Water Hammer in Piping Systems

(Introduction Pressure Transient)

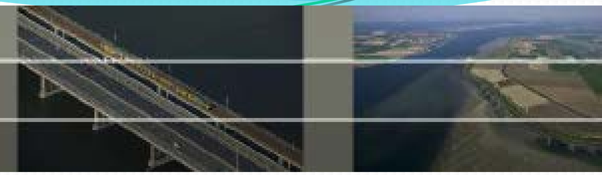
Transient Flow

Surge or
Rigid Water
Column

Elastic or
Water
Hammer

Rigid Water Column

Objectives



Explanation of rigid column method

Simplification of water hammer equations

Understanding of

- assumptions of rigid column method
- applications of rigid column method

Using the rigid column method to estimate the results of water hammer.

Rigid column method

Continuity equation

Assumptions

- Relative slow changes
- Velocity change slower than 5 * reflection time
- Information is instantaneously known everywhere in the pipeline
- Velocity gradient is almost zero along pipeline
- C is "infinite"

Continuity equation rigid column

> Velocity is constant over pipe, changes only in time.

Governing Equations

$$\frac{P_1}{\gamma} - \frac{P_2}{\gamma} - \frac{F\,L\,V^2}{2\,g\,d} = \frac{L}{g}\,\frac{dv}{dt}$$

The time necessary to accelerate the flow to a given velocity V

$$t = \frac{L\,V_0}{2\,g\,H_0}\,\ln\frac{V_0 + V}{V_0 - V}$$

$$t_{99} = 2.65\,\frac{L\,V_0}{g\,H_0}$$

Simplified Analysis Water Hammer

- Water hammer phenomenon can be simply described as the 'inertia pressure' resulting from either acceleration of-deceleration of a water column.
- The same result can be obtained from the detailed analysis above by neglecting the friction losses, where the unsteady equation takes the form.

$$\Delta H = -\frac{L}{g}\frac{dv}{dt}$$

Valve Partial Closure

- It was assumed that the change in velocity with time is linear.
- However, it is more realistic to assume that the valve area decreases linearly with time. By doing this the change in velocity with time will not be linear any more and the problem will be solved by dividing the closure time into smaller steps.

Valve Partial Closure

$$\Delta H = -\frac{L}{g}\frac{V_f - V_0}{\Delta t}$$

$$\frac{V}{V_0} = \alpha\sqrt{\frac{H_0 + \Delta H}{H_0}}$$

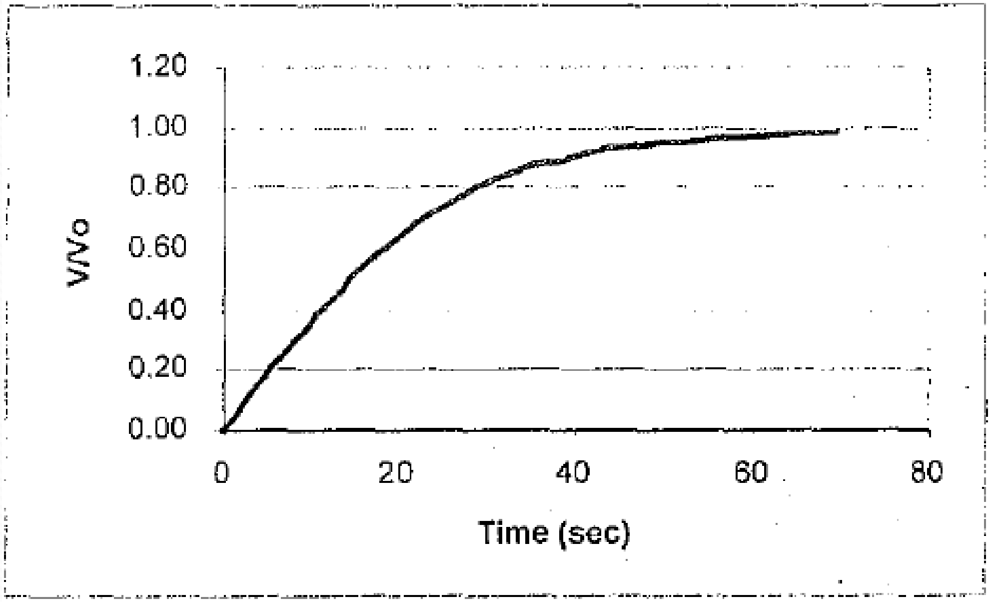
$$\alpha = \frac{a}{a_0}$$

Example 1

A horizontal pipe 24 inch in diameter and 10000 foot long leaves a reservoir 100 ft below the surface and terminate in a valve. The steady state friction factor is 0.018 and its assumed to remain constant during the acceleration process. If the valve opens suddenly, calculate how long it will take for the velocity to reach 99 percent of its final values. Neglect minor losses.

