-Williams equation:

It was developed for water flow in larger pipes (D≥5 cm, approximately 2 in.) within a moderate range of water velocity (V≤3 m/s, approximately 10 ft/s).

Hazen-Williams equation, originally developed fort he British measurement system, has been writtten in the form

$$V = 1.318 C_{HW} R_h^{0.63} S^{0.54}$$

S= slope of the energy grade line, or the head loss per unit length of the pipe (S=hf/L).

R_h = the hydraulic radius, defined as the water cross sectional area (A) divided by wetted perimeter (P). For a circular pipe, with $A=\pi D^2/4$ and $P=\pi D$, the hydraulic radius is

$$R_h = \frac{A}{P} = \frac{D^2/4}{\pi} = \frac{D}{4}$$

Emprical Equations for Friction Head Loss

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Hazen-Williams equation, originally developed fort he British measurement system, has been writtten in the form

$$V = 1.318 C_{HW} R_h^{0.63} S^{0.54}$$ in British System

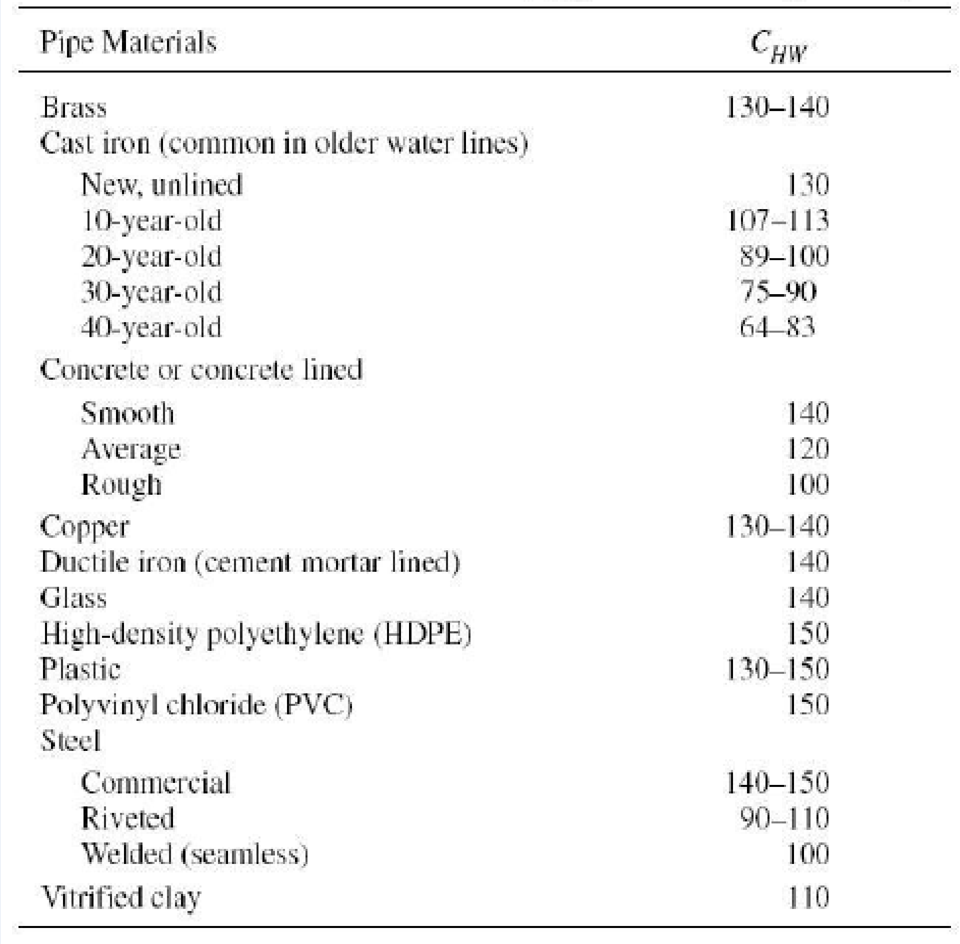
$$V = 0.849 C_{HW} R_h^{0.63} S^{0.54}$$ in SI System

S= slope of the energy grade line, or the head loss per unit length of the pipe (S=hf/L).

