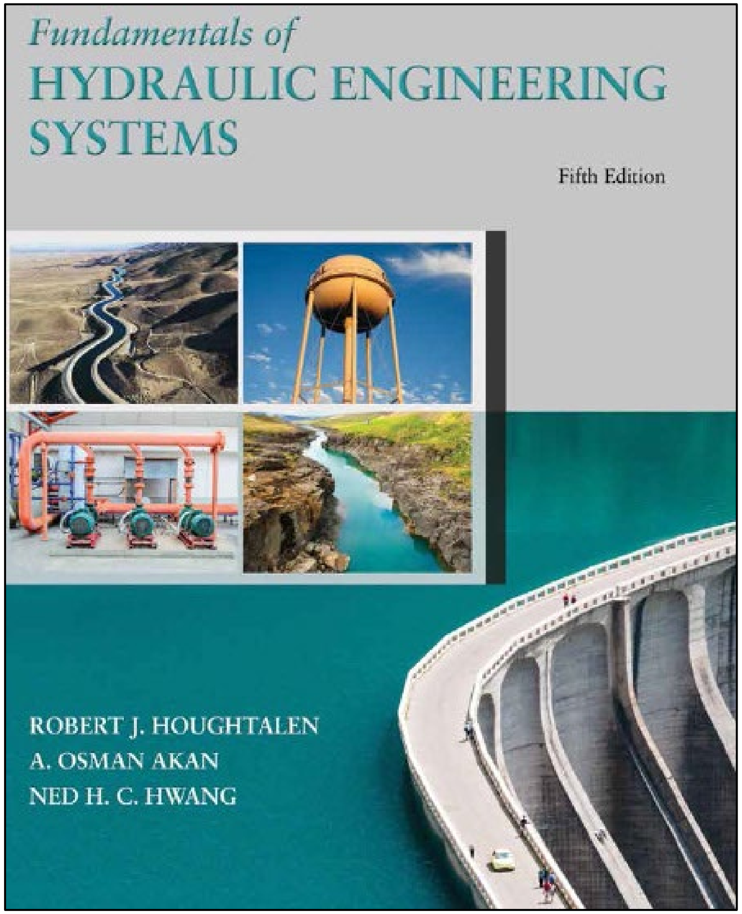
# Fundamentals of Hydraulic Engineering Systems

