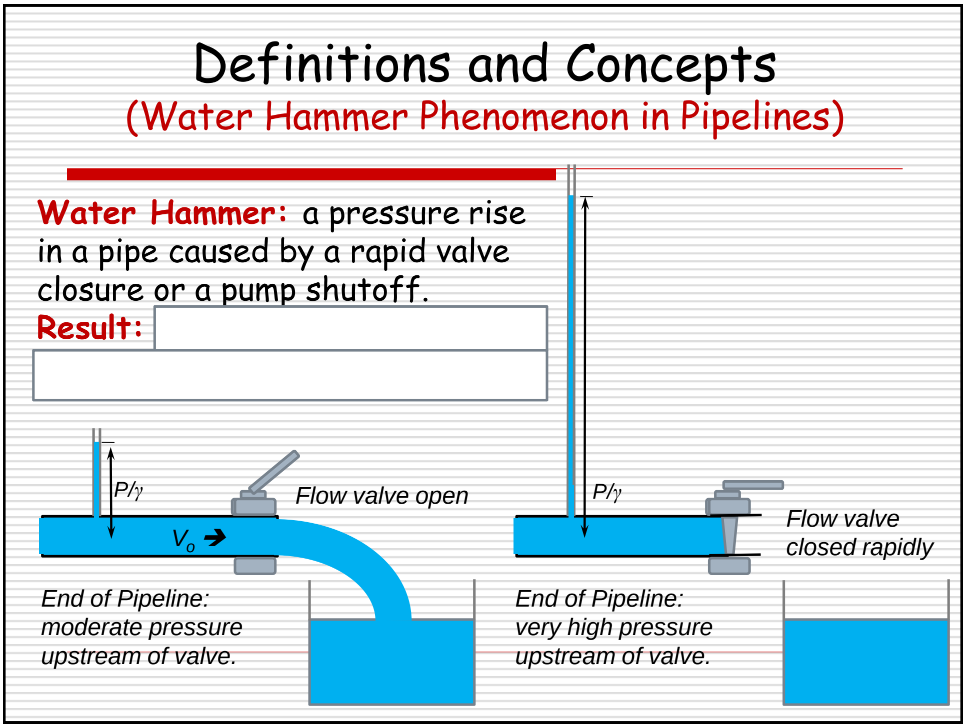


Definitions and Concepts

(Water Hammer Phenomenon in Pipelines)

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

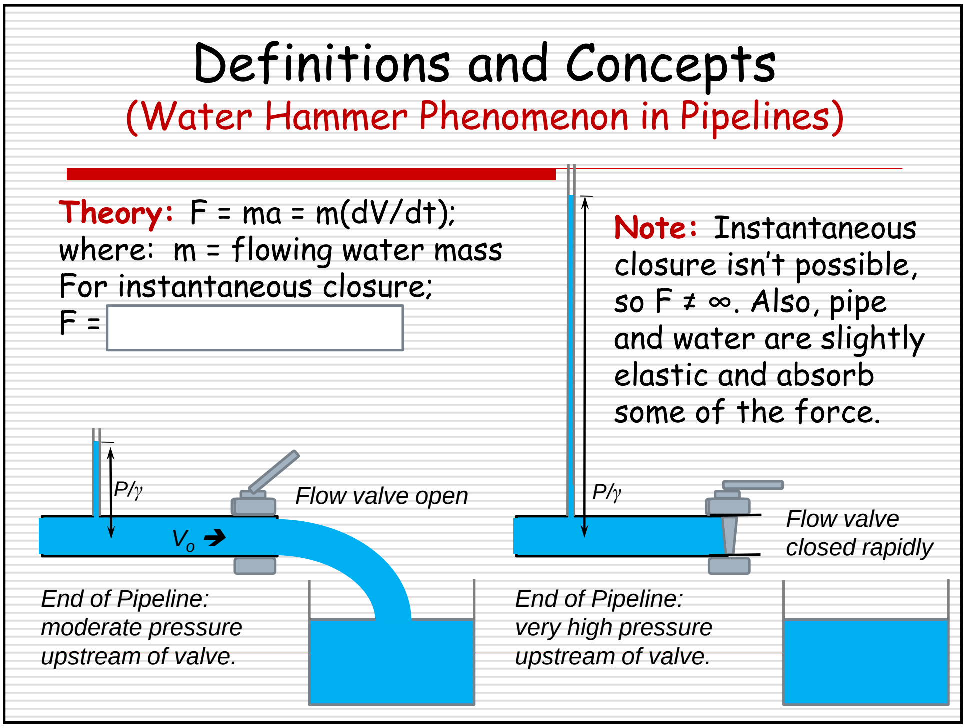
Result:

