Fundamentals of Hydraulic Engineering Systems

Fifth Edition

Chapter 3b

Water Flow in Pipes

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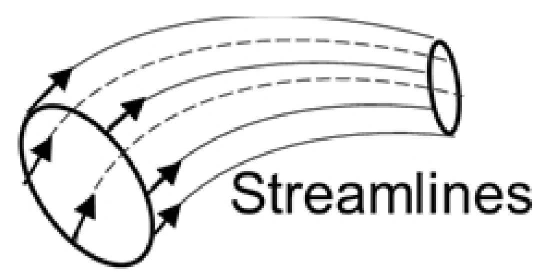
Description of Pipe Flow Definitions and Visualization

Definitions and Visualization

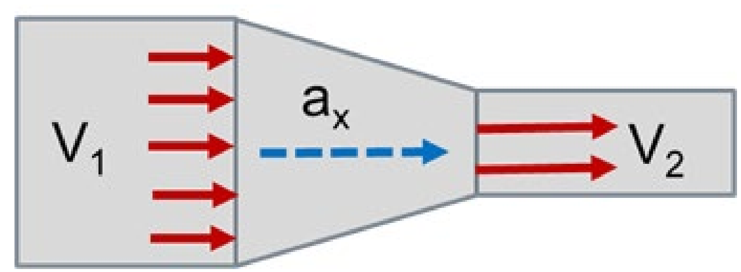
Questions: What is a streamline? What is a stream tube?
Streamline: imaginary lines drawn in the flow field which are everywhere tangent to velocity vectors
Stream tube: a grouping (bundle) of streamlines
Visualization:

Question: Define steady flow?
Question: Given steady flow, is fluid acceleration possible?



Local acceleration: (dV/dt)
(equals zero in steady flow)
Convective acceleration:

$V(dV/ds) \rightarrow$ V change over distance



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Flow Continuity - Pipe Flow

(Importance: Determining pipe velocities and flows.)

Mass flux in = Mass flux out

$$\gamma[d(Vol_{1\text{-}1'})/dt] = \gamma[d(Vol_{2\text{-}2'})/dt]$$

$$\gamma A_1[d(S_1)/dt] = \gamma A_2[d(S_2)/dt]$$

where S = velocity, thus

$$\gamma A_1(V_1) = \gamma A_2(V_2)$$

$$A_1(V_1) = A_2(V_2)$$

(2nd Key Equation)

The **continuity equation** for steady, incompressible flow.

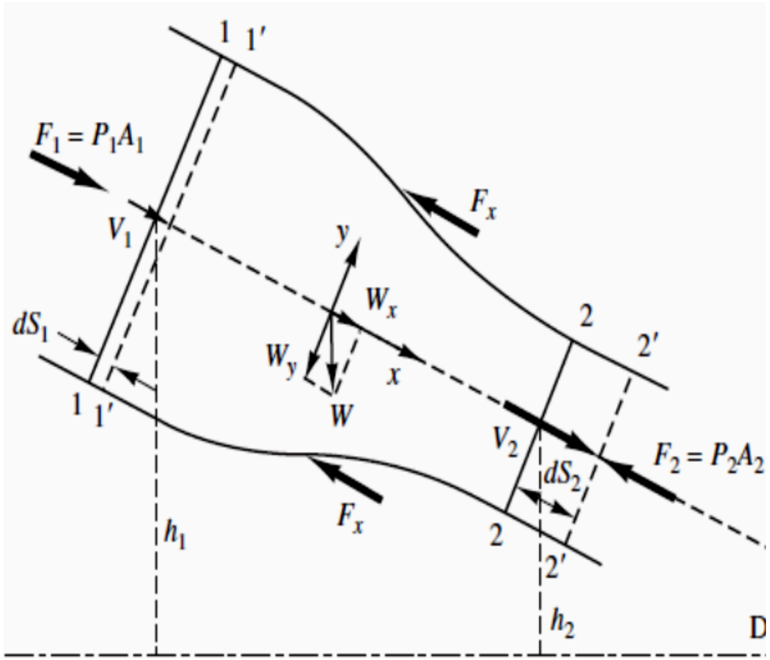

Figure 3.3 General description of flow in pipes

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Forces in Pipe Flow (1 of 3)

Importance: Anchoring pipe bends and nozzles.