Fifth Edition



## Chapter 4c

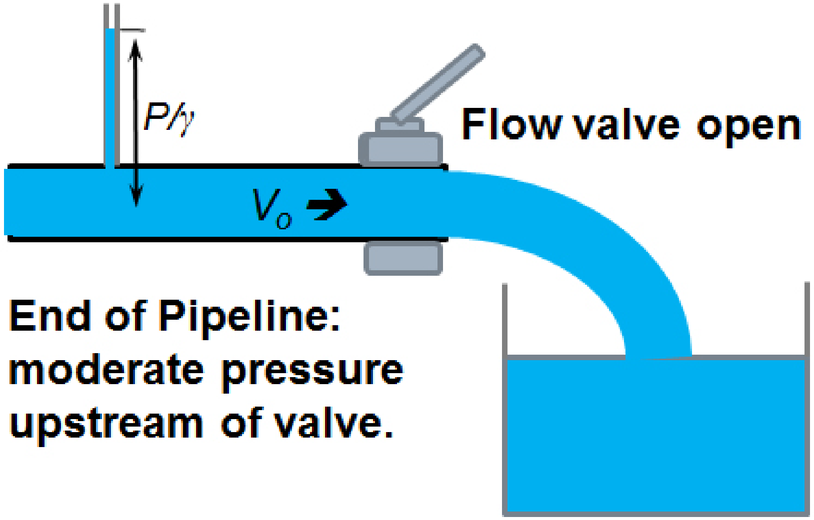
Pipelines and Pipe Networks

# Definitions and Concepts (1 of 2)

## Water Hammer Phenomenon in Pipelines

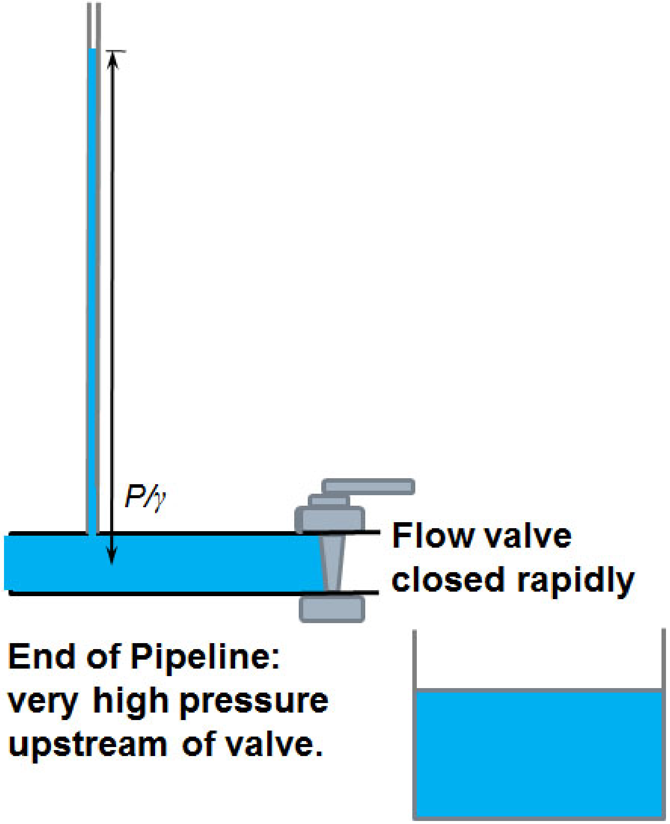
**Water Hammer:** a pressure rise in a pipe caused by a rapid valve closure or a pump shutoff.

**Result:** pipe noise/knocking, pipe fracture, or valve damage.



**Flow valve open**

**End of Pipeline: moderate pressure upstream of valve.**



**Flow valve closed rapidly**

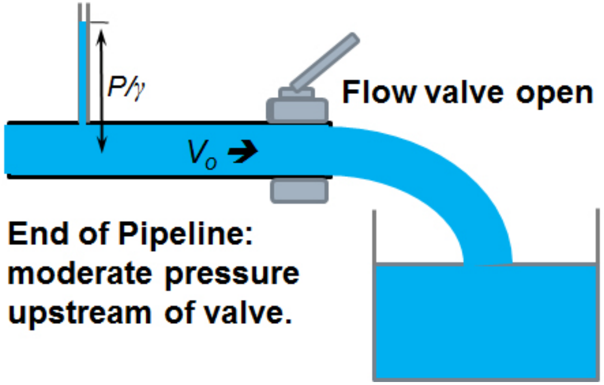
**End of Pipeline: very high pressure upstream of valve.**

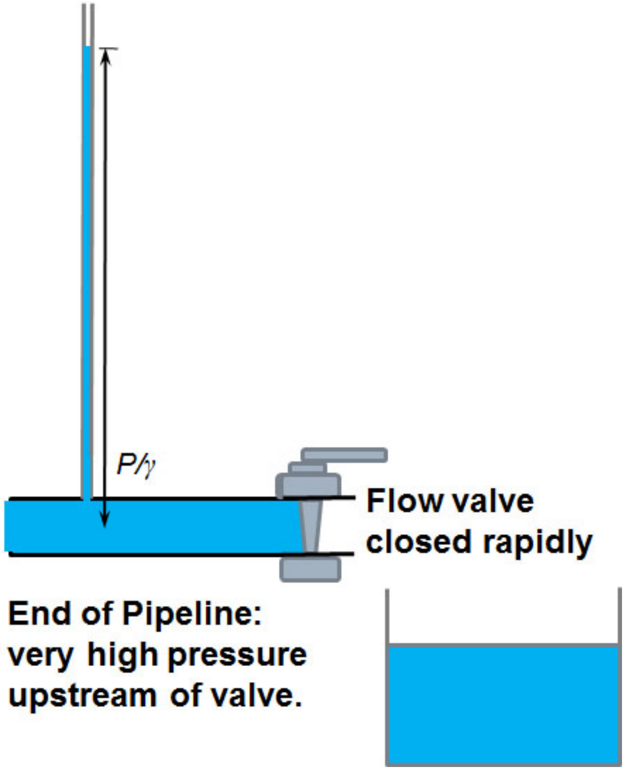
# Definitions and Concepts (2 of 2)

**Theory:** $F = ma = m\left(\dfrac{dV}{dt}\right)$;

where: m = flowing water mass
For instantaneous closure;

$$F = \frac{m(V_o - 0)}{0} = \infty$$





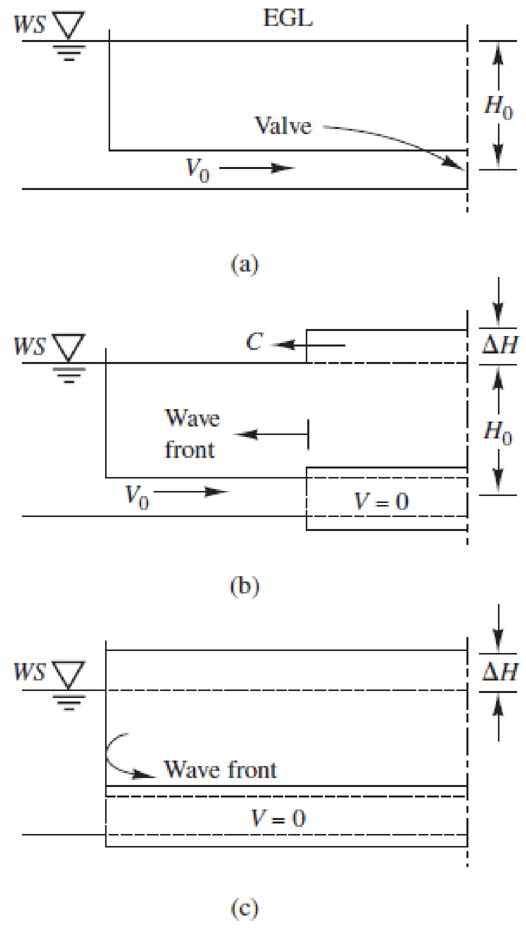
**Note:** Instantaneous closure isn't possible, so $F \neq \infty$. Also, pipe and water are slightly elastic and absorb some of the force.

# Water Hammer Phenomenon (1 of 3)

**Fig (a)** Valve open, EGL assumes no losses, initial velocity is $V_o$

**Fig (b)** Valve closes, pressure increase as water compresses, pipe expands, & pressure wave travels upstream w/velocity C.

**Fig (c)** Pressure wave reaches reservoir producing an energy imbalance. What happens next? Energy imbalance produces flow.

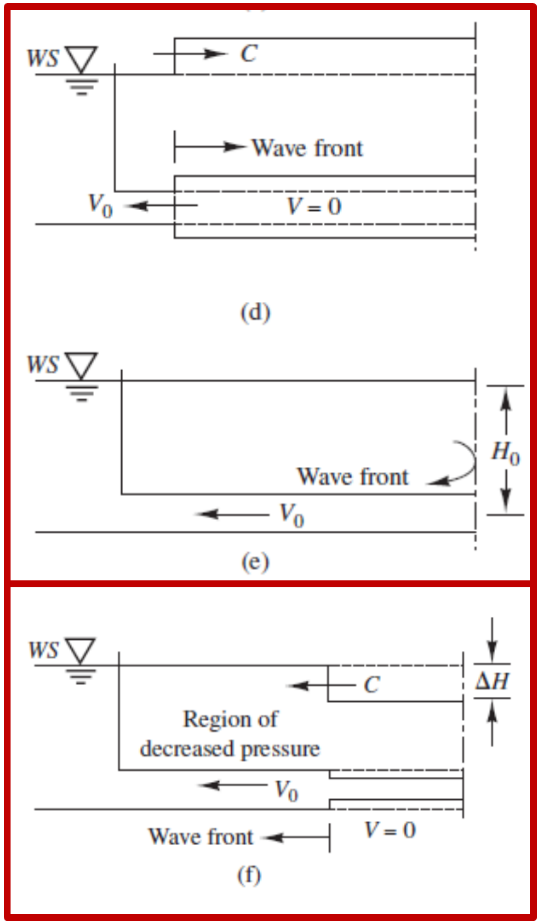


# Water Hammer Phenomenon (2 of 3)

**Fig (d)** Flow → pipe to reservoir (high to low energy level), negative wave moves downstream with velocity C, pressure decreases, pipe contracts, & water expands.

**Fig (e)** Negative wave hits closed valve, original EGL, but flow away from valve & not toward valve.

**Fig (f)** Negative pressure wave moves upstream as pressure decreases and pipe contracts.



(d)

(e)

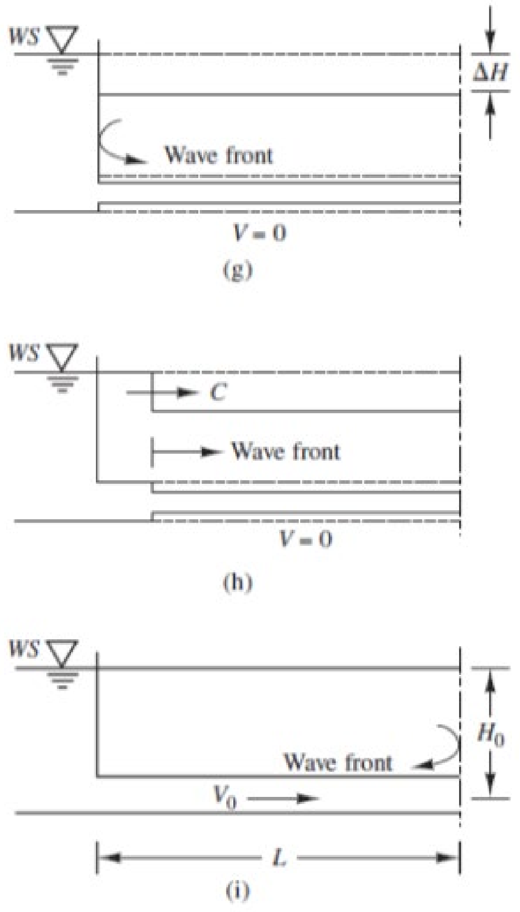
(f)

# Water Hammer Phenomenon (3 of 3)

**Fig (g)** Pressure wave reaches reservoir producing energy imbalance. What happens next? Energy imbalance produces flow.

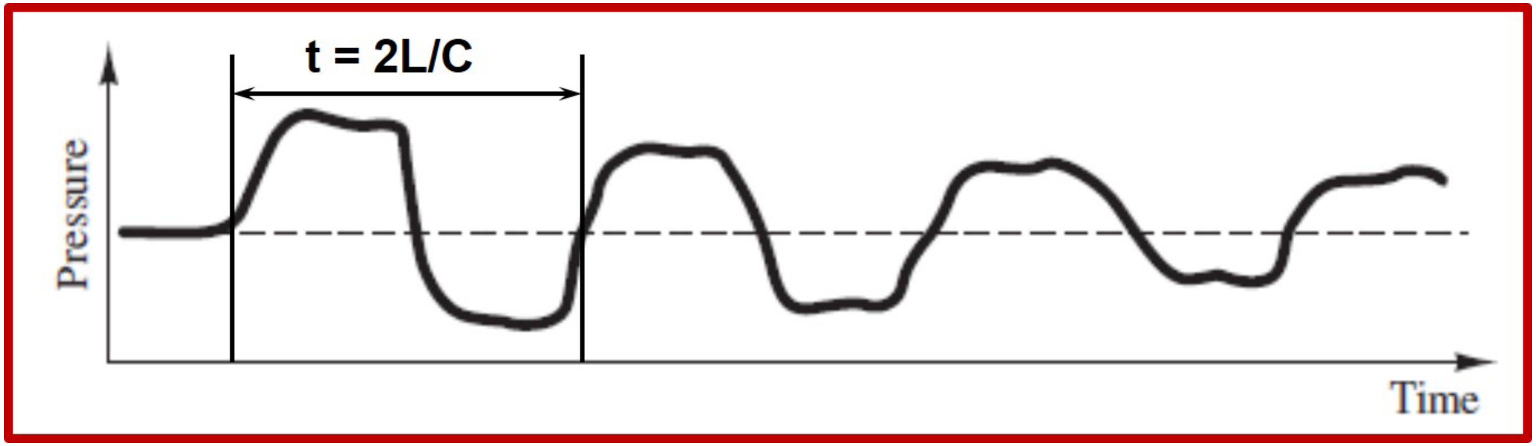
**Fig (h)** Flow → reservoir to pipe positive wave moves downstream w/velocity C, pressure increases, pipe expands, & water contracts.

**Fig (i)** Positive wave hits closed valve, original EGL, then what? Process starts all over again.



# Water Hammer Oscillations

**Time History of Pressure Oscillations in a Pipeline**



**Question 1:** Based on variables we previously defined on the last slide, define the equation for the time it takes for a full oscillation cycle as depicted in the figure above?

**Question 2:** Why does the amplitude of the oscillations decrease in magnitude over time in successive cycles?

**Answer:** Friction losses (moving water mass and pipe wall)

# Water Hammer Equations (1 of 2)

**Background Information**

**Basic Principles:** Speed of a pressure wave (C) and the composite modulus of elasticity - pipe/water system ($E_c$).

$$C = \left[\frac{E_c}{\rho}\right]^{1/2}, \text{ and } \frac{1}{E_c} = \left(\frac{1}{E_b}\right) + \left(\frac{D_k}{E_p . e}\right)$$

**Question:** Define all variables. ($E_p$→See Table 4.1)

$K = (1 - \varepsilon^2)$ for pipes anchored at both end against longitudinal movement,

$K = \left(\frac{5}{4} - \varepsilon\right)$ for pipes free to move longitudinally(negligible stresses),and

$K = (1 - 0.5\varepsilon)$ for pipes with expansion joints,

$\varepsilon =$ **Poisson’s ratio = 0.25** (for common pipe materials)

Pearson

# Water Hammer Equations (2 of 2)

**Find Maximum Water Hammer Pressure,** $DP$

**Fundamental Principles Used:** Mass balance, modulus of elasticity, wave speed, Newton's 2nd Law, and $F = P \times A$.

$$\Delta P = \frac{E_c V_o}{C} = \rho C V_o = V_o \left(\rho E_c\right)^{1/2}, \text{and } \Delta H = \frac{\Delta P}{(\rho g)} = \frac{V_o C}{g}$$

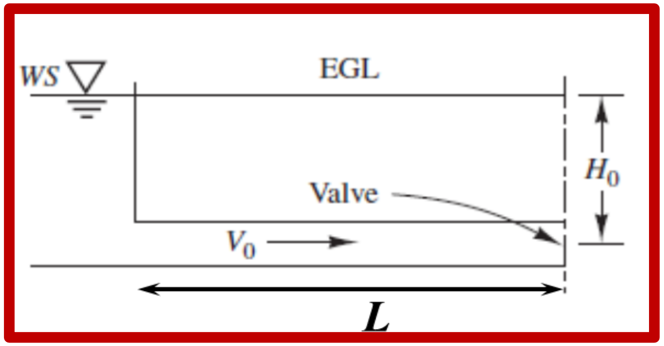
Define all the variables in these equations.

**Note:** These equations apply only for rapid valve closure, that is $t \le \frac{2L}{C}$. For valve closure that is not rapid,

$$\Delta P = P_o \left[ \frac{N}{2} + \left\{ \left( \frac{N^2}{4} \right) + N \right\}^{1/2} \right]$$, Where

$P_o$ = static pipe pressure and, $N = \left[ \frac{\rho L V_o}{(P_o t)} \right]^2$

# Water Hammer Example Problem



A pipe (rigid walls and D = 60 cm) conveys 0.28 $m^3/sec$ with an open valve. Find the pressure head rise (m) if the valve is closed instantaneously.

**Ans.** For rigid pipes, $E_p \to \infty$ and then from Eq. 4.22a, $E_c = E_b$ and from Eq. 4.21, $C = (E_c/\rho)^{1/2}$