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

(Water Hammer Phenomenon in Pipelines)

Theory: F = ma = m(dV/dt);
where: m = flowing water mass
For instantaneous closure;
F =

Note: Instantaneous closure isn't possible, so F ≠ ∞. Also, pipe and water are slightly elastic and absorb some of the force.

Flow valve open

End of Pipeline: moderate pressure upstream of valve.

Flow valve closed rapidly

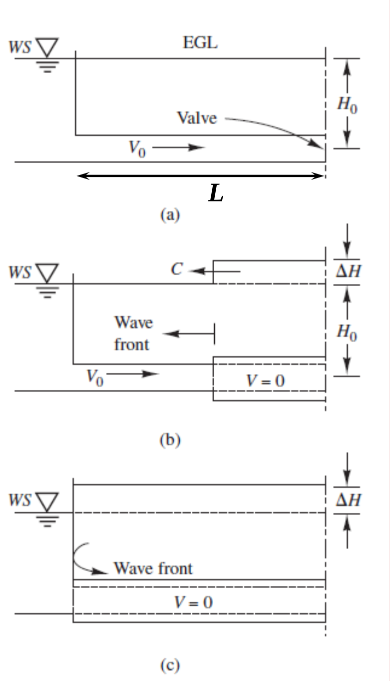
End of Pipeline: very high pressure upstream of valve.

Water Hammer Phenomenon

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

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

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

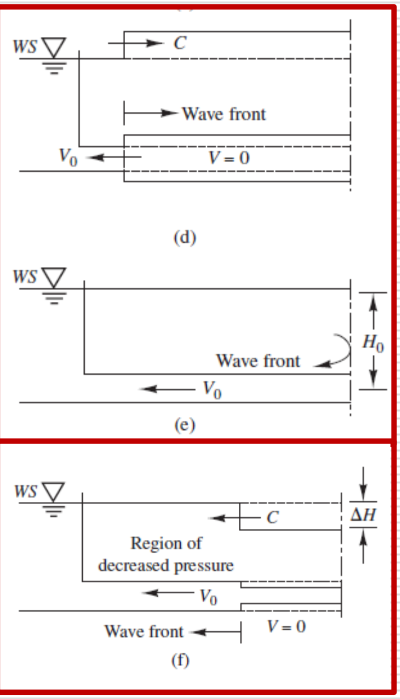


Water Hammer Phenomenon – cont.

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

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 and pipe

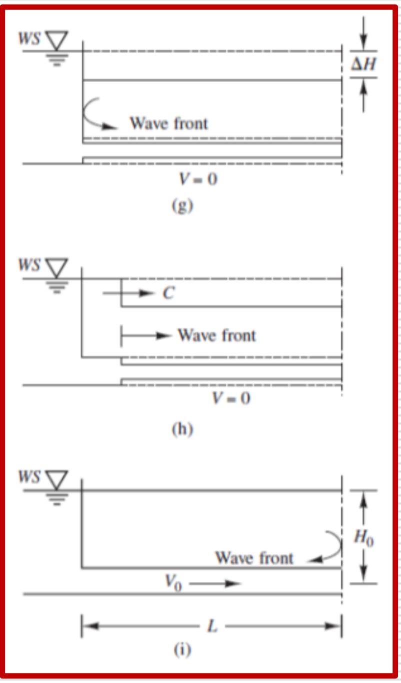


Water Hammer Phenomenon – cont.