R_h = the hydraulic radius, defined as the water cross sectional area (A) divided by wetted perimeter (P). For a circular pipe, with $A=\pi D^2/4$ and $P=\pi D$, the hydraulic radius is

$$R_h = \frac{A}{P} = \frac{D^2/4}{\pi D} = \frac{D}{4}$$

C_{HW}= Hazen-Williams coefficient. The values of C_{HW} for commonly used water-carrying conduits



Pipe Materials	C_{HW}
Brass	130–140
Cast iron (common in older water lines)	
New, unlined	130
10-year-old	107–113
20-year-old	89–100
30-year-old	75–90
40-year-old	64–83
Concrete or concrete lined	
Smooth	140
Average	120
Rough	100
Copper	130–140
Ductile iron (cement mortar lined)	140
Glass	140
High-density polyethylene (HDPE)	150
Plastic	130–150
Polyvinyl chloride (PVC)	150
Steel	
Commercial	140–150
Riveted	90–110
Welded (seamless)	100
Vitrified clay	110

Emprical Equations for Friction Head Loss

Manning's Equation

- Manning equation has been used extensively open channel designs. It is also quite commonly used for pipe flows. The Manning equation may be expressed in the following form:

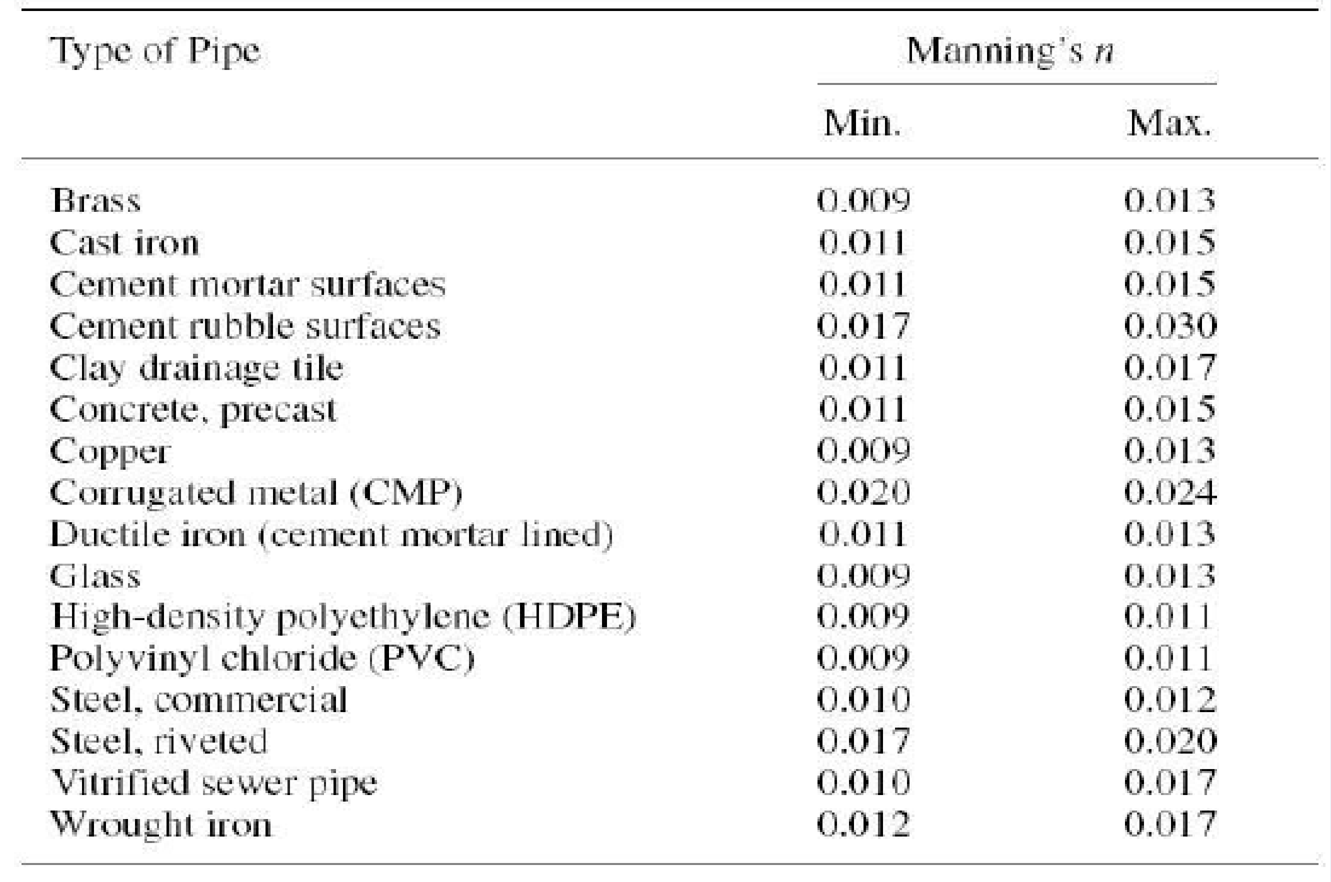
$$V = \frac{1}{n} R_h^{2/3} S^{1/2}$$

n= Manning's coefficient of roughness. In British units, the Manning equation is written as

$$V = \frac{1.486}{n} R_h^{2/3} S^{1/2}$$

where V is units of ft/s.