Applying Newton's 2nd Law to

the moving mass in the CV:

$$\sum F = ma = m(dV/dt)$$

In finite difference form:
(for convective acceleration)

$$\sum F = (mV_2 - mV_1)/\Delta t$$

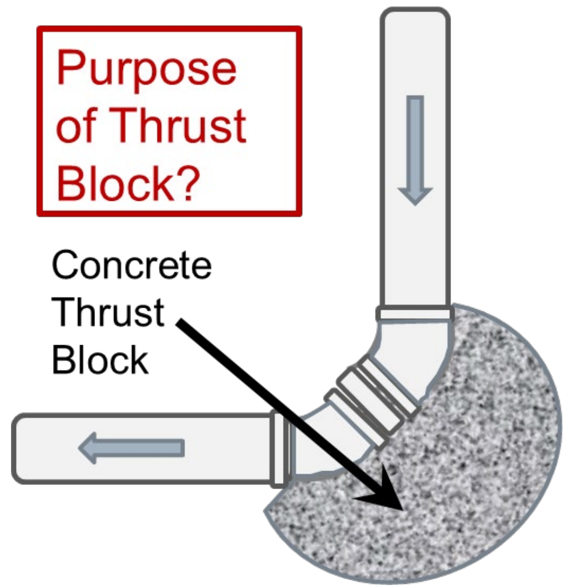
but since Mass $(m) = \gamma(\text{Vol})$;

$$\sum F = [\gamma(\text{Vol})(V_2) - \gamma(\text{Vol})(V_1)]/\Delta t$$

and since $\rho Q = \text{Vol}/\Delta t$

$$\sum F = \rho Q(V_2 - V_1)$$

3rd Key Equation



The **impulse-momentum equation** for steady, incompressible flow.

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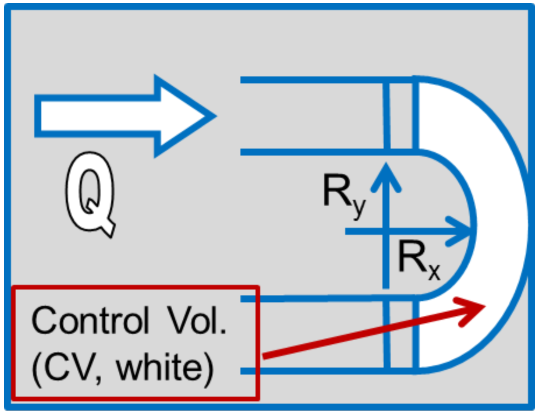
Forces in Pipe Flow (2 of 3)

Example Problem

Find the anchoring force required to hold the bend in place. The 180-degree bend is in the horizontal plane with $Q = 0.40\,m^3/s$, water pressure = 100 k Pa, pipe diameter = 20 cm, bend volume $= 0.100\,m^3$, and pipe bend weight = 400N.



Note: Forces that need to be accounted for: weight, pressure (pA), and reaction forces due to change of direction, drag, and contraction/expansion.

Note: The impulse-momentum equation is in vector form, so we need to solve it in all directions:

$$\sum F_x = \rho Q(Vx_2 - Vx_1);\ \text{etc.}$$

Note: Pressure forces always act toward the control volume.

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Forces in Pipe Flow (3 of 3)

Example Problem – Solve on White Board

$$\sum F_x = \rho Q(V_{x_2} - V_{x_1}); \rightarrow + (\text{positive})$$

$$\sum F_x = R_x + P_1A_1 + P_2A_2$$

$$P_1A_1 = P_2A_2 = (100)[\pi(0.1)^2] = 3.14 \text{ kN}$$

$$V = Q / A = 0.4 / [\pi(0.1)^2] = 12.7 \text{ m/s}$$

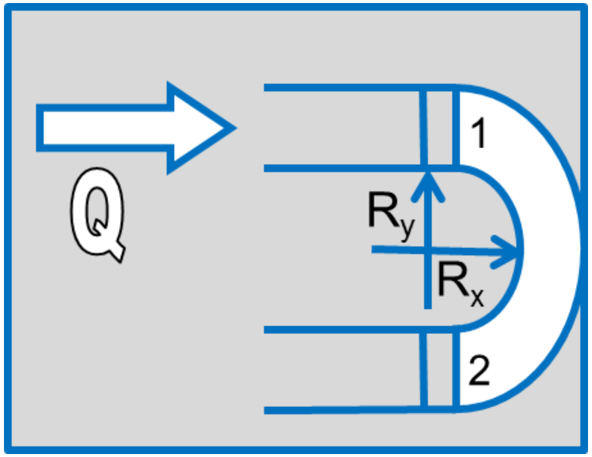
$$R_x + 2(3{,}140) = (998)(0.40)(-12.7 - 12.7)$$

$$\mathbf{R_x} = -16{,}400 = -16.4 \text{ kN or } \mathbf{16.4\ kN} \leftarrow$$

$$\sum F_y = \rho Q(V_{y2} - V_{y1}); \mathbf{R_y} = \mathbf{0\ kN}$$

$$\sum F_z = \rho Q(V_{z_2} - V_{z_1}); R_z = \text{Wt.}$$

$$\mathbf{R_z} = 400 + (0.1)(9790) = \mathbf{1.38\ kN\ (up)}$$



Homework Problems:

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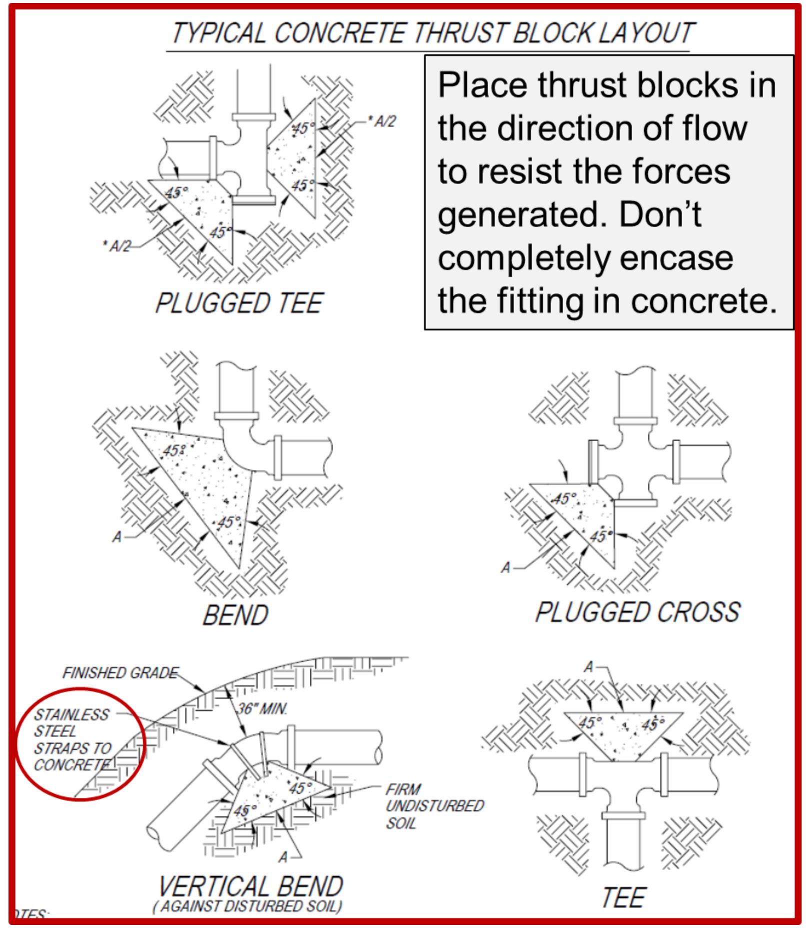
Thrust Block Details

Rf: City of Auburn, AL

https://www.auburnalabama.org/PWDir/Specs%20and%20Details/Revised%20WRM%20Standard%20Details%202012/Water%20Details%20-%2024X36%20REVISED%202012.pdf

Note: A preferred method of thrust restraint requires externally restrained joint devices: Mega-Lugs in lieu of concrete blocks.

For an excellent article on advances in pipe restraints, see: bulldogrestraintsystem.com/TexasASCESectionalPaper.pdf



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