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# FLOW FRICTION CHARACTERISTICS OF CONCRETE PRESSURE PIPE

*Concrete pressure pipe lining is produced either by centrifugal casting or, as for the lining in this picture, by vertical "wet-casting" against a smooth steel form.*

This paper presents formulas to assist in hydraulic design of concrete pressure pipe. There are many formulas to calculate the head loss from flow friction in a pipeline; however, there are three formulas that are typically used in the industry. These three are presented in this paper. Also, the method used to determine minor and total head losses are presented.

The most frequently used formulas by the waterworks industry in establishing the capacity of pipelines are the Hazen-Williams formula, the Darcy-Weisbach formula and the Manning formula. Any of these formulas are acceptable in the industry. The user of this information is cautioned not to expect identical answers to a problem from the three formulas. The proper formula to be used in a given condition remains a matter of engineering judgment.

## REGARDING FLOW COEFFICIENTS

It is important to note that new pipe of any material or lining will almost always have better flow coefficients than pipe in service for a period of time. Even in pipelines conveying disinfected water, biofilms are common on the pipe lining surface. In raw water lines, biofilms can include fibrous growths that significantly disrupt smooth flow, regardless of the pipe lining material. Chemical deposits can occur from some waters. Water pipe linings may also be corroded or roughened by scouring.

The coefficients presented herein are based upon data determined from pipelines in service for a period of time, and for most applications may be used to approximate the anticipated performance of new installations. Even so, each installation must be evaluated for circumstances that may degrade flow over time. Pig insertion stations, chemical treatment facilities, specific linings, or other pipeline appurtenances may be justified to assure

AMERICAN Concrete Pressure Pipe ASSOCIATION that continuing flow degradation does not result in unnecessarily excessive pumping costs.

## THE HAZEN-WILLIAMS FORMULA

Probably the most popular flow formula in current use in waterworks engineering is the Hazen-Williams formula. The advantage of this equation is that the coefficient C is not a function of the Reynolds number. Its disadvantage is that it is valid only for water and does not account for temperature or viscosity variations. This formula was developed and published in the early 1900's as:

$$V = 1.318 C_h r^{0.63} s^{0.54}$$

Where:

$V$ = velocity, ft/sec

$C_h$ = Hazen-Williams roughness coefficient

$r$ = hydraulic radius of pipe, ft

$s$ = slope of hydraulic grade line, ft/ft calculated as $h_L/L$, where $h_L$ equals head loss in feet occurring in a pipe of length L in ft.

For circular conduit flowing full, the head loss $h_L$ may be calculated from:

$$h_L = (4.726\, Q^{1.852}\, L)/(C_h^{1.852}\, d^{4.87})$$

*Centrifugal casting packs the aggregate into the lining, resulting in a smooth pipe interior.*

Where:

$h_L$ = frictional head loss in pipe length L, ft

$Q$ = discharge, $ft^3$/sec

$L$ = length of pipe, ft

$d$ = inside diameter of pipe, ft

Tests have shown that the value of the Hazen-Williams coefficient $C_h$ is dependent not only on the surface roughness of the pipe interior but also on the diameter of the pipe. Flow measurements indicate that for pipe with smooth interior linings in good condition, the average value of $C_h$ = 139.3 + 2.02D.

However, for design purposes the following conservative values are suggested:

| Diameter, in. | $C_h$ Value |
|---|---|
| 16 to 48 | 140 |
| 54 to 108 | 145 |
| 114 and larger | 150 |

## THE DARCY-WEISBACH FORMULA

The second formula frequently used in waterworks engineering is the Darcy-Weisbach formula. Its general form can be derived analytically for laminar flow, and it can be used for any fluid. The formula is:

$$h_L = f\, L\, V^2 / d\, 2g$$

Where:

$h_L$ = Head loss, in feet of water

$f$ = Darcy friction factor

$L$ = pipeline length, ft

$V$ = velocity, ft/sec

$d$ = inside diameter of the pipe, ft

$g$ = gravitational constant, 32.2 ft/$sec^2$

The Darcy friction factor (f) is determined from the Moody diagram, illustrated in Figure 1. The Reynolds number ($R_e$) and the relative roughness (e/d) must first be calculated.

The Reynolds number is a function of the flow in the pipe and may be calculated as:

$$R_e = d\,V / \nu$$

Where:

Re = Reynolds number

d = inside diameter of the pipe, ft

V = velocity, ft/sec

$\nu$ = kinematic viscosity of the fluid, $ft^2/sec$

The kinematic viscosity of water at various temperatures from freezing to boiling can be obtained from any hydraulic manual.

The relative roughness (e/d) of a pipe is a function of the absolute roughness (e), in feet, of the interior surface of the pipe and the pipe diameter (d), in feet. Values of the absolute roughness (e) for concrete pipe range from $8.0 \times 10^{-5}$ to $7.5 \times 10^{-4}$, and the recommended design range is $3.5 \times 10^{-4}$ to $4.0 \times 10^{-4}$. Once the Reynolds number and the relative roughness are determined, the Moody diagram (figure 1) can be used to determine values of the Darcy friction factor (f), which may then be used to solve the Darcy-Weisbach formula.