Manning Rougness Coefficient for pipe flows



Type of Pipe	Manning's n	
	Min.	Max.
Brass	0.009	0.013
Cast iron	0.011	0.015
Cement mortar surfaces	0.011	0.015
Cement rubble surfaces	0.017	0.030
Clay drainage tile	0.011	0.017
Concrete, precast	0.011	0.015
Copper	0.009	0.013
Corrugated metal (CMP)	0.020	0.024
Ductile iron (cement mortar lined)	0.011	0.013
Glass	0.009	0.013
High-density polyethylene (HDPE)	0.009	0.011
Polyvinyl chloride (PVC)	0.009	0.011
Steel, commercial	0.010	0.012
Steel, riveted	0.017	0.020
Vitrified sewer pipe	0.010	0.017
Wrought iron	0.012	0.017

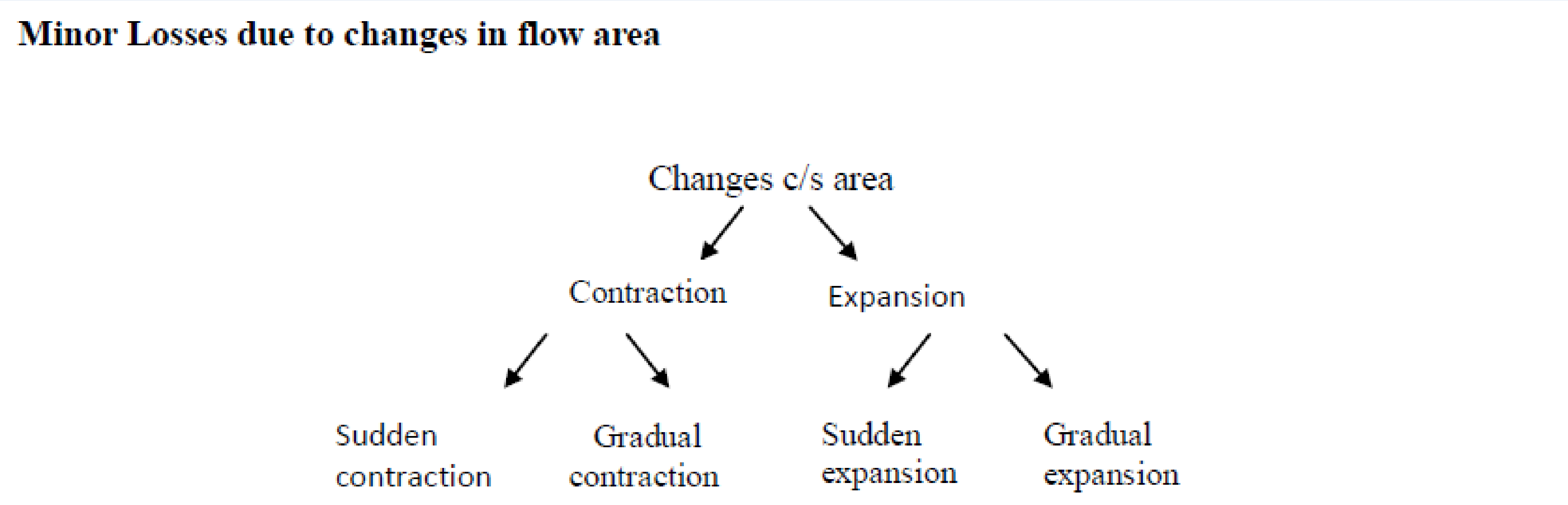
MINOR LOSS

Losses caused by fittings, bends, valves etc.

Each type of loss can be quantified using a loss coefficient (K). Losses are proportional to velocity of flow and geometry of device.

$$H_m = K \, . \, \frac{V^2}{2g}$$

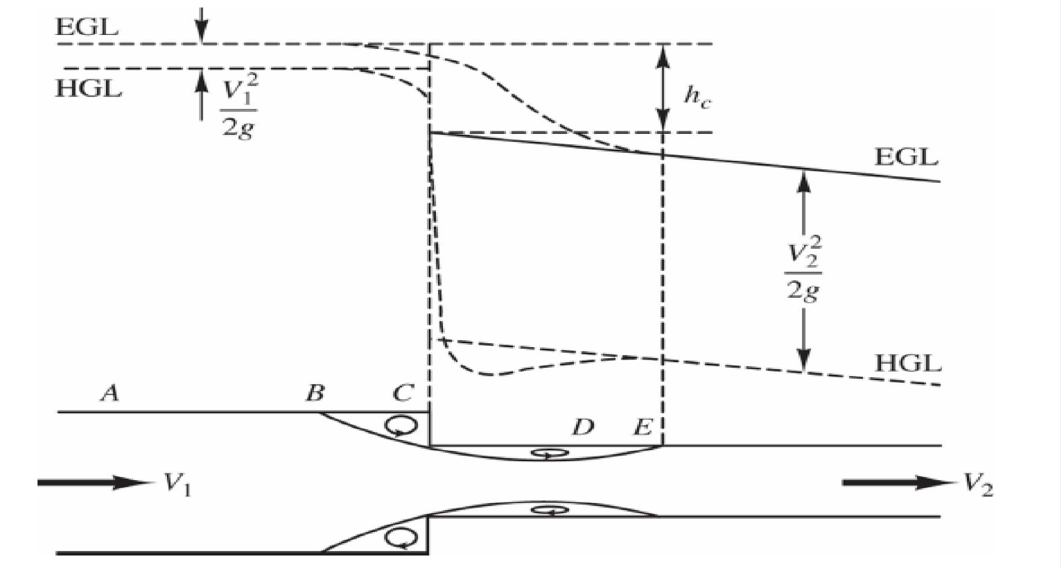
K=Minor loss coefficient



Minor Losses due to changes in flow area

- Changes c/s area
  - Contraction
    - Sudden contraction
    - Gradual contraction
  - Expansion
    - Sudden expansion
    - Gradual expansion

2.1. Minor Loss at Sudden Contraction

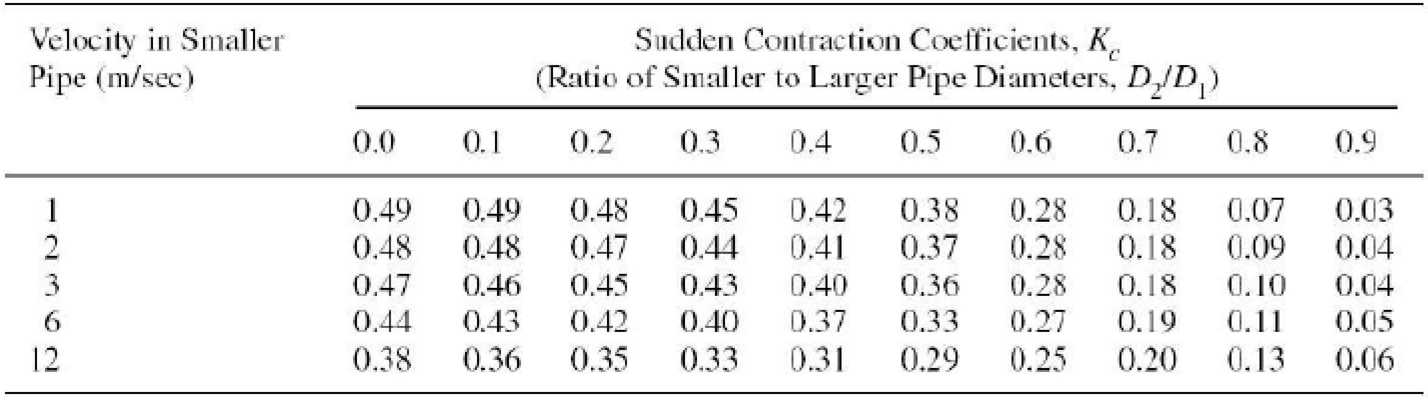


$$H_m = Kc\frac{V_2^2}{2g}$$

V_2= Velocity in smaller pipe

K_C = varies with D_2/D_1 ratio and velocity in smaller pipe (V_2) (Table 2.1)

Table 2.1 Values of the Coefficient K_c for Sudden Contraction



Velocity in Smaller Pipe (m/sec)	Sudden Contraction Coefficients, K_c (Ratio of Smaller to Larger Pipe Diameters, D_2/D_1)									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.49	0.49	0.48	0.45	0.42	0.38	0.28	0.18	0.07	0.03
2	0.48	0.48	0.47	0.44	0.41	0.37	0.28	0.18	0.09	0.04
3	0.47	0.46	0.45	0.43	0.40	0.36	0.28	0.18	0.10	0.04
6	0.44	0.43	0.42	0.40	0.37	0.33	0.27	0.19	0.11	0.05
12	0.38	0.36	0.35	0.33	0.31	0.29	0.25	0.20	0.13	0.06

2.2. Minor Loss at Gradual Contraction

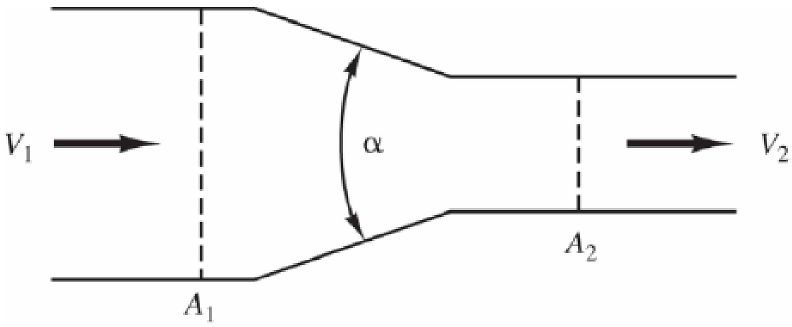


Figure 2.2. Pipe Confusor

$$H_m' = Kc'\frac{V_2^2}{2g}$$

The value of Kc' vary with transition angle α and the area ratio A_2/A_1 as shown in Figure 2.3

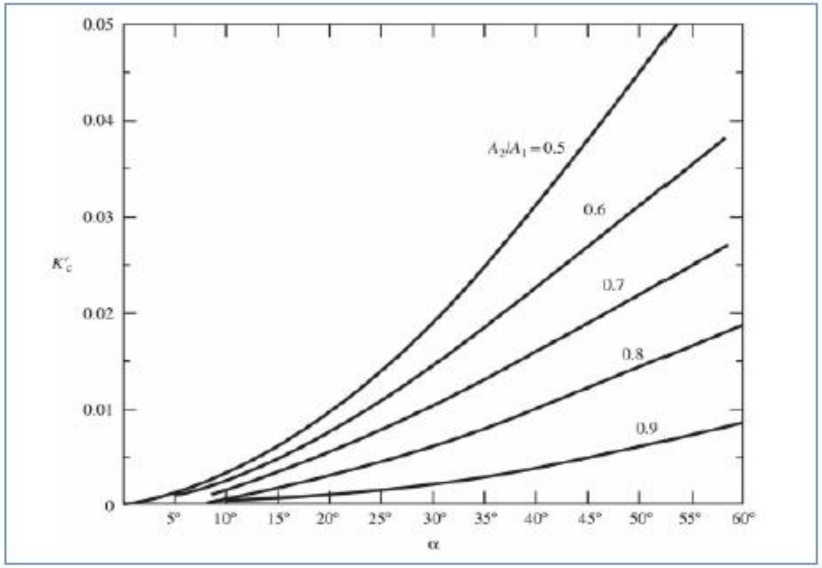
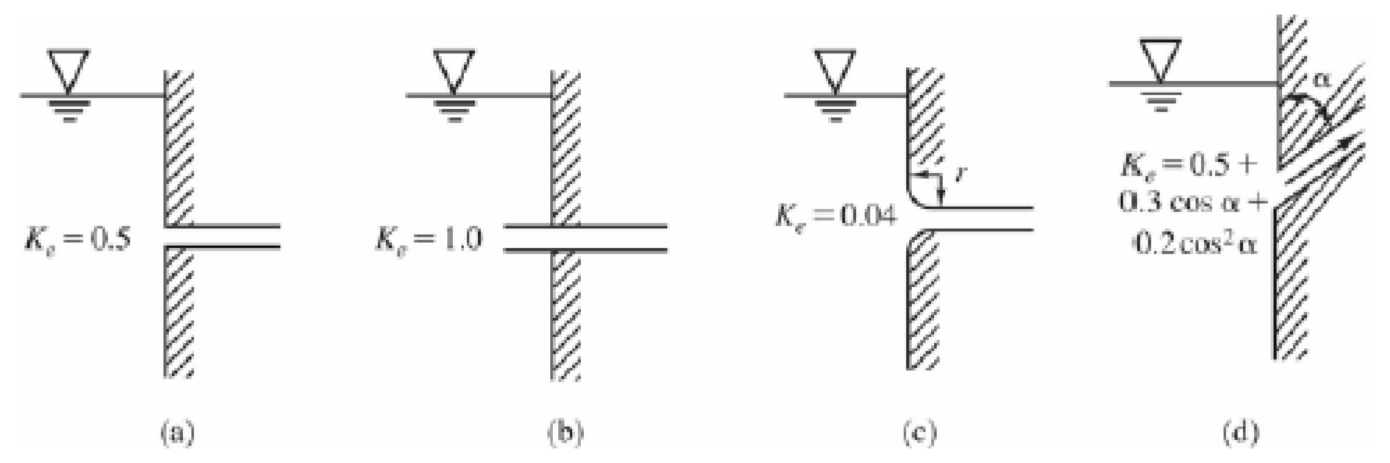


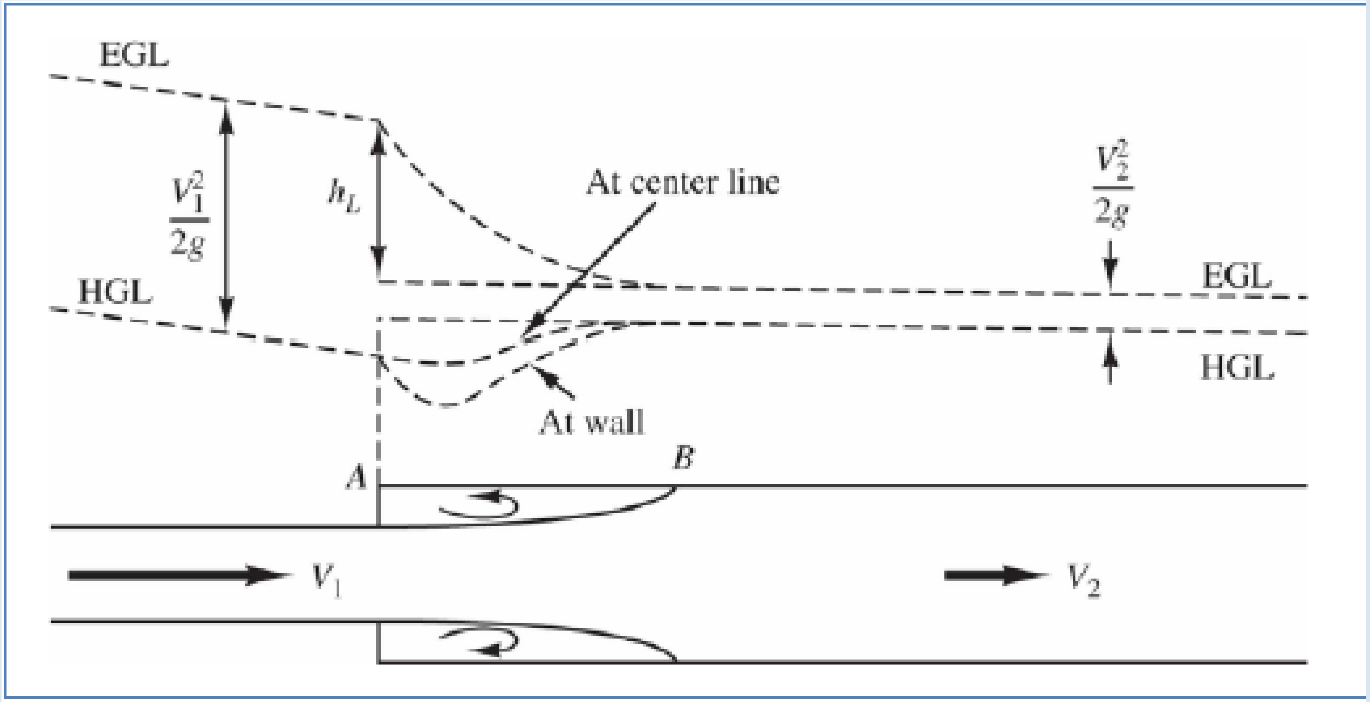
Figure 2.3 Coefficient K'c for pipe confusor.

Head Loss at the entrance of a pipe from a large reservoir



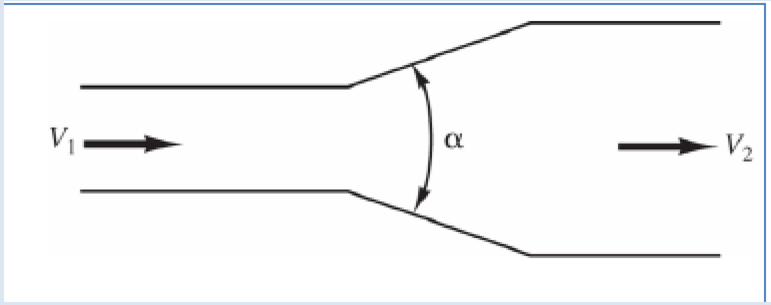
$$he = Ke(\frac{V^2}{2g})$$

2.3. Minor Loss in Sudden Expansions

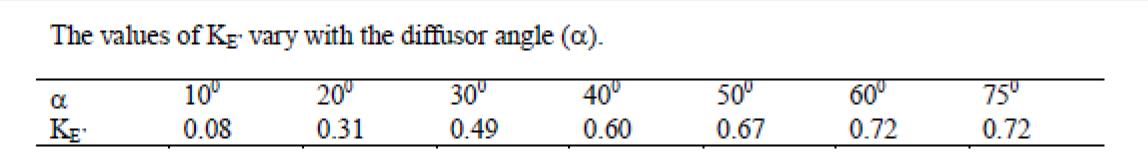


$$H_L = \frac{(V_1 - V_2)^2}{2g}$$

2.4. Minor Loss in Gradual Expansions



$$H_{L\,minor} = K_e \,.\, \frac{(V_1{}^2 - V_2{}^2)^2}{2g}$$



The values of $K_{E'}$ vary with the diffusor angle (α).

α	10^0	20^0	30^0	40^0	50^0	60^0	75^0
$K_{E'}$	0.08	0.31	0.49	0.60	0.67	0.72	0.72

Head Loss due to a submerging pipe discharging into a large reservoir

$$H_d = K_d \frac{V^2}{2g}.$$

Kd = 1.0

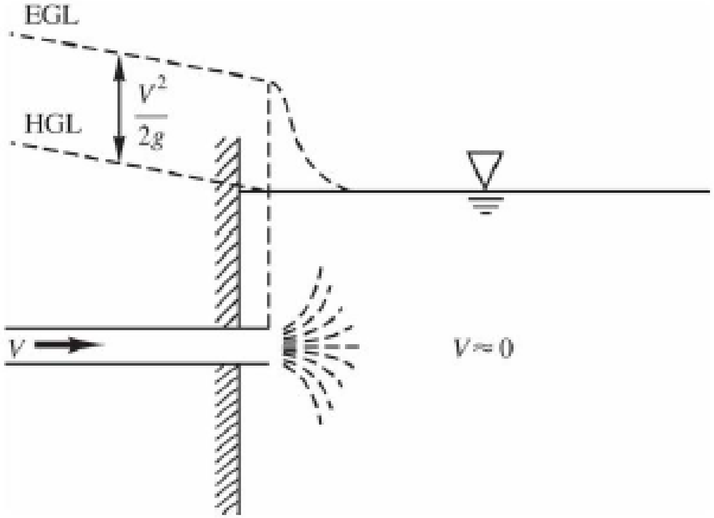


Figure 2.7. Exit (discharge) head loss

Minor Loss in pipe valves

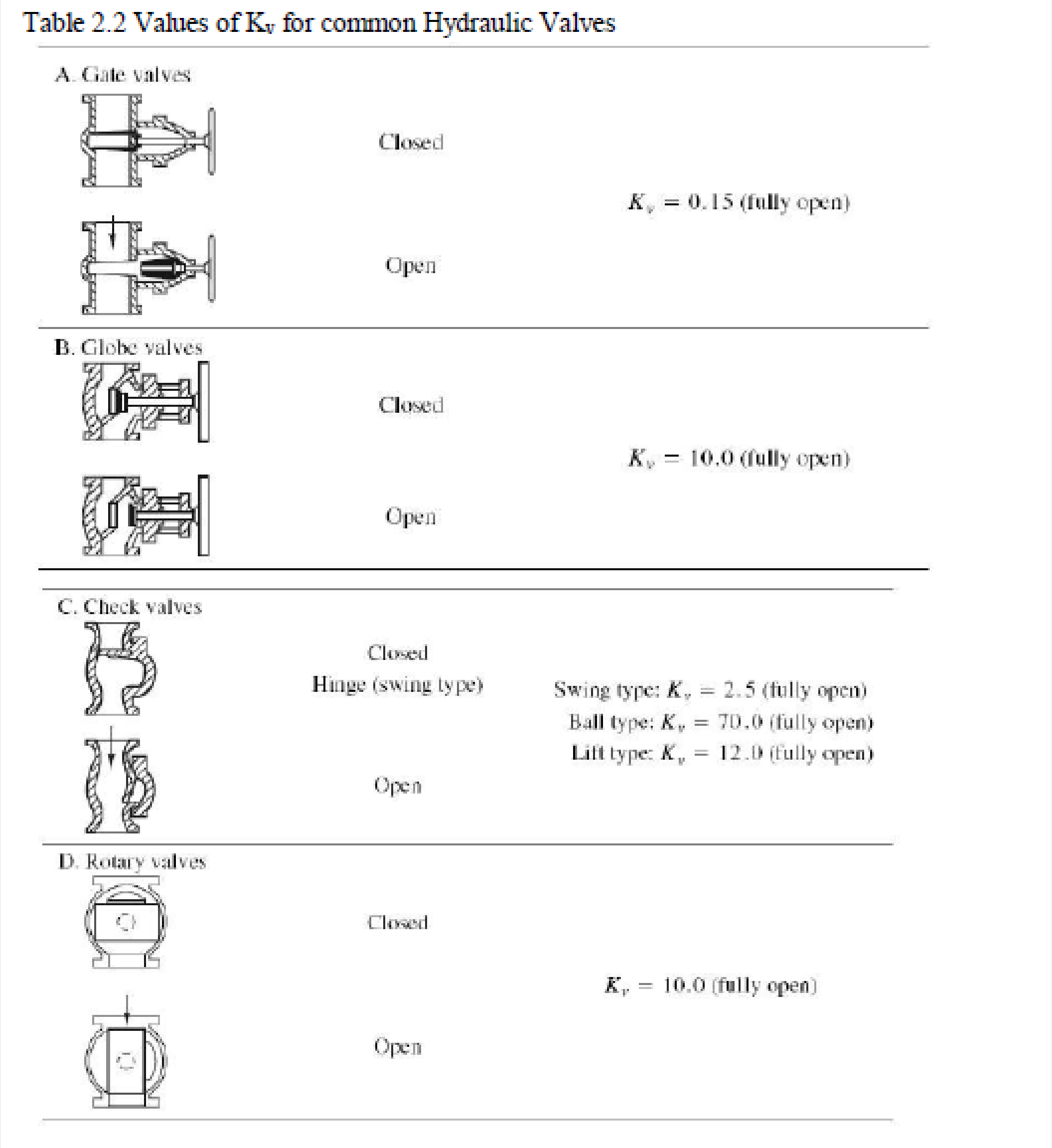
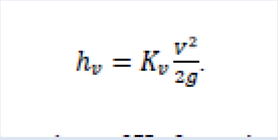


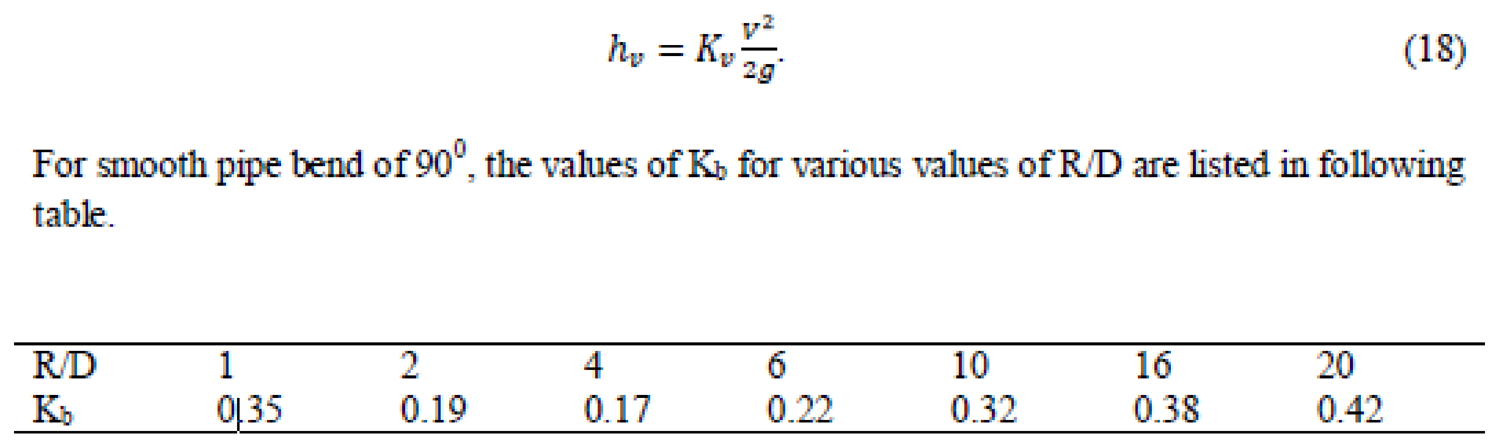
Table 2.2 Values of K_v for common Hydraulic Valves

A. Gate valves	Closed Open	$K_v = 0.15$ (fully open)
B. Globe valves	Closed Open	$K_v = 10.0$ (fully open)
C. Check valves	Closed Hinge (swing type) Open	Swing type: $K_v = 2.5$ (fully open) Ball type: $K_v = 70.0$ (fully open) Lift type: $K_v = 12.0$ (fully open)
D. Rotary valves	Closed Open	$K_v = 10.0$ (fully open)



$$h_v = K_v \frac{v^2}{2g}.$$

Minor Loss in Pipe Bends



$$h_v = K_v \frac{v^2}{2g}. \tag{18}$$

For smooth pipe bend of 90^0, the values of K_b for various values of R/D are listed in following table.

R/D	1	2	4	6	10	16	20
K_b	0.35	0.19	0.17	0.22	0.32	0.38	0.42