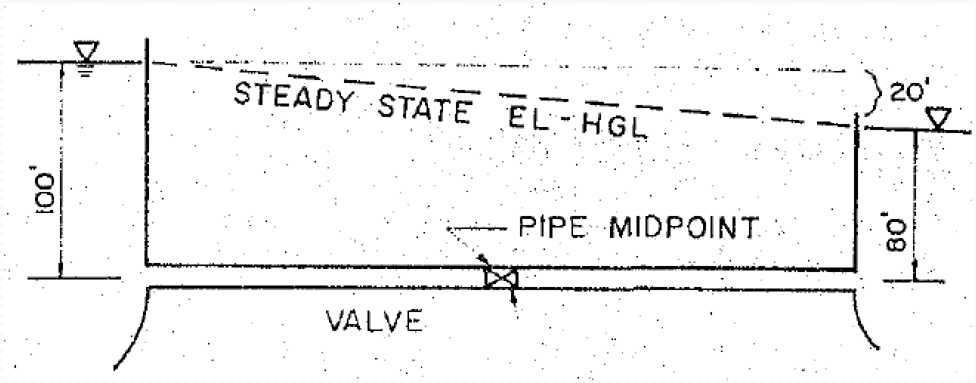
Example 1

The graph illustrates how the velocity approaches its steady state value with time.



Example 2

Water flows from one reservoir to another through the pipe at a velocity of 10 fps. The shutdown plan calls for a valve closure scheme which will cause the velocity to decrease linearly to zero in 100 sec. The valve is located at the center of a 6440 ft long pipeline. Estimate the maximum and minimum pressure which will occur in the system, locate them, and give the time at which they will occur.



Example 3

Assuming water is discharged from a reservoir through a pipe of length 1500 m, where the steady state velocity is 2.3 *m/s, and the head over the pipe* outlet is 120 m. If a valve at the downstream end of the pipe is closed so that the velocity decreases to 1.2 *m/s in 20 seconds. Calculate the max increase* in pressure using the simplified equation above.

Example 4

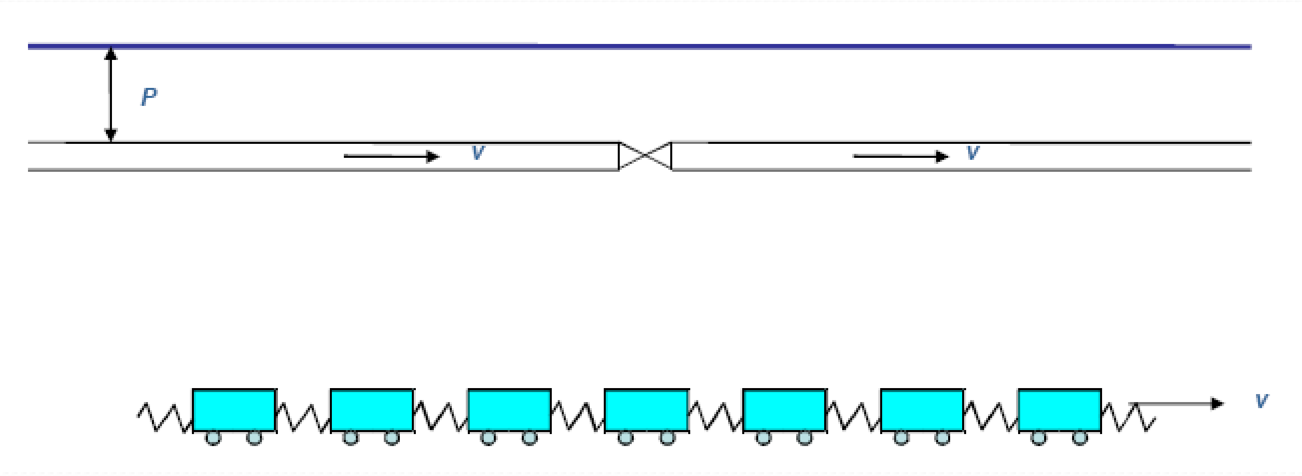
Assuming water is discharged from a reservoir through a pipe of length 1500 m, where the steady state velocity is 2.3 m/s, and the head over the pipe outlet is 120 m. If a valve at the downstream end of the pipe is closed so that the valve area is closed from 100 to 55% in 20 seconds. Calculate the max increase in pressure using the simplified equation above.

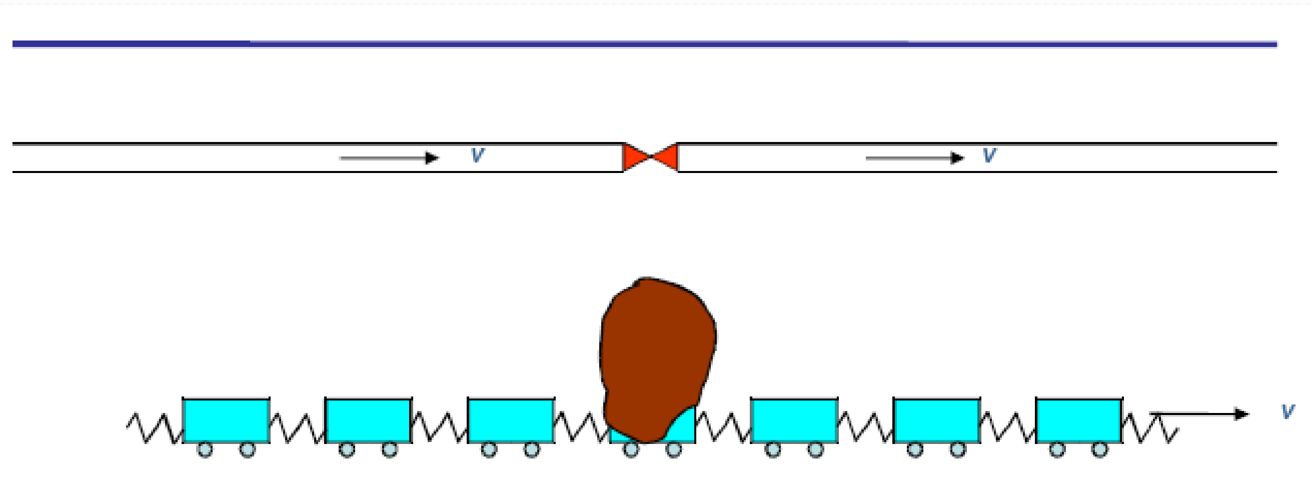
Application of rigid column equation

- Return flow velocity check valve
- Driving out an air pocket
- Swinging behaviour of pipe flow between reservoirs
- Dimensioning of surge towers
- Dimensioning of air vessel

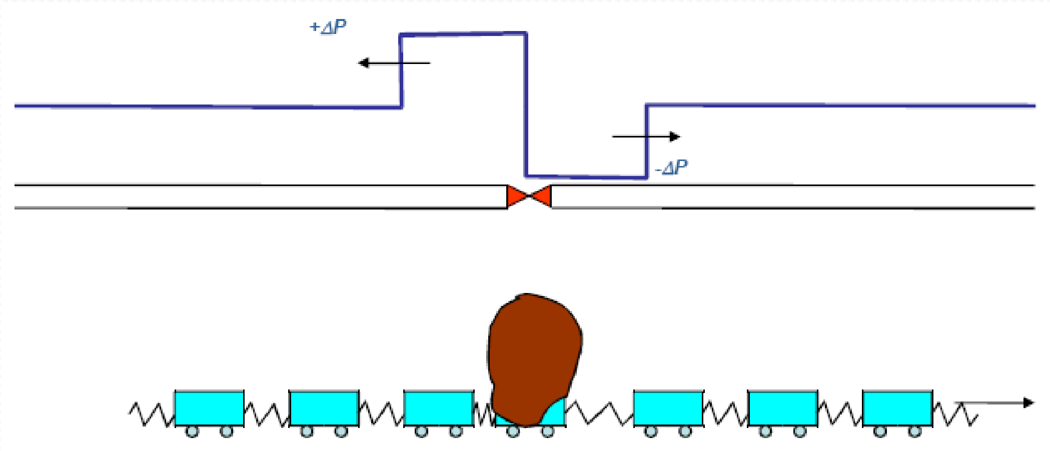
Water Hammer

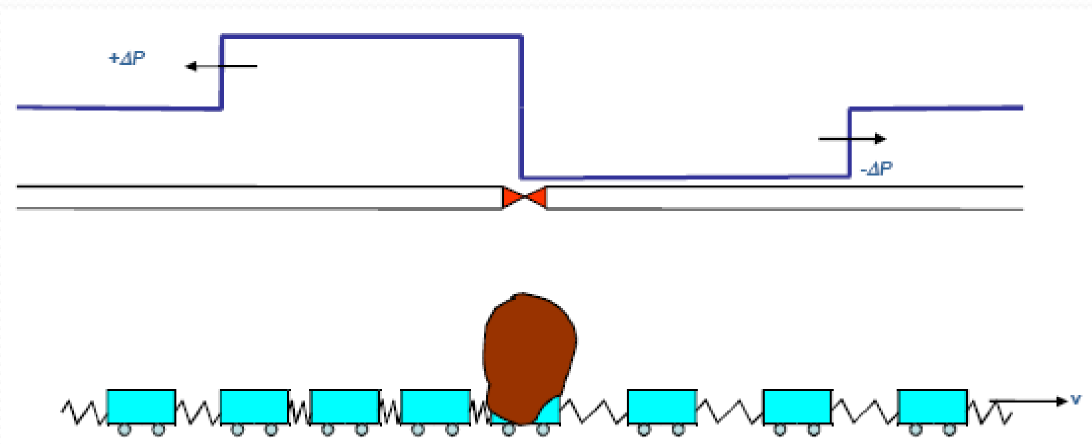
The Water Hammer Phenomena





The Water Hammer Phenomena





- Overpressure and underpressure waves.
- Pressure and velocity are linked together.
- Pressure waves propagate through the pipelines.

Definition of Water Hammer

Changes of velocity are linked to changes of pressure and vice versa

or: exchange of kinetic and potential energy (pressure + elastic energy):

velocity changes ⟺ pressure changes

These changes propagate through the pipeline system with high speed as waves (pressure surge, water hammer)

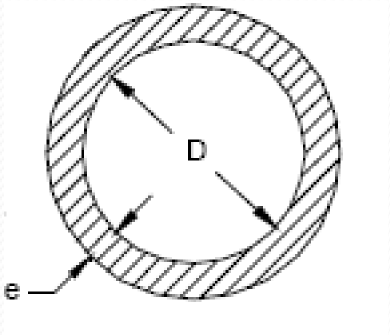
- Closed (pressurised) conduits
- Long as well as short pipelines
- All kinds of fluids

Basic Terms Water Hammer

- Wave speed C
- Travel (Reflection) time (tr or μ)
- Joukowsky pressure

Wave Speed C

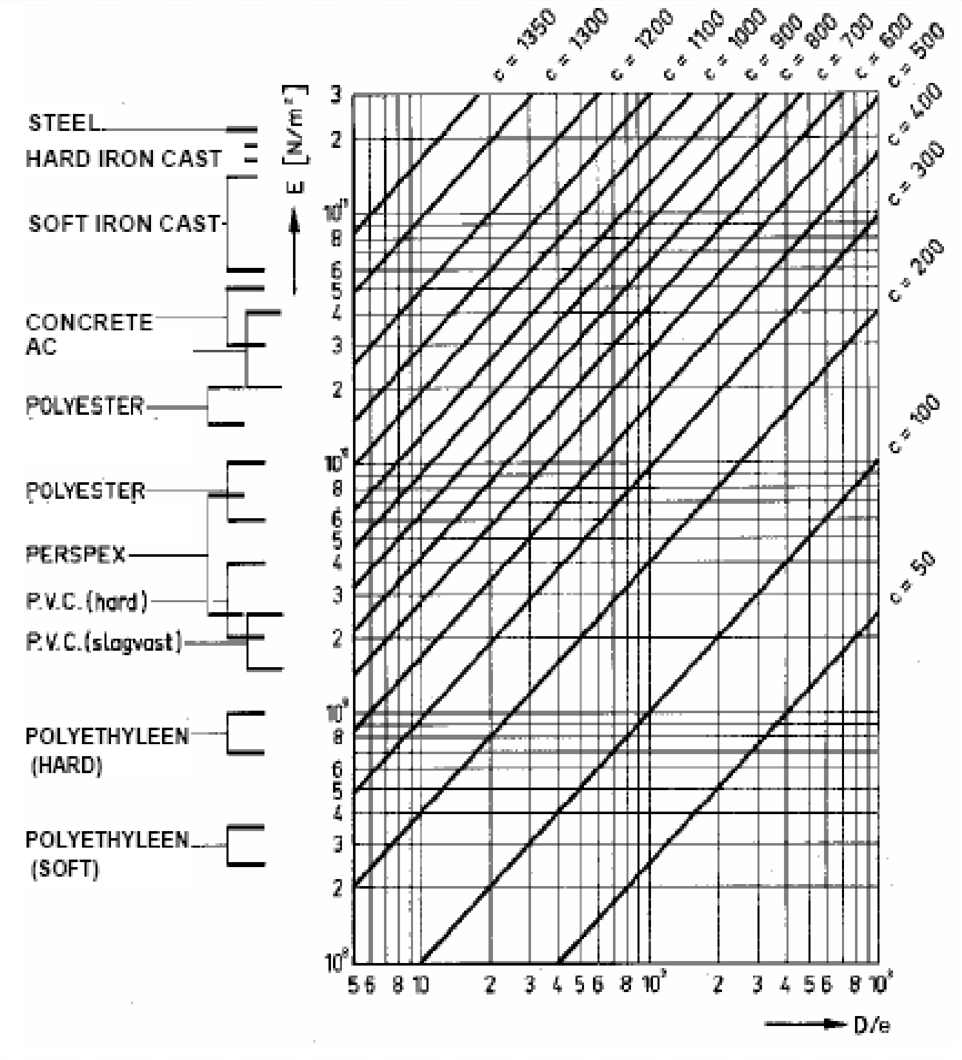
- Elasticity pipe material, Young's modulus (E [Pa]),



- Bulk modulus of the liquid (K [Pa]),
- Density (specific mass) (ρ [kg/m3],
- Ratio of diameter and wall thickness (D/e [-]), -

$$c = \frac{1}{\sqrt{\rho\left(\frac{D}{eE} + \frac{1}{K}\right)}}$$

Wave Speed C

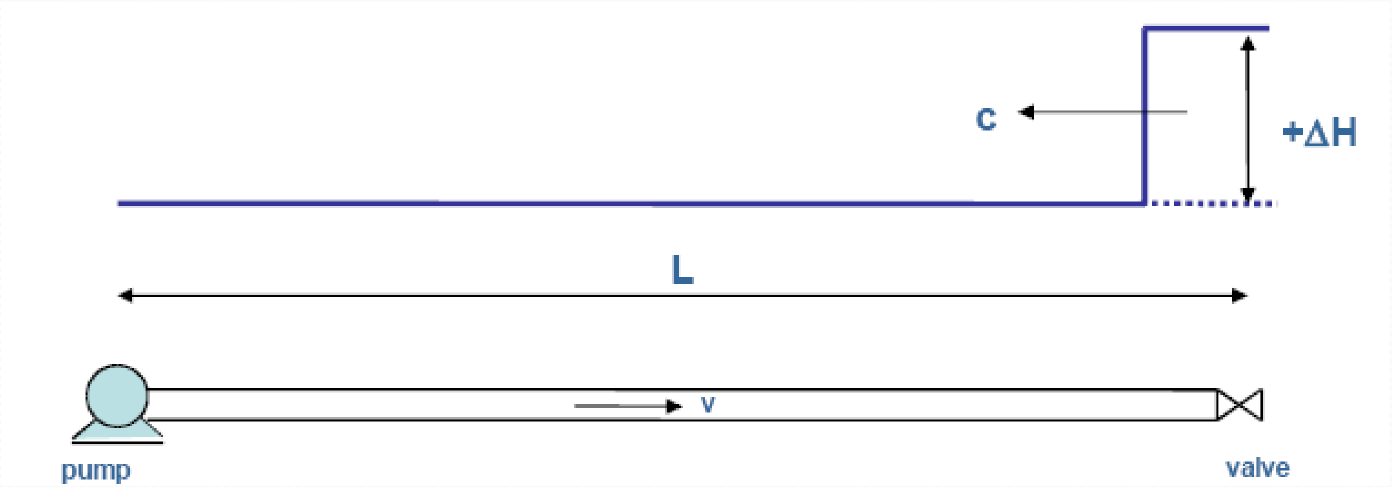


STEEL
HARD IRON CAST
SOFT IRON CAST
CONCRETE
AC
POLYESTER
POLYESTER
PERSPEX
P.V.C. (hard)
P.V.C. (slagvast)
POLYETHYLEEN (HARD)
POLYETHYLEEN (SOFT)
E [N/m²]
c = 1350
c = 1300
c = 1200
c = 1100
c = 1000
c = 900
c = 800
c = 700
c = 600
c = 500
c = 400
c = 300
c = 200
c = 100
c = 50
D/e

Reflection Time

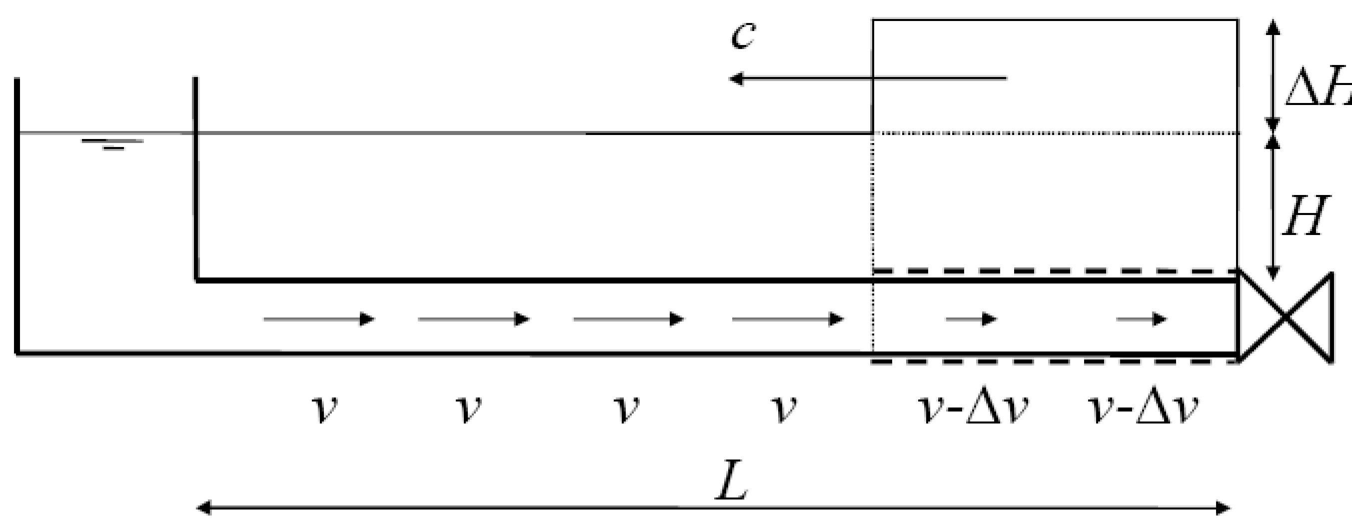
Travel time for a pressure wave to return to the source

$$\mu = \frac{2L}{c}$$



Joukowsky

$$\Delta H = \pm \frac{c}{g} \Delta v \quad \text{of:} \quad \Delta p = \pm \rho \, c \, \Delta v$$

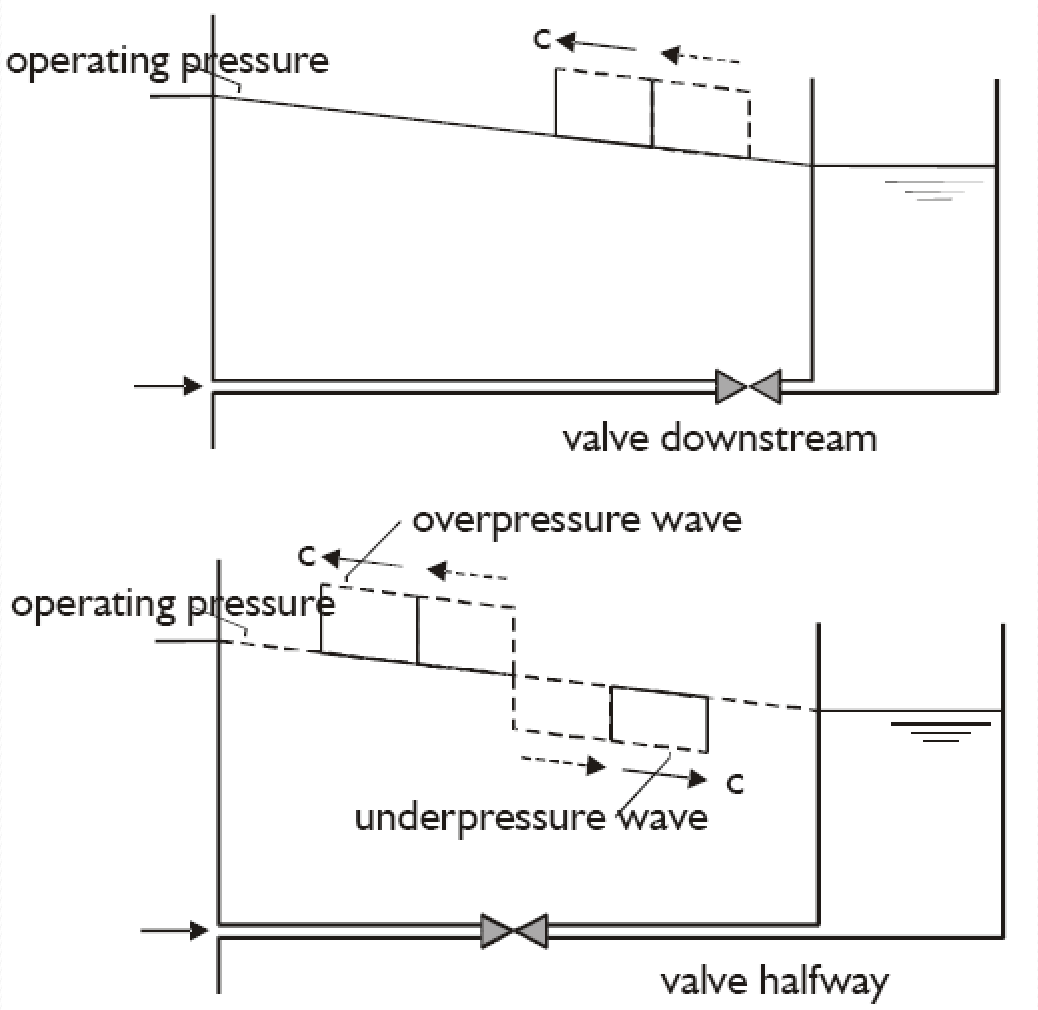


Requirements for application:

- Velocity change occurs within travel time.
- Friction effects negligible.

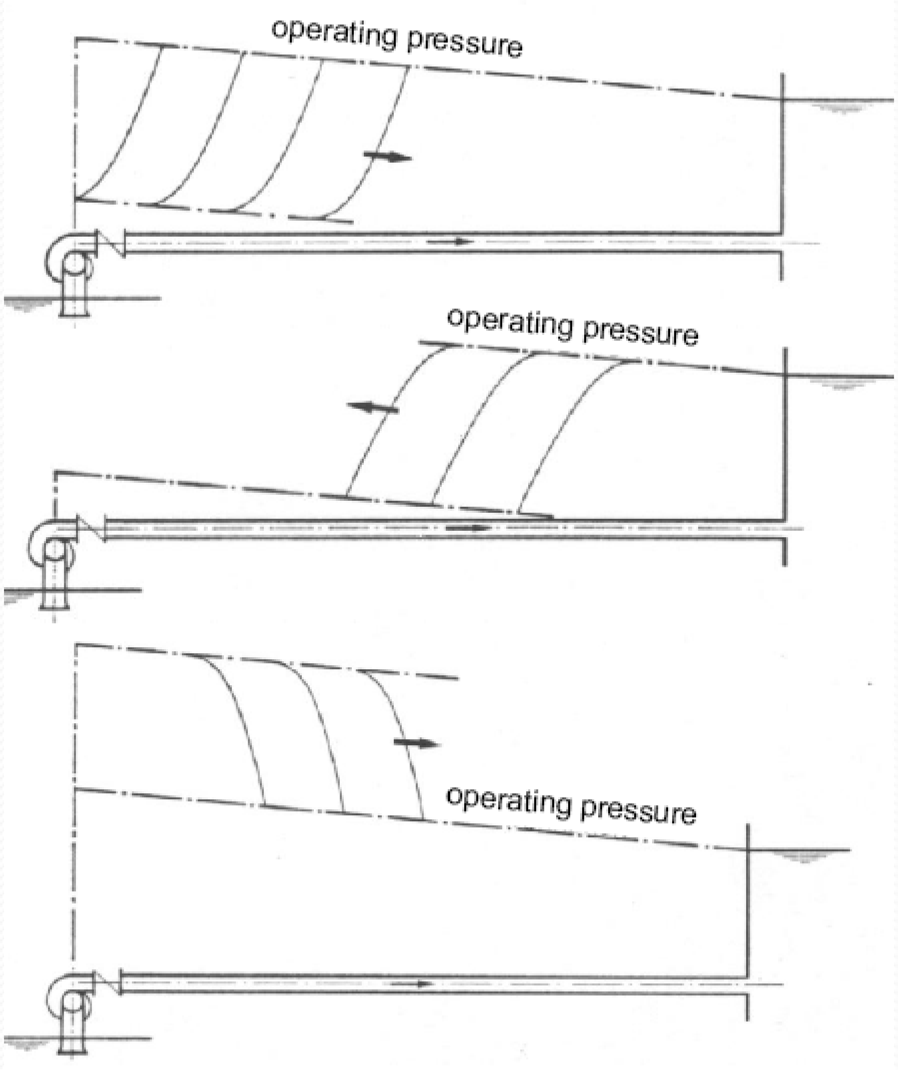
Application Examples

Valve Closure



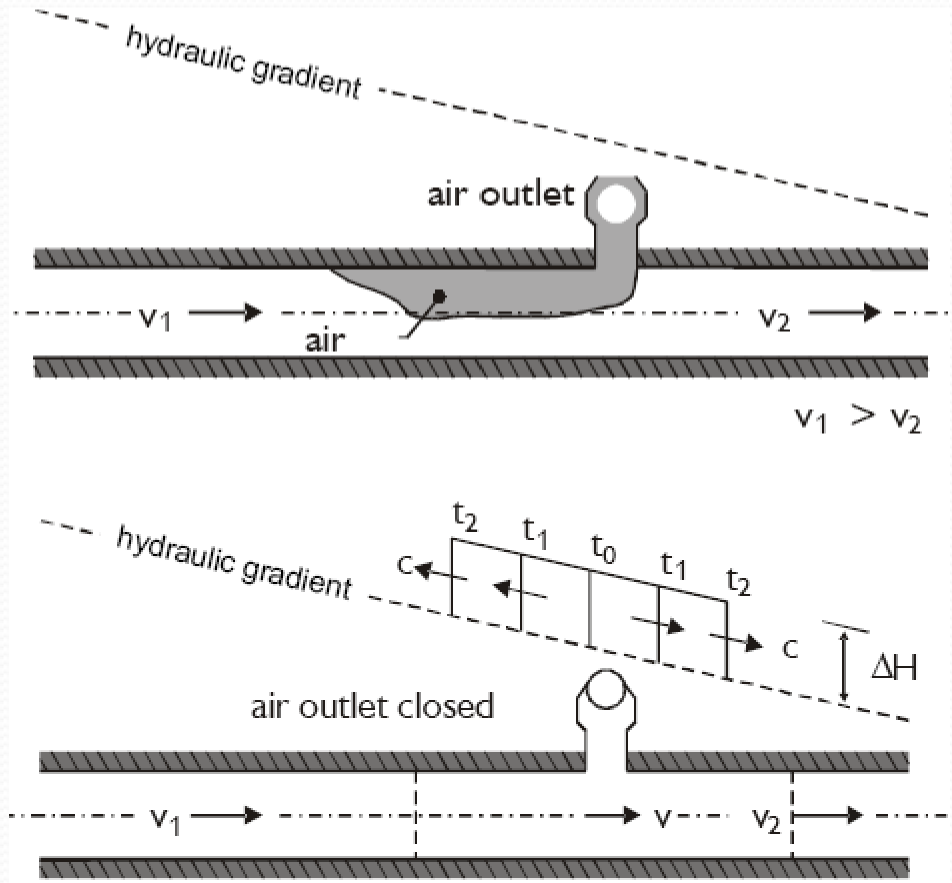
Application Examples

Pump trip



Application Examples

Closing Air Valve



$$\Delta H = \frac{c}{g}\left(v_1 - \tfrac{1}{2}\left(v_1 + v_2\right)\right) \qquad v = \tfrac{1}{2}\left(v_1 + v_2\right)$$

$$= \frac{c}{g} \cdot \frac{(v_1 - v_2)}{2}$$