$$C = [(2.2 \times 10^9 \, N/m^2)/(998 \, kg/m^3)]^{1/2} = 1{,}420 \, m/sec;$$

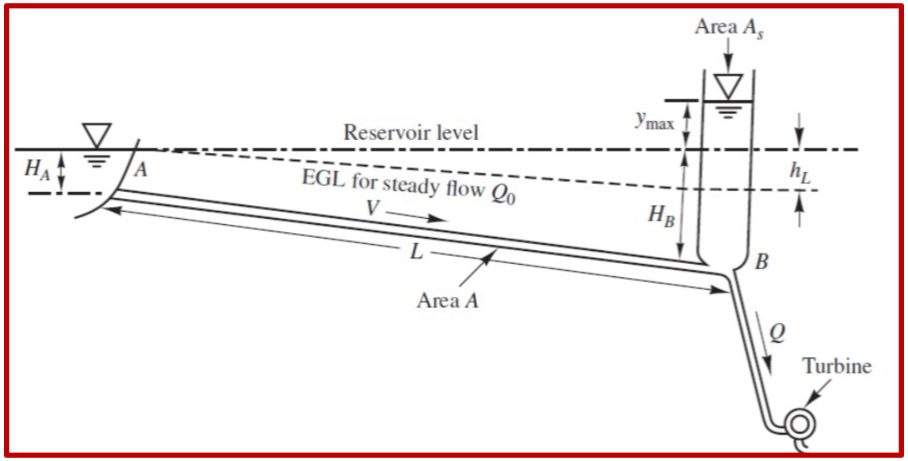
$$V_0 = \frac{Q}{A} = (0.28 \, m^3/sec)/[\pi(0.3 \, m)^2] = 0.990 \, m/sec; \text{ and}$$

$$\Delta H = \frac{(V_0 \cdot C)}{g} = \frac{\left[(0.99 \, m/s)(1{,}420 \, m/s)\right]}{(9.81 \, m/s^2)} = 143 m$$

# Water Hammer Impacts

**How can we eliminate damage to pipelines?**

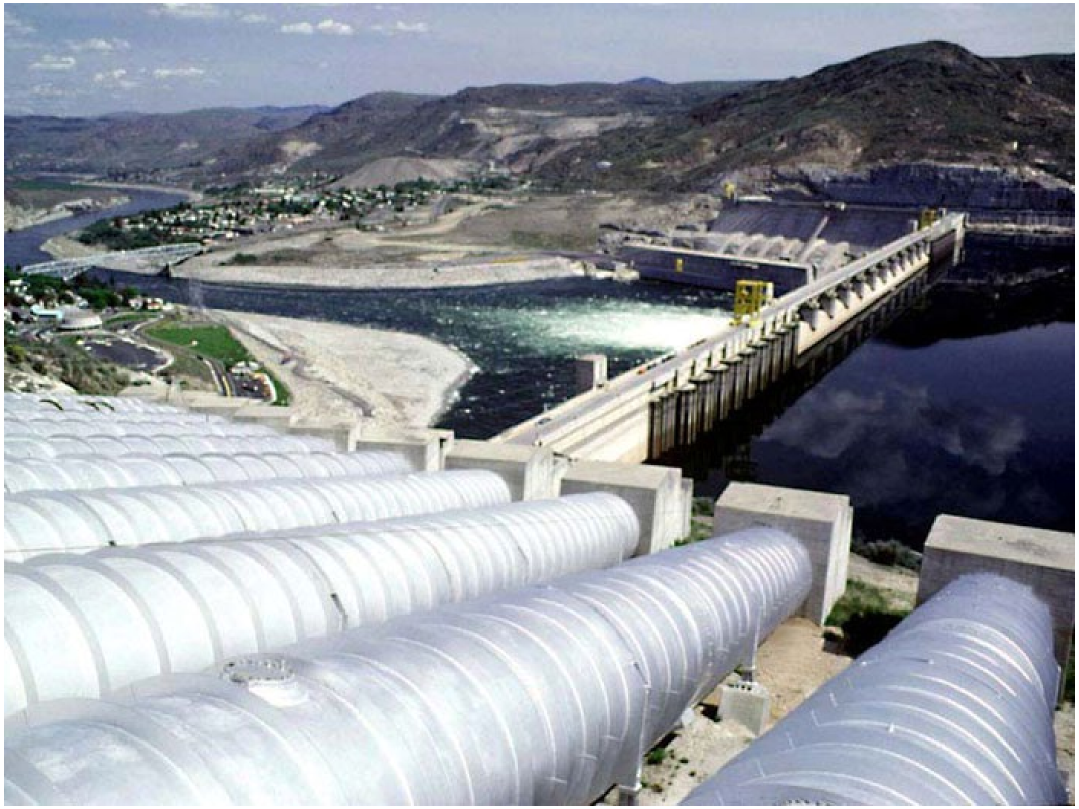
- Thick-walled pipes.
- Slow valve closure.
- Relief valves
- Surge tanks.



**Homework Problems:**

# Pipelines at the Grand Coulee Dam pump Station

**U.S. Bureau of Reclamation photo, 1983**



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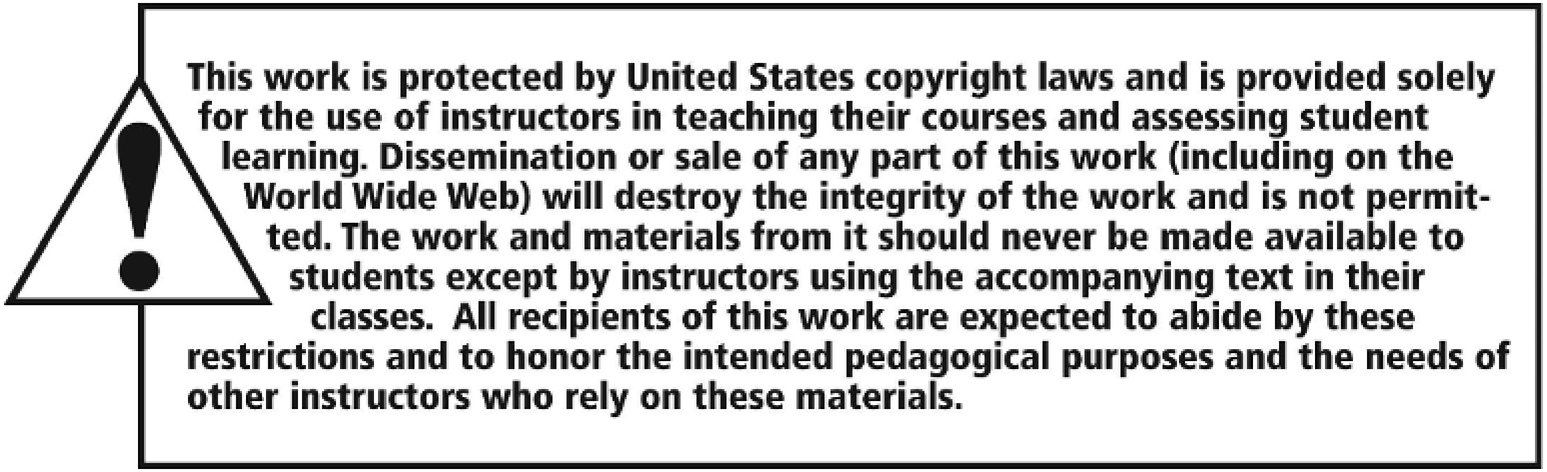
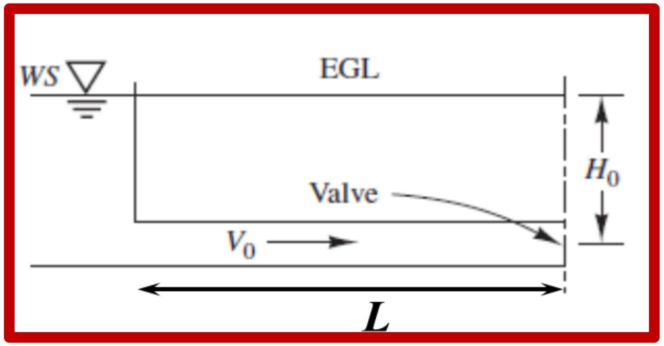


# Water Hammer Example Problem



A pipe (rigid walls and D = 60 cm) conveys 0.28 $\text{m}^3/\text{sec}$ with an open valve. Find the pressure head rise (m) if the valve is closed instantaneously.

**Ans.** For rigid pipes, $E_p \rightarrow \infty$ and $\left(\frac{Dk}{E_p}\cdot e\right) = 0$

Since $\frac{1}{E_c} = \left(\frac{1}{E_b}\right) + \left(\frac{Dk}{E_p}\cdot e\right)$, $E_c = E_b$. Thus, $C = \left(\frac{E_b}{\rho}\right)^{1/2}$

$$C = [(2.2\times 10^9\ \text{N/m}^2)/(998\ \text{kg/m}^3)]^{1/2} = 1{,}420\ \text{m/sec};$$

$$V_0 = \frac{Q}{A} = (0.28\ \text{m}^3/\text{sec})/[\pi(0.3\ \text{m})^2] = 0.990\ \text{m/sec; and}$$

$$\Delta H = \frac{(V_0 \cdot C)}{g} = \frac{\left[(0.99\ \text{m/s})(1{,}420\ \text{m/s})\right]}{(9.81\ \text{m/s}^2)} = 143\text{m}$$