If an analytical solution for the Darcy friction factor (f) is required, it may be obtained by interaction from the Colebrook-White equation:

$$1/\sqrt{f} = -2 \log_{10} [(e/3.7d) + (2.51/R_e\sqrt{f})]$$

Where:

f = Darcy friction factor

e = absolute roughness, ft

d = inside diameter of the pipe, ft

$R_e$ = Reynolds number

## **THE MANNING** FORMULA

The third formula frequently used in the water industry is the Manning formula. This formula is more commonly used to establish the flow in partially filled gravity lines; however it can be used for fully developed flow in conduits. The formula for pressure flow in round conduits is:

$$V = (0.590d^{0.67}/n_M)\,(h_L/L)^{0.5}$$

Where:

V = velocity, ft/sec

d = inside diameter of the pipe, ft

$h_L$ = head loss, in feet, in a length L, ft

$n_M$ = Manning roughness coefficient

The recommended Manning roughness coefficient value $n_M$ for concrete pressure pipe should be approximately 0.011 when the velocity is 3 ft/s and 0.010 when the velocity is 5 ft/s.

## **MINOR** LOSSES

Minor losses in pipelines are caused by turbulence resulting from changes in flow geometry. Minor losses, which are generally expressed as a function of the velocity head, will occur at entrances, outlets, contractions, enlargements, bends, and other fittings. In long pipelines, the minor losses are usually small compared to losses from pipe friction and may be neglected. In shorter lines or plant piping, the sum of these minor losses may become significant. The formula for calculating minor losses is:

$$h_L = C_L V^2/(2g)$$

Where:

$h_L$ = head loss, ft

$C_L$ = a dimensionless coefficient

V = velocity, ft/sec

g = gravitational constant, 32.2 $ft/sec^2$

Figure 2 presents values of $C_L$ for common flow configurations.

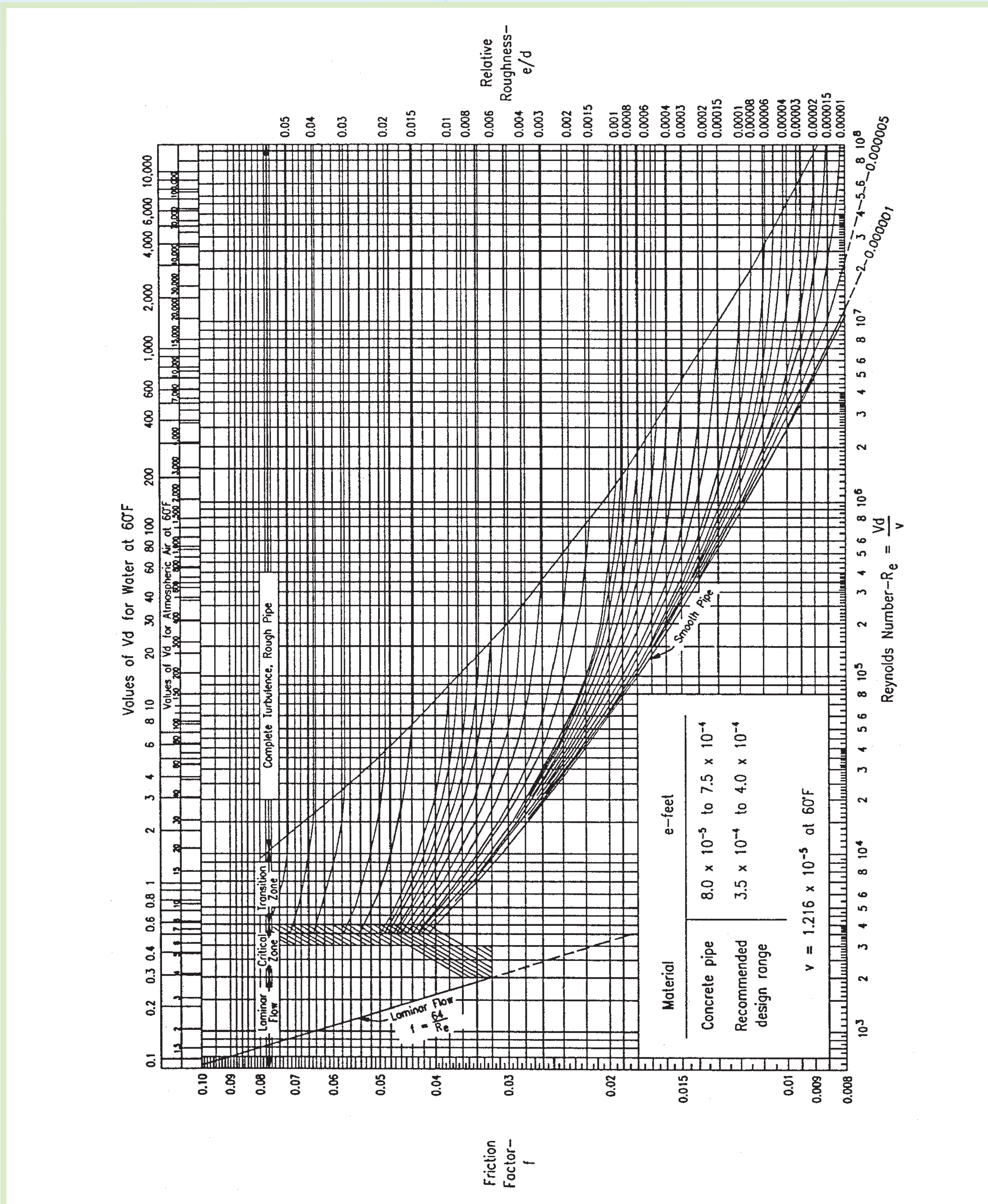
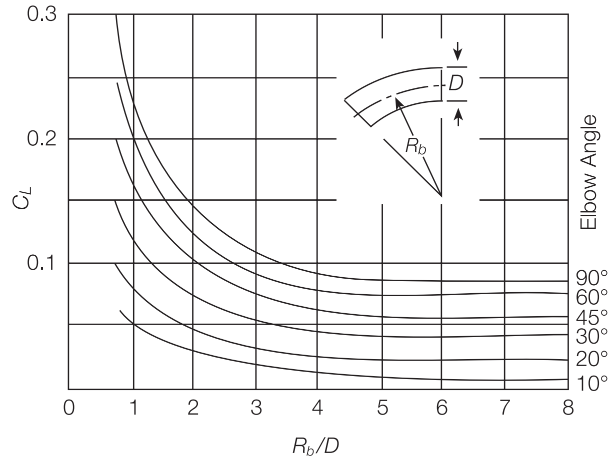



*Figure 1. The Moody diagram for friction in pipe. Reprinted from* AWWA Manual M9, 3rd edition *by permission. Copyright © 2008 the American Water Works Association.*




Loss Coefficient $C_L$ for Elbows

| Flow Configurations | | $C_L$ |
|---|---|---|
| Elbow | | See figure above |
| Reentrant Entrance | | 0.80 |
| Square–Edged Entrance | | 0.50 |
| Slightly Rounded Entrance | | 0.23 |
| Well–Rounded Entrance | | 0.04 |
| Flow Into Reservoir | | 1.00 |
| Reducer With α ≤ 15° | α | 0.04 |
| Enlarger:<br>ß = 10°<br>ß = 20°<br>ß = 30° | ß | <br>0.20<br>0.40<br>0.70 |
| Tee, Through Run | | 0.60 |
| Tee, Through Side Outlet | | 1.80 |
| Tee Into Side Outlet | | 1.50 |
| 45° Wye | or | 1.30 |
| Gate Valve, Fully Open | | 0.20 |
| Swing Check Valve, Fully Open | | 2.50 |
| Butterfly Valve, Fully Open | | 0.25 |

*Figure 2. Approximate loss coefficients for commonly encountered flow configurations.*
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## **EQUIVALENT** LENGTH METHOD

Each minor head loss in a piping system can be expressed in terms of an equivalent length of pipe $L_e$. This equivalent length of pipe is the number of feet of straight pipe that would have friction head loss equal to the minor losses created by the fitting. The list below shows the equivalent length formulas that correspond to the flow formulas presented earlier.

| Friction Formula | Equivalent Length Formula |
|---|---|
| Hazen-Williams | $L_e=0.331C_L (V^{0.148}d^{1.167}C_h^{1.852})/2g$ |
| Darcy-Weisbach | $L_e = C_L (d/f)$ |
| Manning | $L_e = 0.348C_L (d^{1.333})/2g(n_M)^2$ |

Where:

$L_e$ = length of pipe that would have a frictional lead loss equal to the minor loss created by fitting, ft

$C_L$ =loss coefficient

V = velocity, ft/sec

d = inside diameter of the pipe, ft

$C_h$ = Hazen-Williams roughness coefficient

g = gravitational constant, 32.2 ft/sec$^2$

f = Darcy friction factor,

$n_M$ = Manning roughness coefficient

## **HEAD** LOSS

The total head loss in a pipeline is the sum of minor losses due to changes in flow geometry added to the head loss created due to the friction caused by flow through the pipe. The head loss for the pipeline can be used to calculate the pumping costs which will be incurred for various diameters of pipe. The pumping costs can be compared to the initial costs for the various diameters of pipe so that the most cost-effective size of pipe can be determined.

## LEARN MORE

For more information on flow friction characteristics, speak with your Concrete Pressure Pipe supplier, or contact the American Concrete Pressure Pipe Association at **714.801.0298** or **www.accpa.org**.

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