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

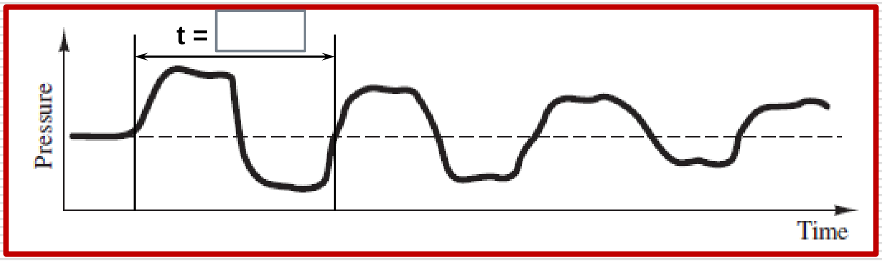
Fig (h) Flow ➔ reservoir to pipe positive wave moves downstream w/velocity C, pressure
pipe & water

Fig (i) Positive wave hits closed valve, original EGL, then what?



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:

Water Hammer Equations

(Background Information)

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

$C = [E_c/\rho]^{1/2}$, and $1/E_c = (1/E_b) + (Dk/E_p \cdot e)$

Question: Define all variables. (E_p ➔ See Table 4.1)

$k = (1 - \varepsilon^2)$ for pipes anchored at both ends 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,

ε = Poisson's ratio = 0.25
(for common pipe materials)

Water Hammer Equations

(Find Maximum Water Hammer Pressure, ΔP)

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

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

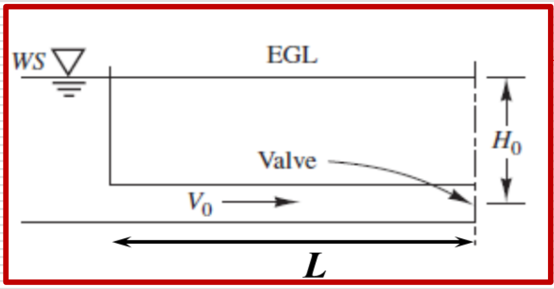
Define all the variables in these equations.

Note: These equations apply only for rapid valve closure, that is $t \leq 2L/C$. For valve closure that is not rapid,

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

P_o = static pipe pressure and, $N = [\rho L V_o/(P_o t)]^2$

Water Hammer Example Problem



A pipe (rigid walls and D = 60 cm) conveys 0.28 m³/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 $(Dk/E_p \cdot e) =$

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

$C =$

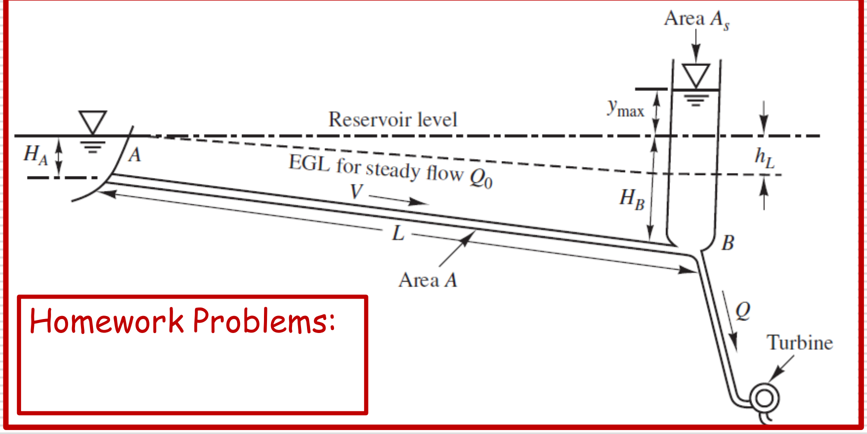
$V_0 =$

$\Delta H =$

Water Hammer Impacts

(How can we eliminate damage to pipelines?)

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



Homework Problems: