Water Hammer and Design of Surge Protection Systems

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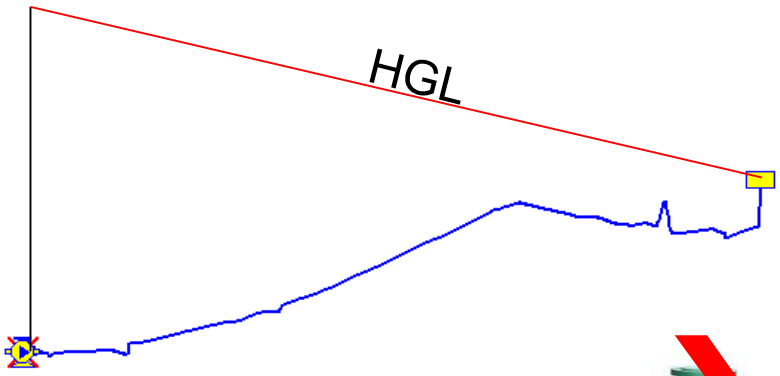
Outline

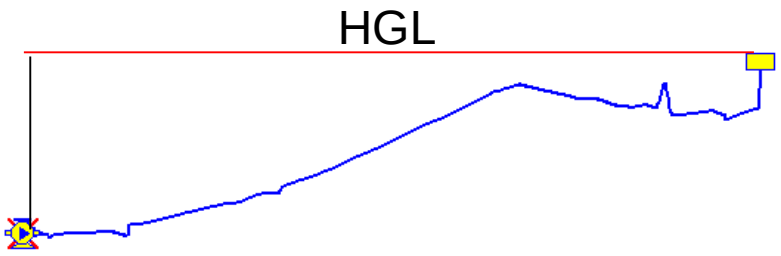
- What is water hammer?
- What causes water hammer ?
- Effects of water hammer on pipeline systems
- Check Valve and Collapse of Cavity
- How to control water hammer?

What is water hammer?

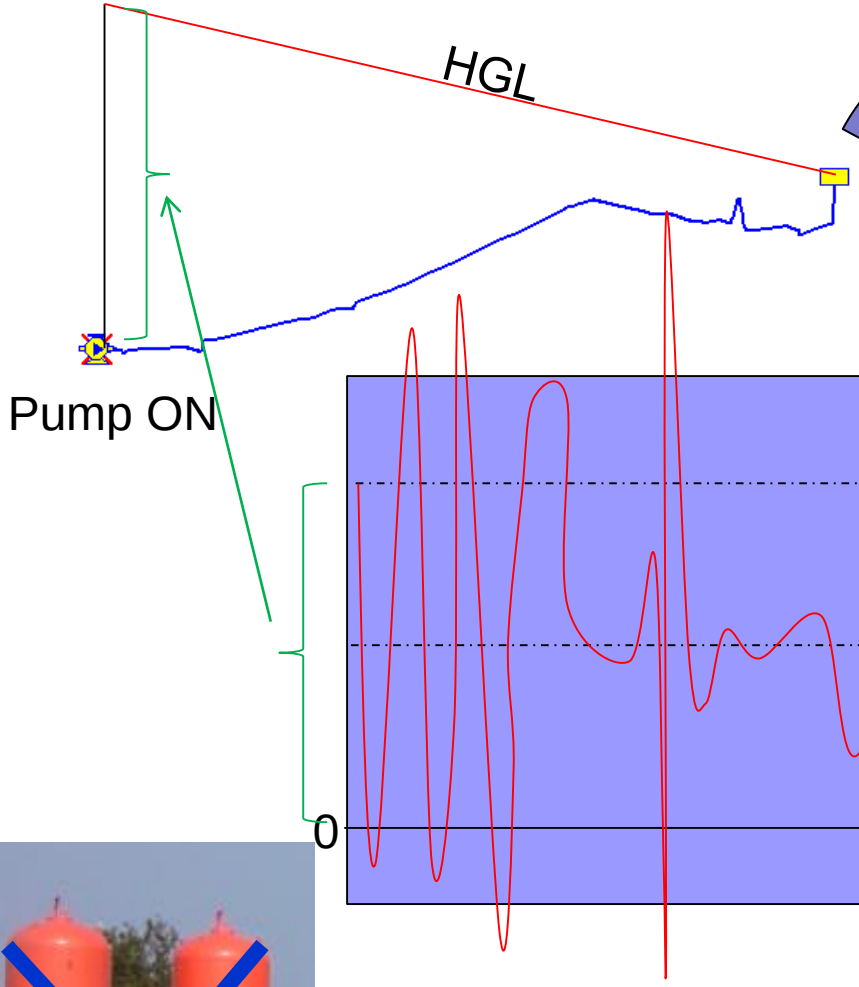
- Water Hammer
- Pressure Surges
- Pressure Transients



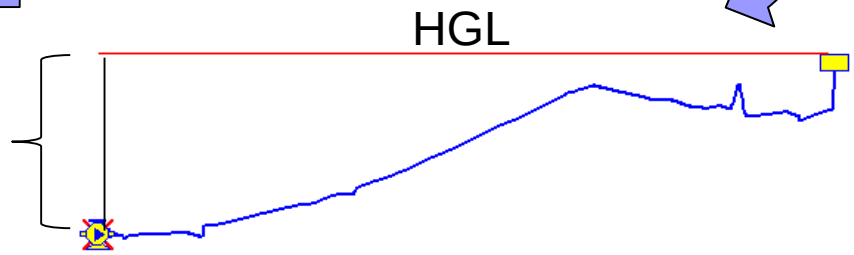
Pump ON

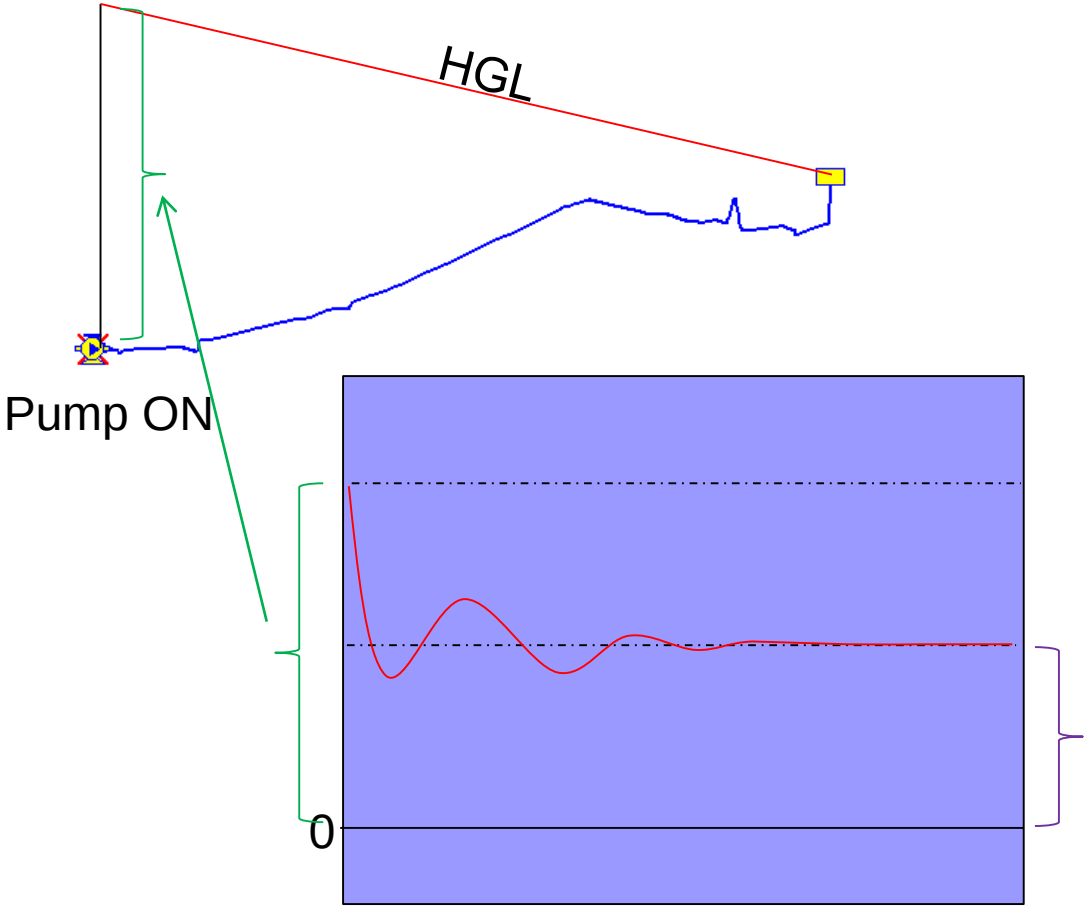


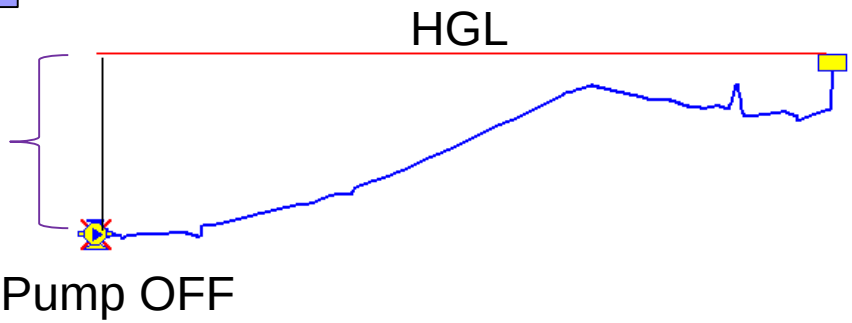
Pump OFF



One steady state condition
to
another
steady state condition




HGL
Pump ON
0


HGL
Pump OFF

Have you heard water hammer?

What causes pressure surges in pipeline systems?

What causes pressure surges in pipeline systems?

- Rapid Change in Velocity or Flowrate in the pipeline

Joukowsky's Equation

$$\Delta H = (c/g)\,\Delta V$$

ΔH is change in pressure head in meters
ΔV is change in velocity (m/s)
c is celerity or wave speed. C about 1000m/s for metal pipes
g gravitational acceleration ($9.81 m/s^2$)

What causes water hammer in pipeline systems?

- Pump trip due to power outage
- Pump shutdown
- Pump startup
- Valve closing
- Valve opening
- Hydrant opening
- Hydrant closing
- Flushing operation
- Collapse of a cavity
- Rapid change in demand
- Rapid change in reservoir level
- Rapid change in tank level
- Pipe break
- Air valve slam
- Check valve slam
- Tank altitude valve shutdown
- Events that results in change in velocity

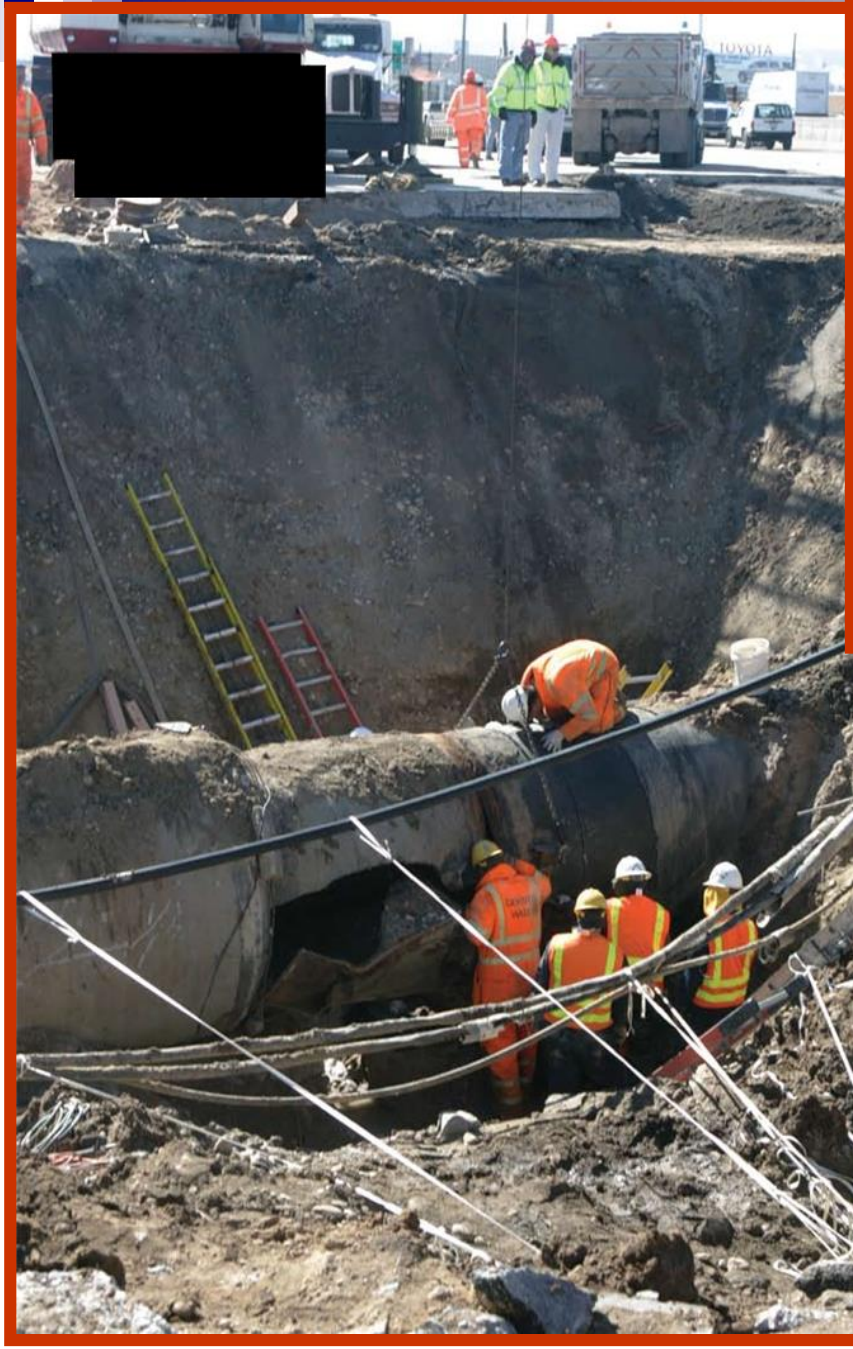
Why Transient Modeling?

Pipelines that are not adequately protected can lead to….

Pipe and elements burst resulting from High Surge pressures

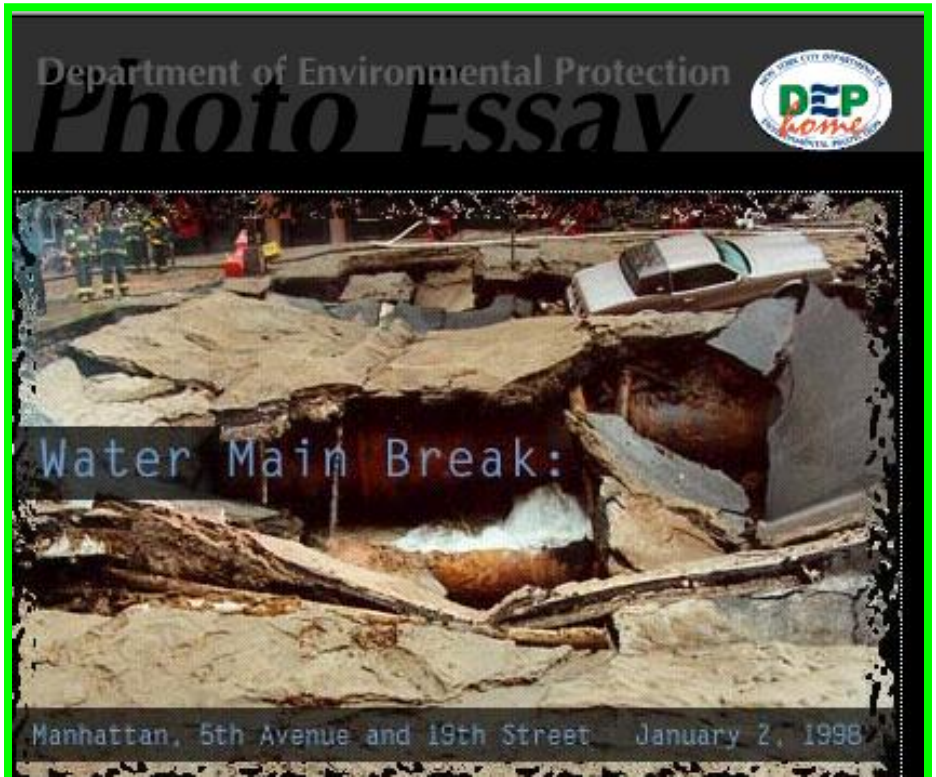

2008 2 17


Kansas City Downtown



City of Denver, Colorado


Midtown Manhattan, New York


Department of Environmental Protection
Photo Essay
DEP home
Water Main Break:
Manhattan, 5th Avenue and 19th Street January 2, 1998

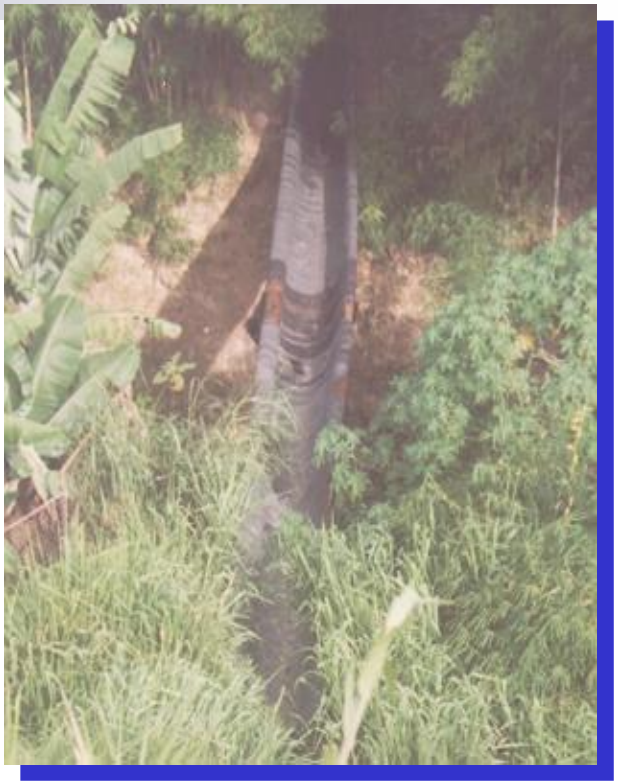

Street Cross-Section
Telecom. & Electric
12" - Water
Steam
36" - Water
48" - Water
20" - Water
Gas
Sewer
Abandoned Hydrant Line

Split Pump Casings….

Low Pressure Problems can also cause lot of damages….

- Pipe collapse
- Pathogen Intrusion-for potable water system is highly health risky
- Damage the internal lining
- Water leakage problems
- Subsequent flow reversal causing collapse of vapor cavities, will result in high pressure spikes
- Eliminating the cavitation pockets will limit the high pressure

URB. MANZANARES / BARUTA / Edo: MIRANDA



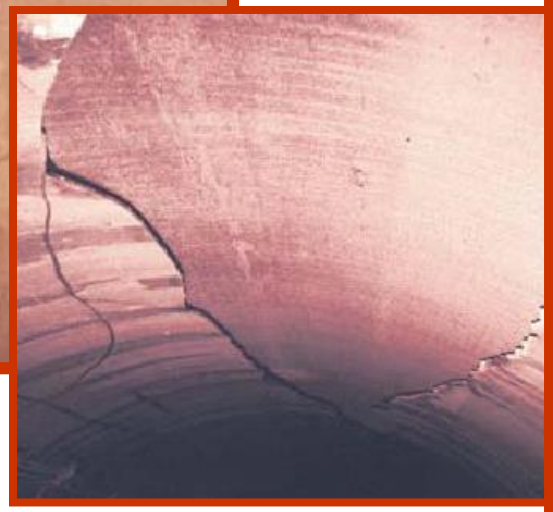
COLLAPSE
MAXIMUM LEVEL

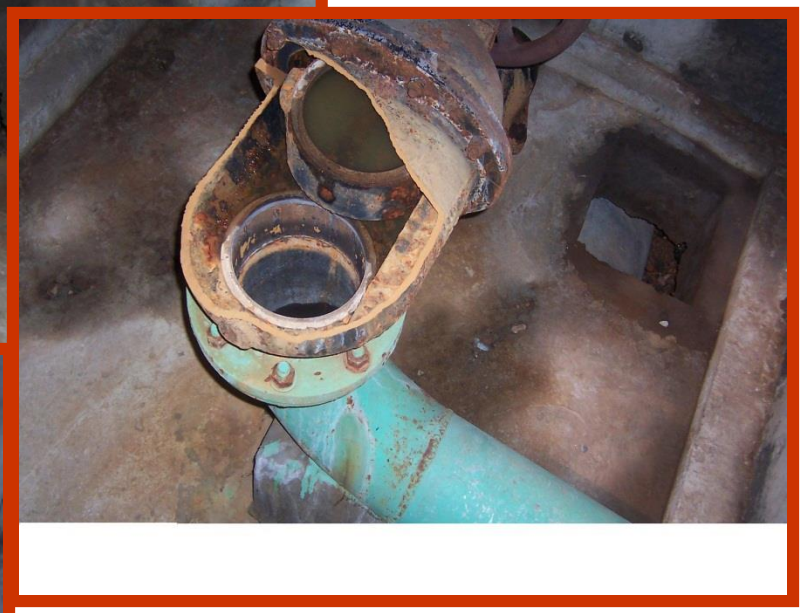
Steel Pipe
Diameter : 1220 mm
Thickness : 7 mm
Length of Collapse : 540 Mts
e / D = 0.005738

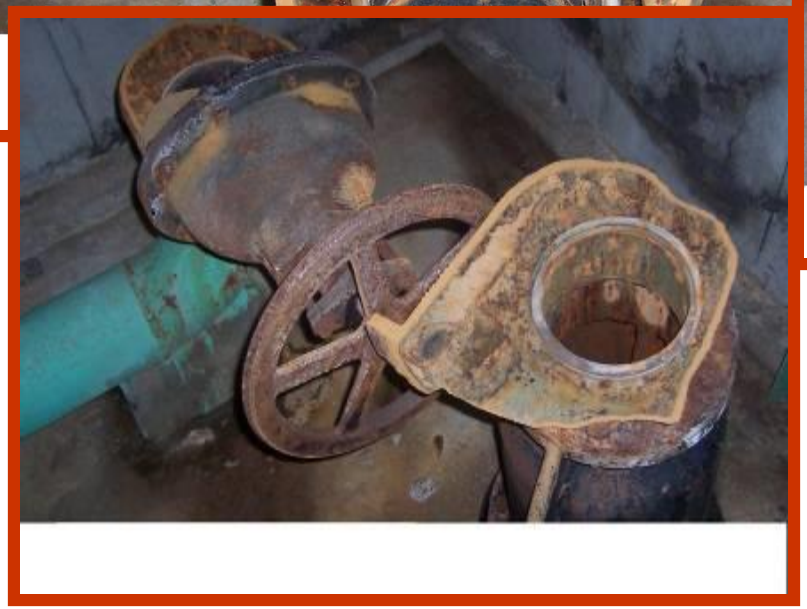
DOWN-SURGE INDUCED Pipe Collapse

Internal lining
(loss of carrying capacity)

Pump Impeller damaged
by cavitation

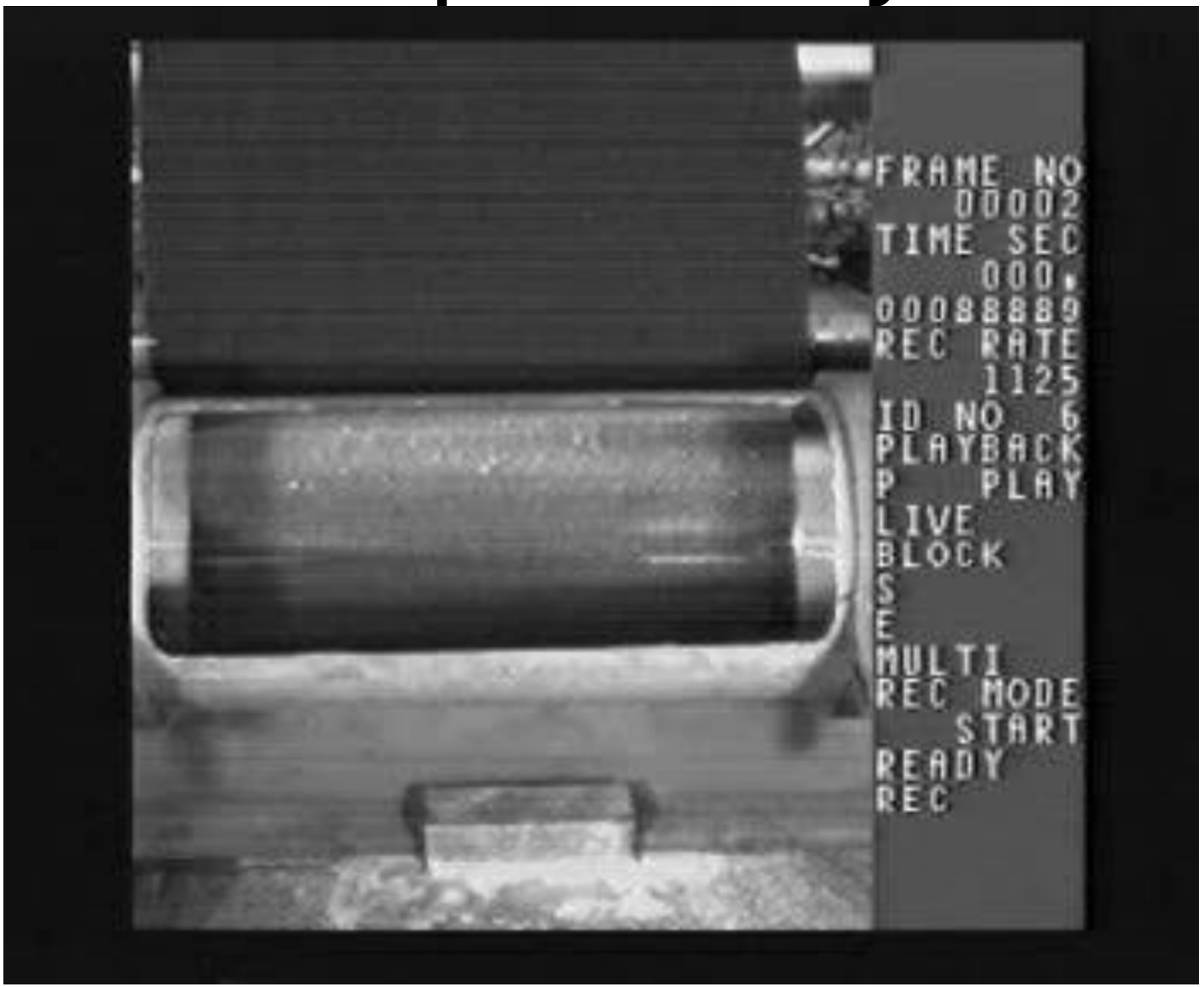




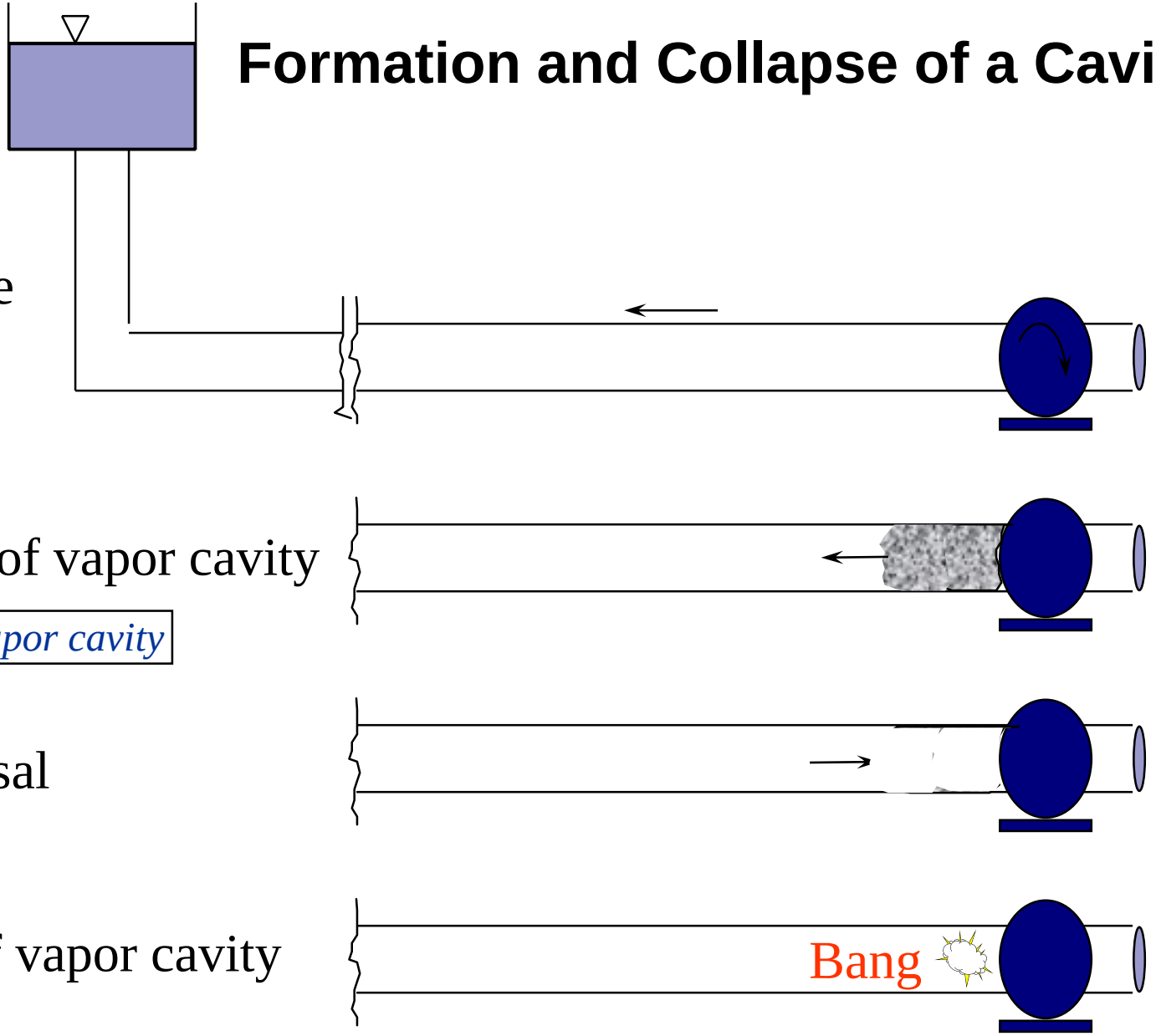


Rapid Collapse of Vapor Cavities

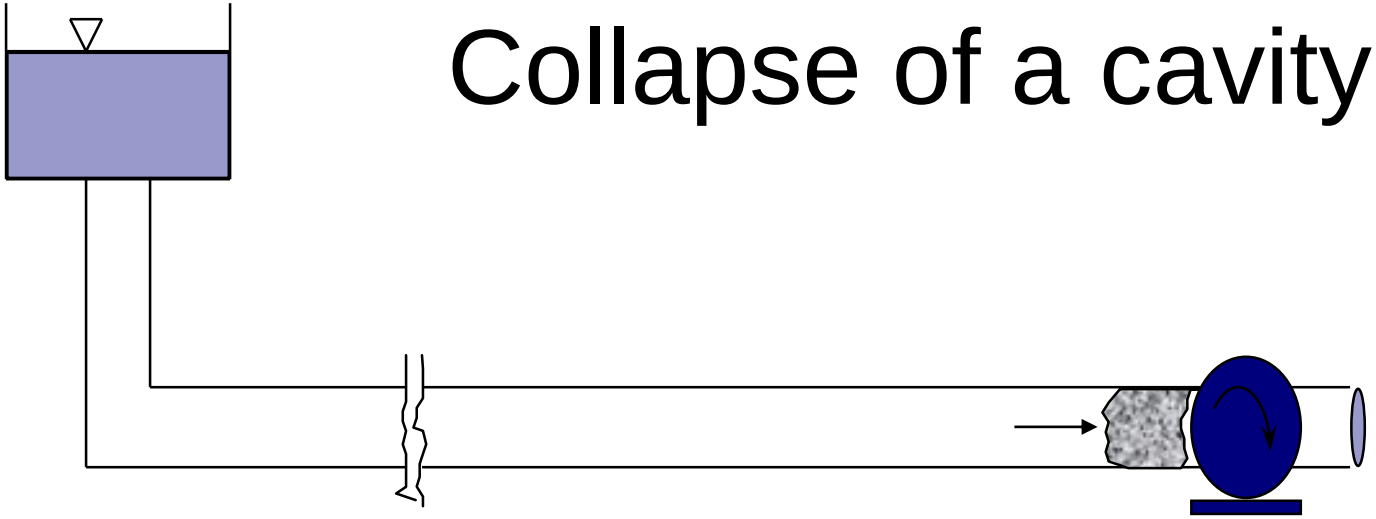
Vapor Cavity

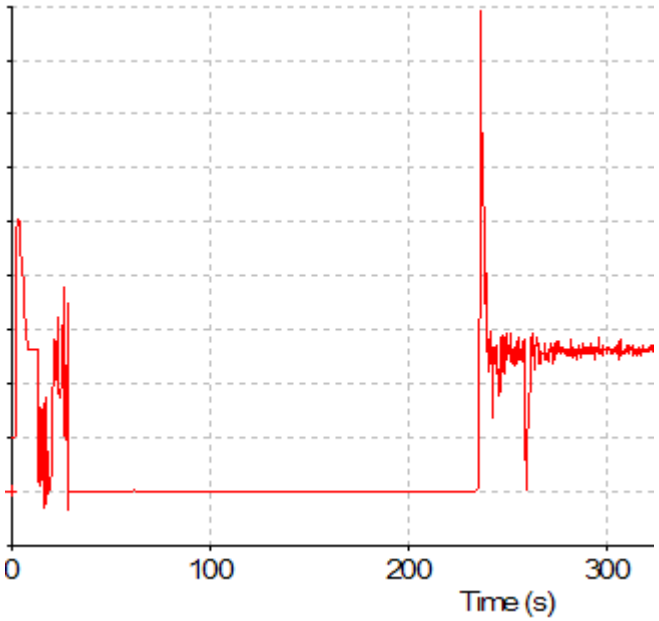


Formation and Collapse of a Cavity



Collapse of a cavity





Water accelerates when flowing towards a cavity

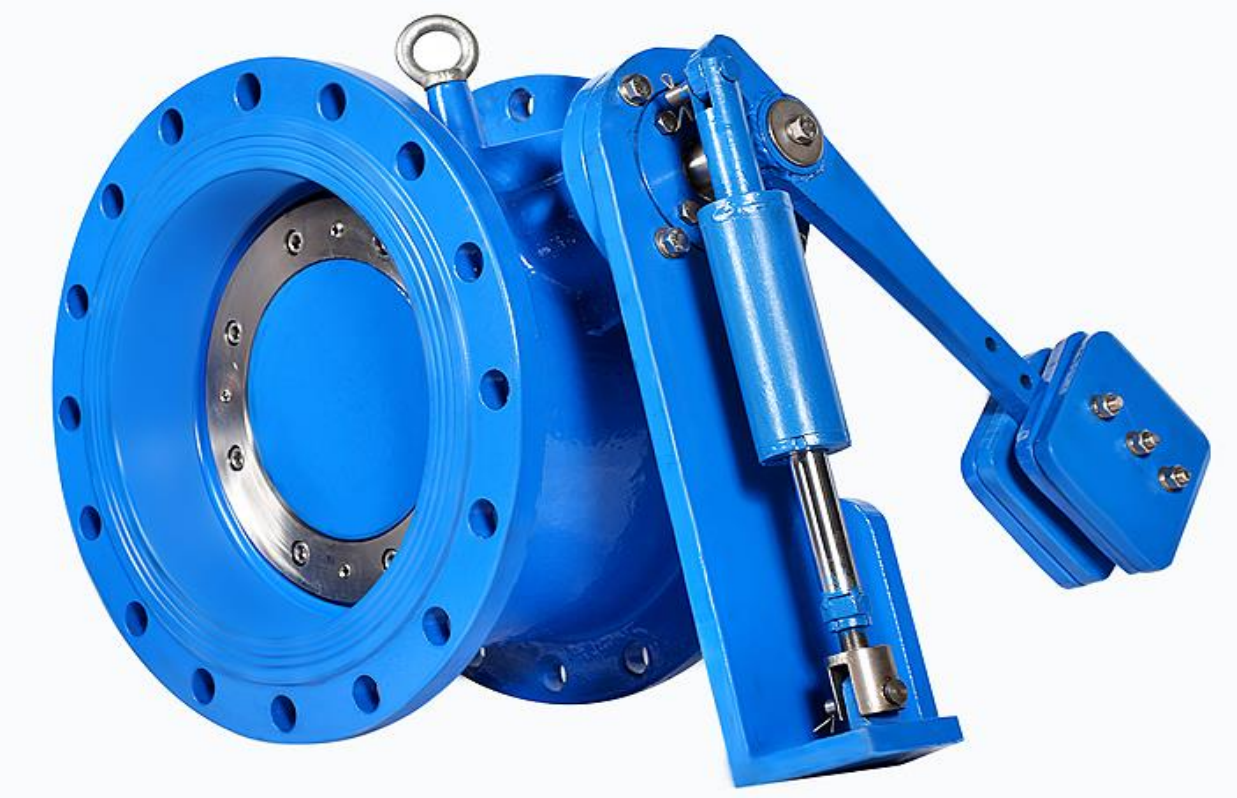
When the cavity is collapsed, there is a sudden change in velocity as water flow comes to a sudden stop – rapid deceleration

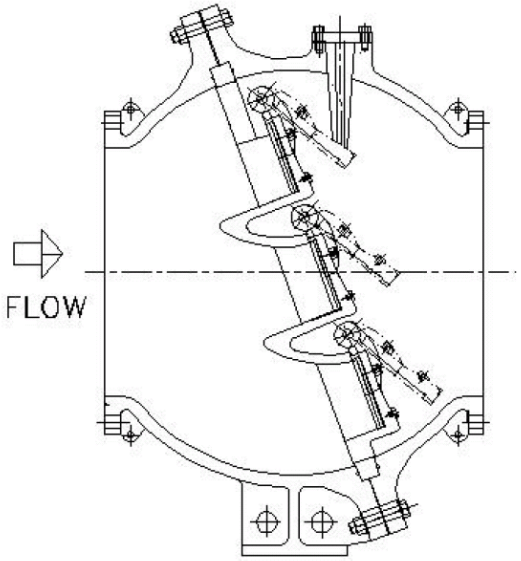
$$\Delta H = (c/g)\,\Delta V$$

Larger cavity volume allows for very high velocity changes

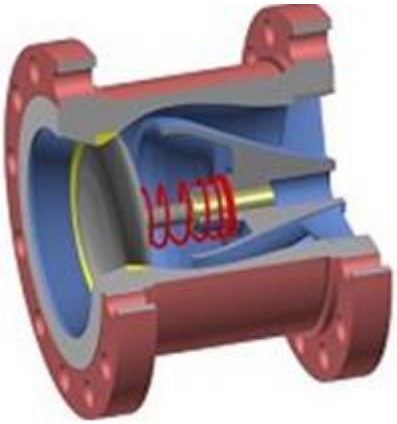

GEFA

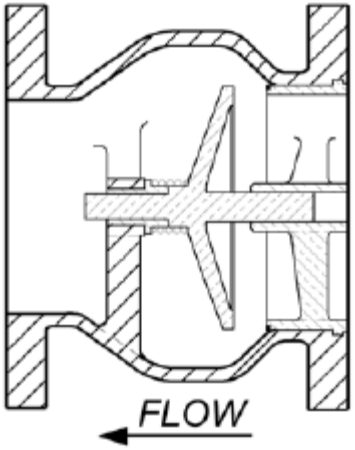
Non Return Valve

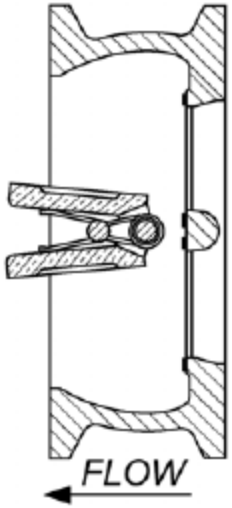


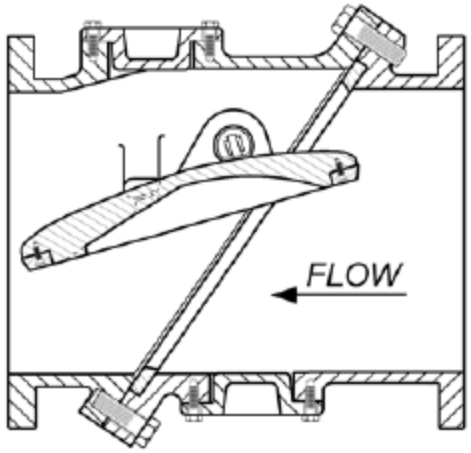


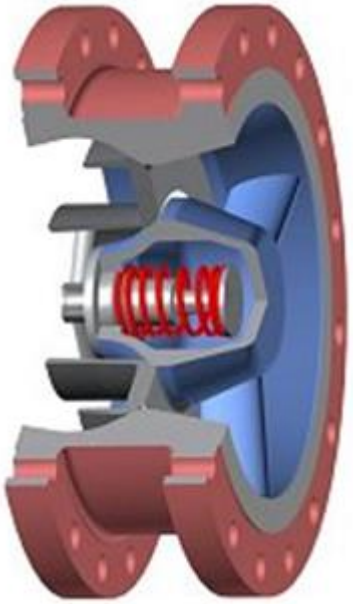
Multi Door Non Return valve



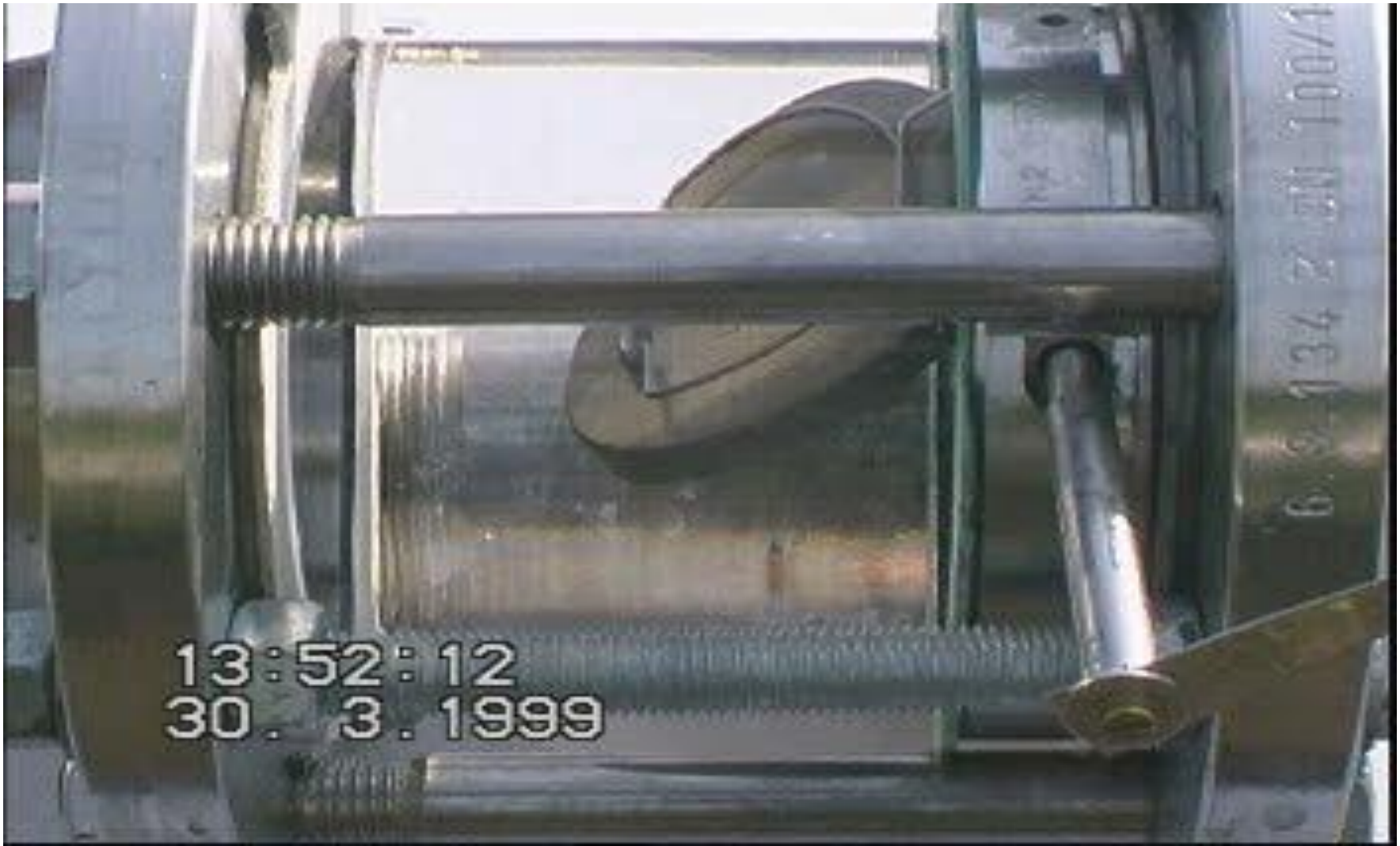




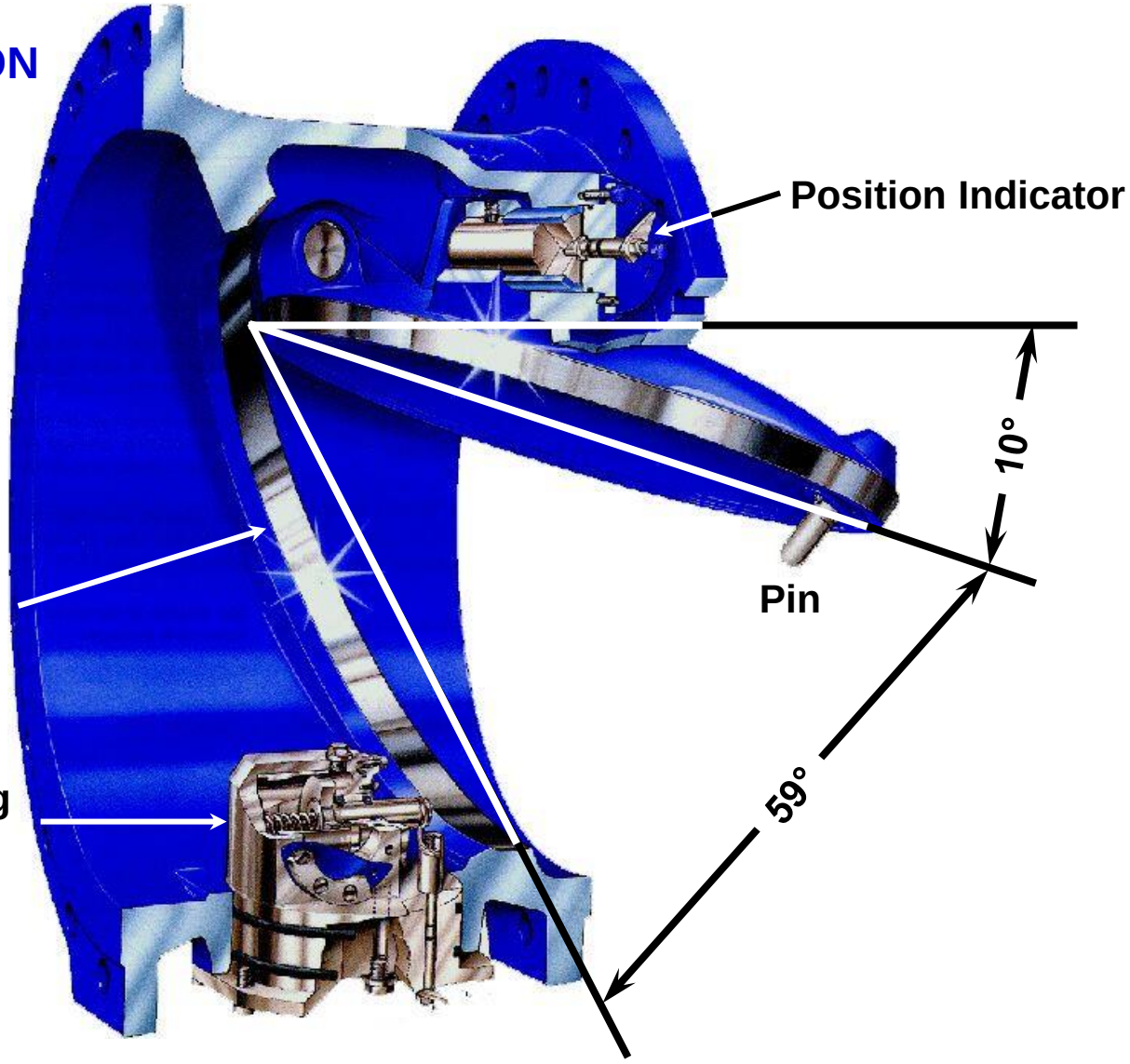




- Selection of Check valve
- Check valve slam

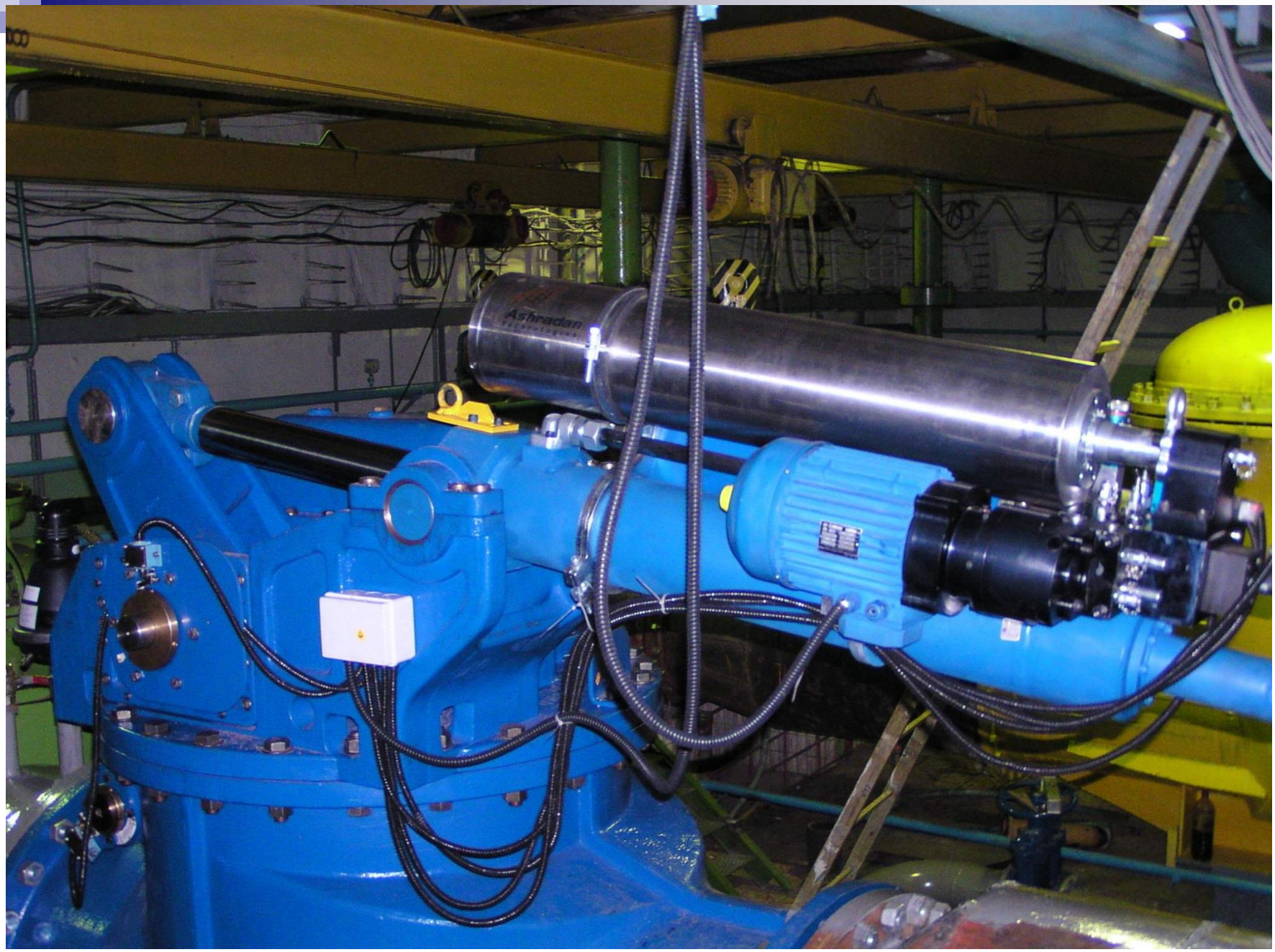


OPEN POSITION



Behaviour | Characteristic | Leakage Rate


26.12.2005 14:43


Ashnadan

Power Pack should be capable of withstanding dynamic pressure loading conditions

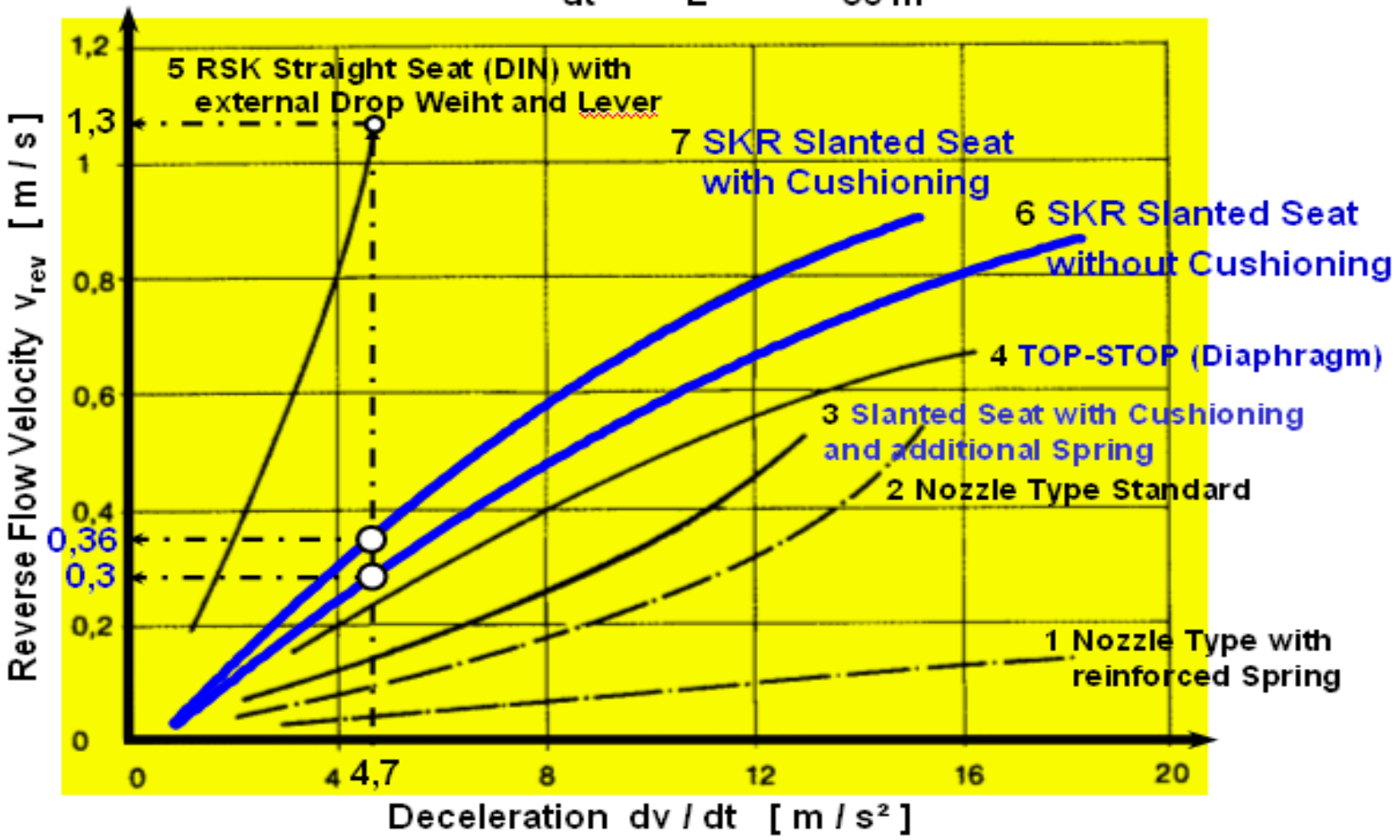
What kind of data we can get from check valve manufacturers that is useful for modeling water hammer?

DYNAMIC BEHAVIOUR OF NON-RETURN VALVES

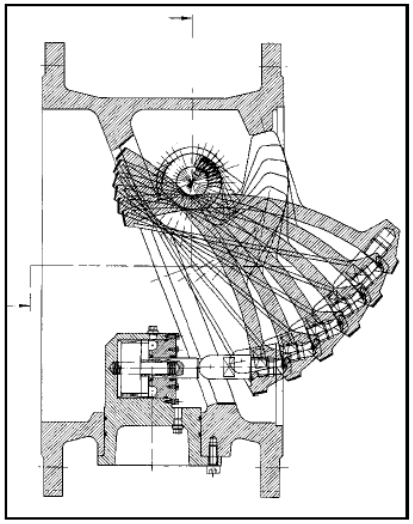
VAG VAG-Armaturen GmbH

Bopp & Reuther Armaturen GmbH

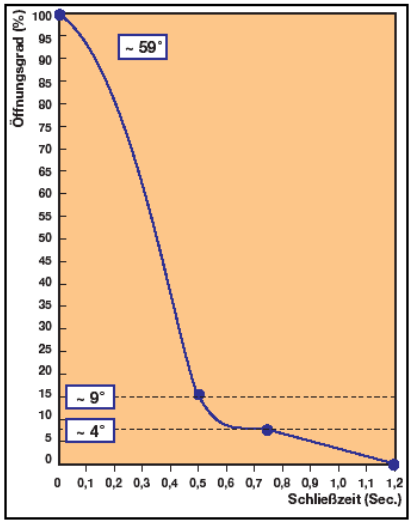
EXAMPLE: Deceleration $\frac{dv}{dt} = \frac{g \times \Delta H}{L} = \frac{9{,}81 \times 24\ m}{50\ m} = \underline{4{,}7\ m/s^2}$

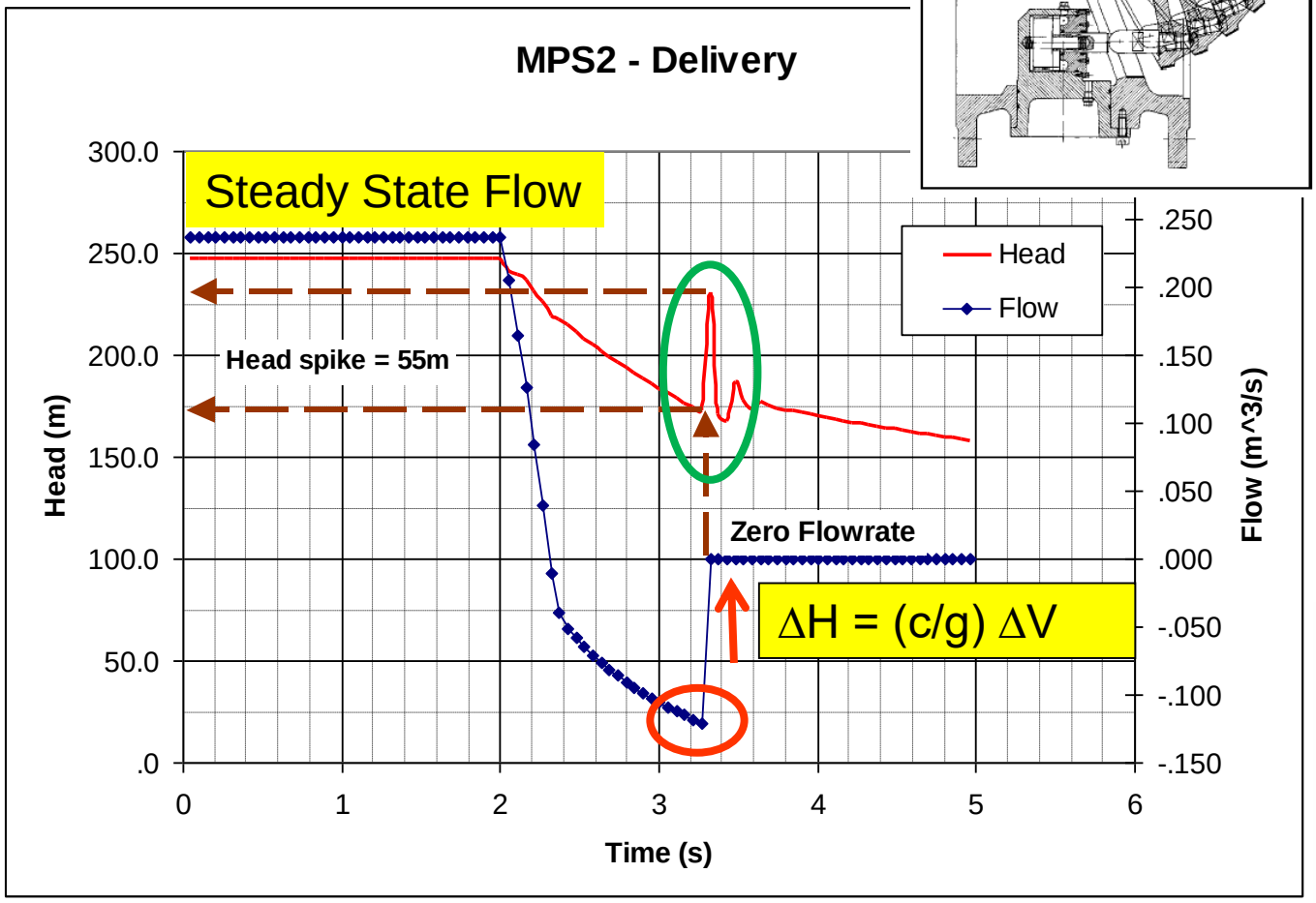


Damping movement



Closing characteristic





How to control Surge Pressures?

Methods of controlling water hammer effects

- Direct Action Methods
  - Modifications to original design requirements
    - a. Alter design parameters
      - Flowrate
      - Velocity
      - Pressure
    - b. Alter operational parameters
      - Pump speed controls (VFD)
      - Valve operational controls
    - c. Alter component characteristics
      - Transient friendly control valves
      - Fast acting check valves
      - Pumps with higher inertia
      - Flywheel

  - Pipeline Alignment (Realign pipeline to reduce peaks and valleys-Tunneling in places instead of going over a mountain)
  - Pipe Material (Stronger pipe to withstand both low and high pressures)
  - Pipe and Pump Sizes

Diversion Tactics

Water Hammer Protection Systems

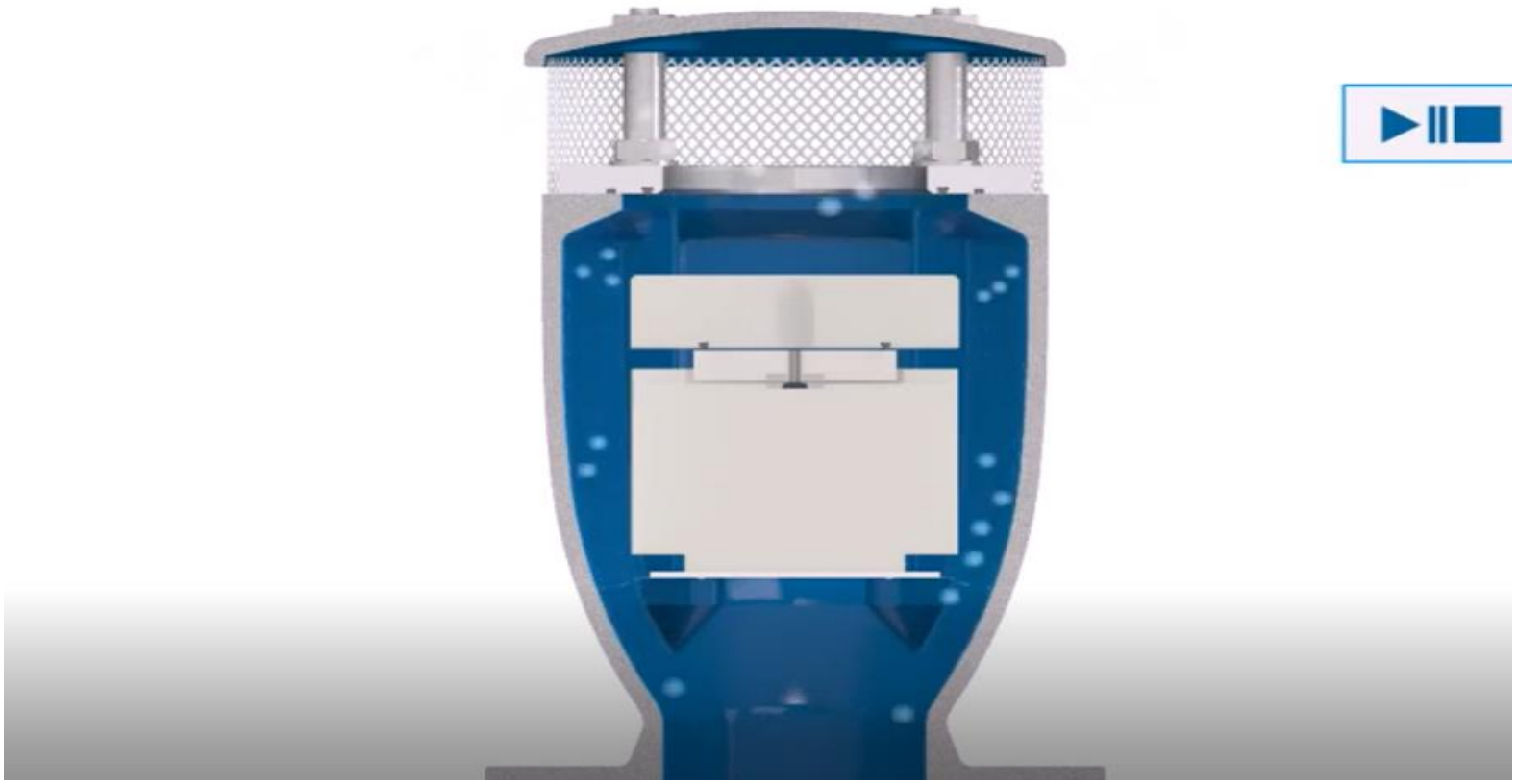
- Divert pressure waves to safer zones
  - High pressures as well as low pressures
  - 1. Surge tanks can safely absorb both high pressure and low pressure waves
  - 2. Air valves can alleviate low pressure problems by letting air into the system at close to atmospheric pressures
  - 3. Relief valves can alleviate high pressures problems

Air Valves
for safe and efficient air management

- Allowing air in the pipeline to prevent negative pressure
- Release air during pipe filling
- Release air during normal operation
- Releasing air in a controlled manner to avoid air slamming

Air Valves

Water combination air valve with surge prevention mechanism Mod. FOX 3F - RFP

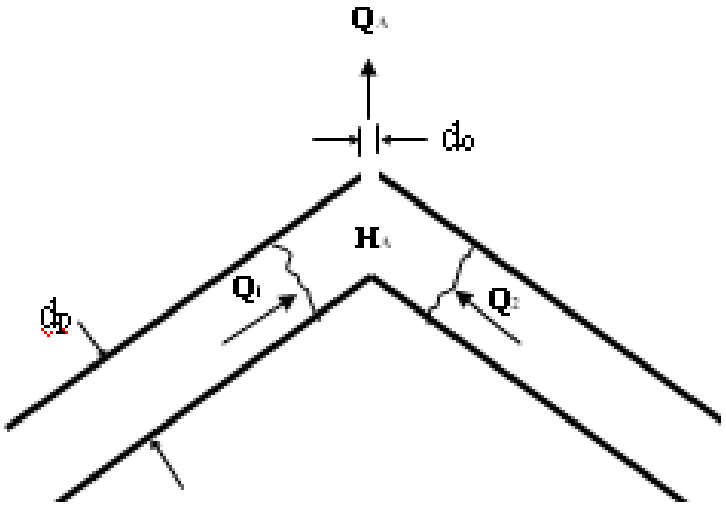


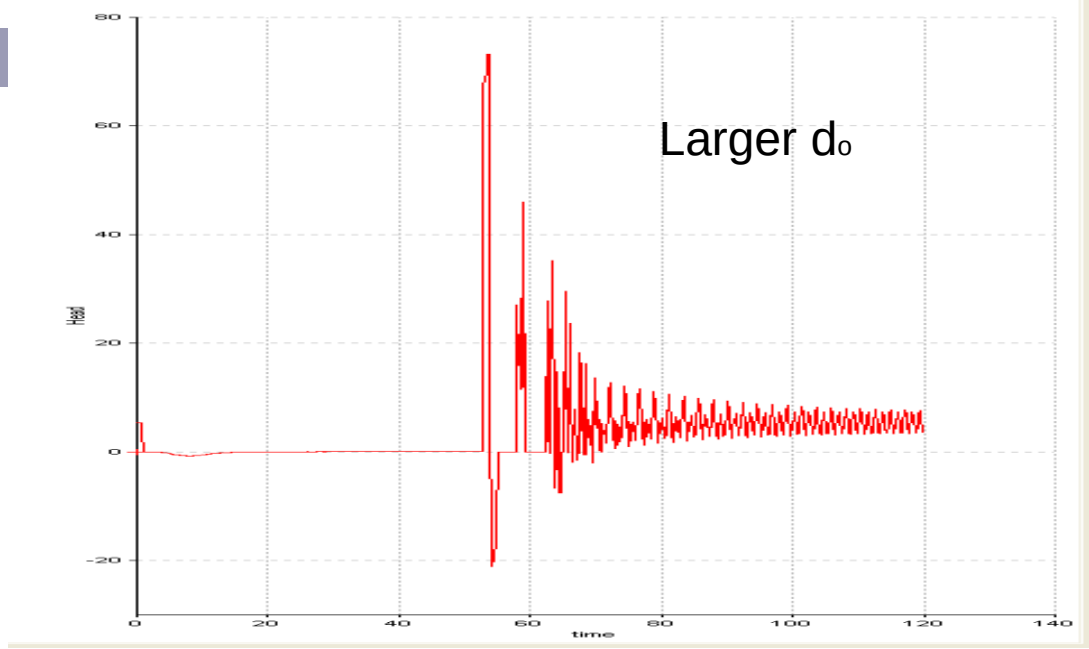
Air valves for surge protection

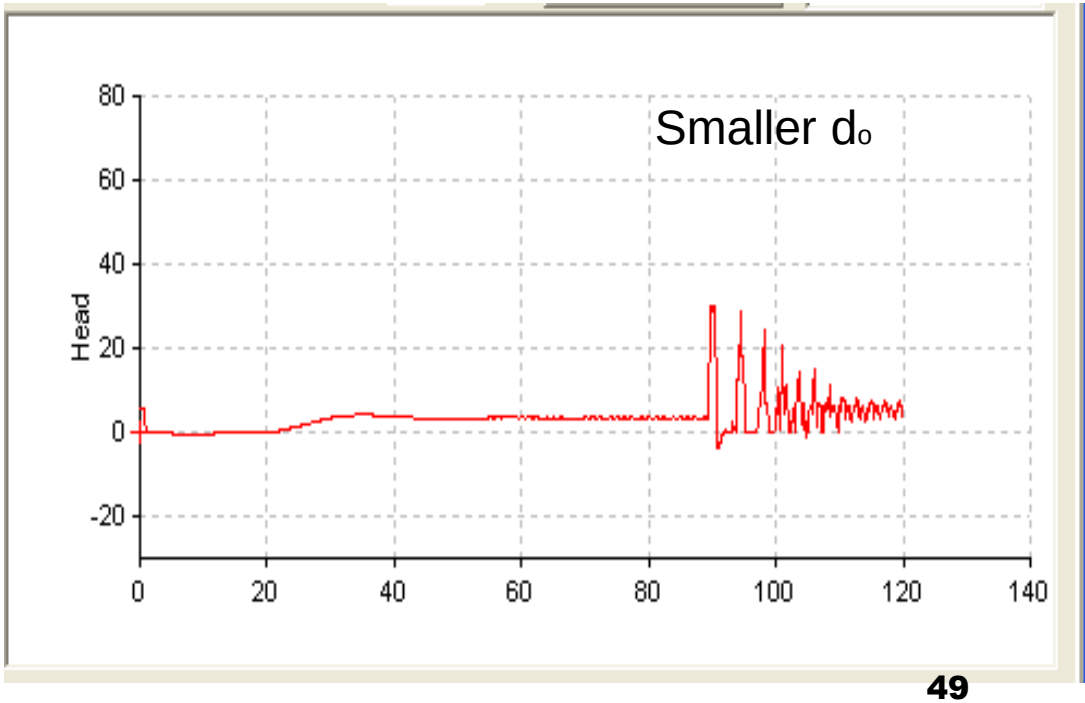
- Prevent extreme low pressures
  - For most pipeline systems, severe high pressure transients are resulted because of initial low pressure transients
    - Pump trip
      - No air valves → potential for cavitation conditions
      - Collapse of vapor cavities → large pressure spikes
  - Preventing initial low pressures can prevent subsequent high pressure transients

Air Slam

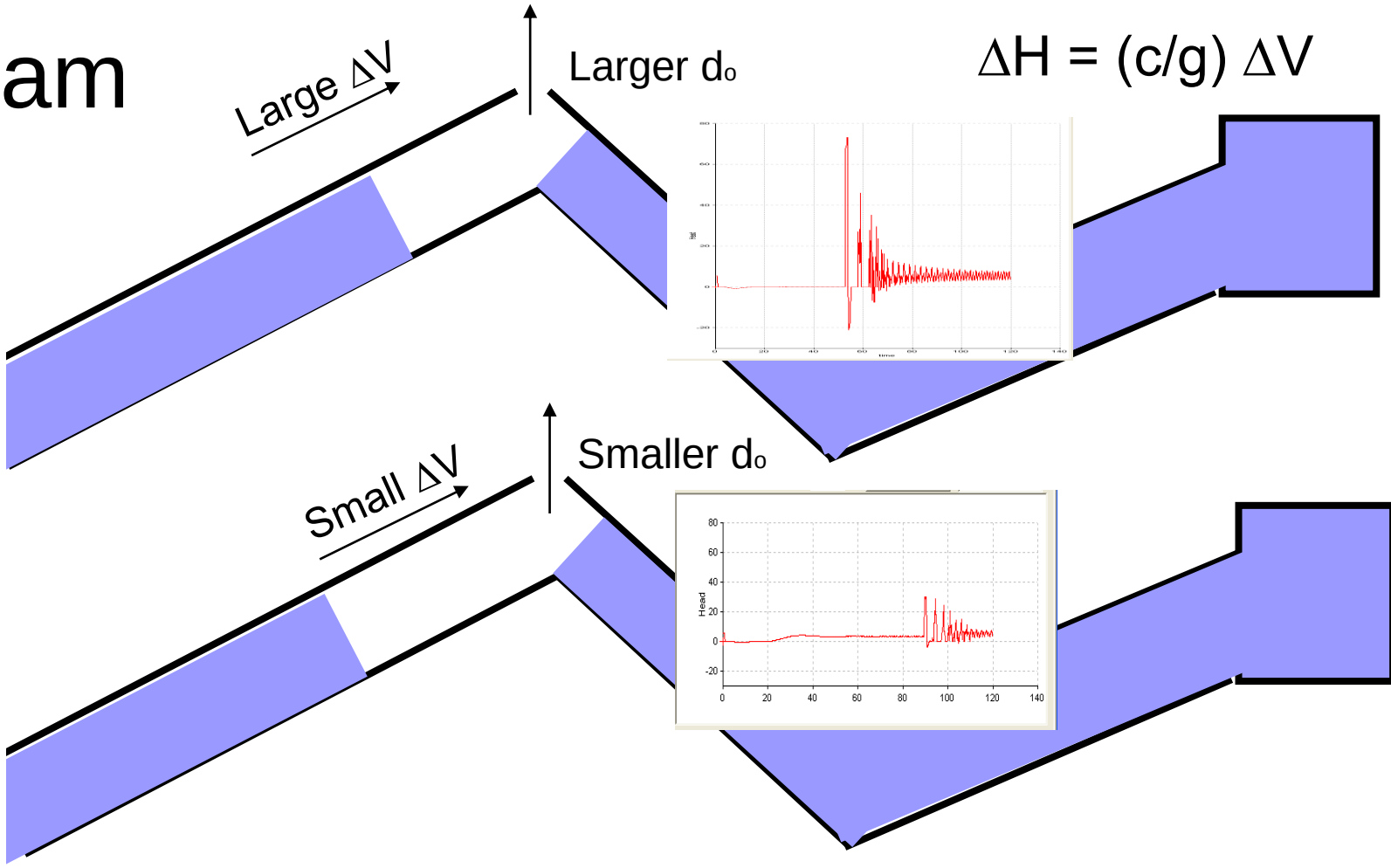
$\Delta H = (c/g)\,\Delta V$







Air Slam

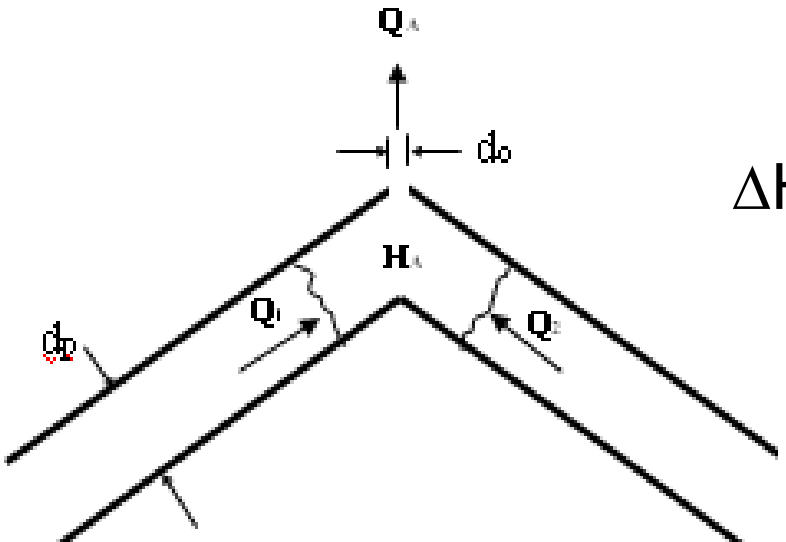


$\Delta H = (c/g)\,\Delta V$

$V = U + a * t$

Mechanical Slam vs. Hydraulic Slam

- Mechanical Slam
  - Rapid lifting of float
- Hydraulic Slam
  - Rapid deceleration of velocity



$$\Delta H = (c/g)\,\Delta V$$

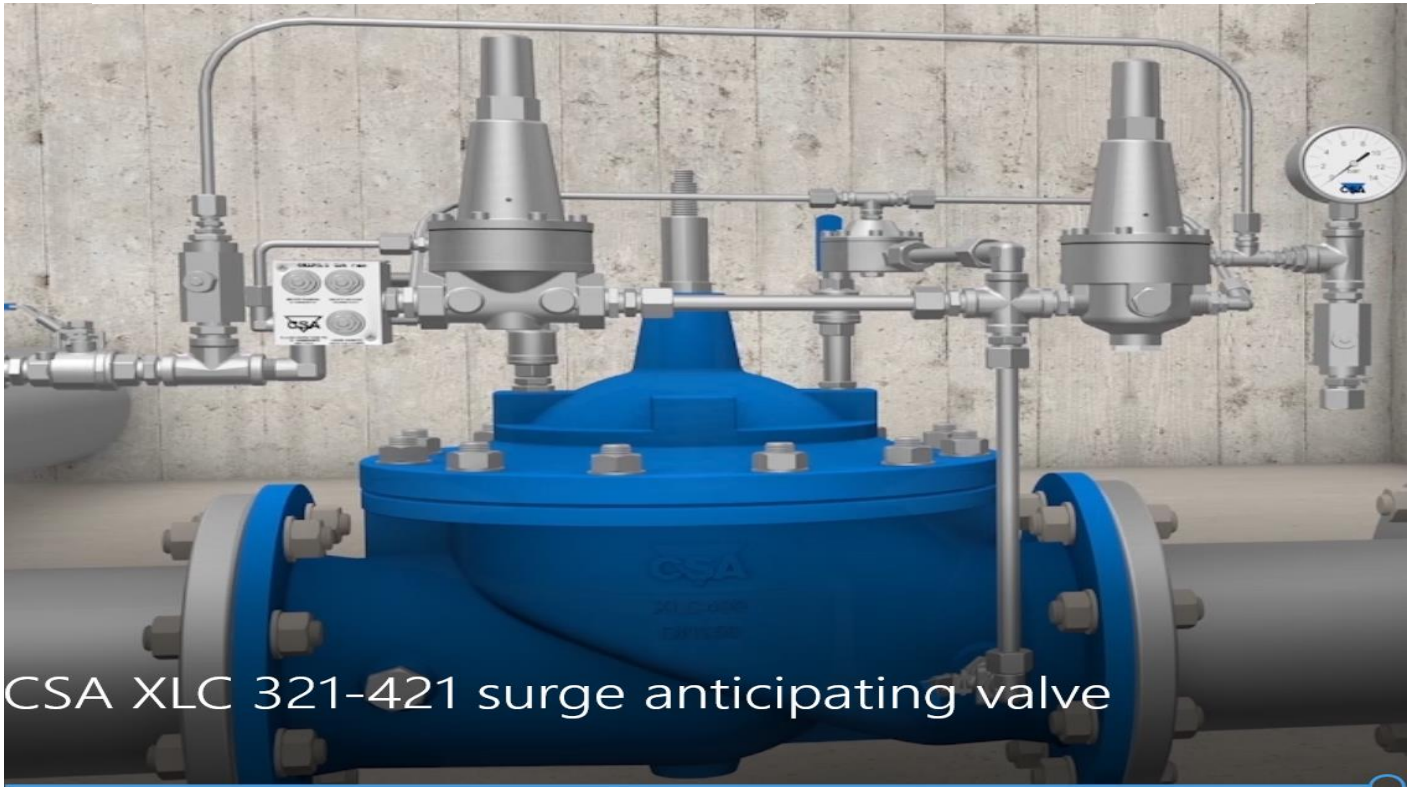
Relief valves

Relief Valves offer protection against high pressure transients

- Pressure relief valves
- Surge anticipation valves
- Rupture discs

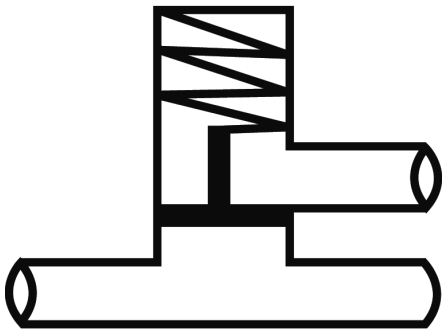
CSA

Valves manufacturer since 1987

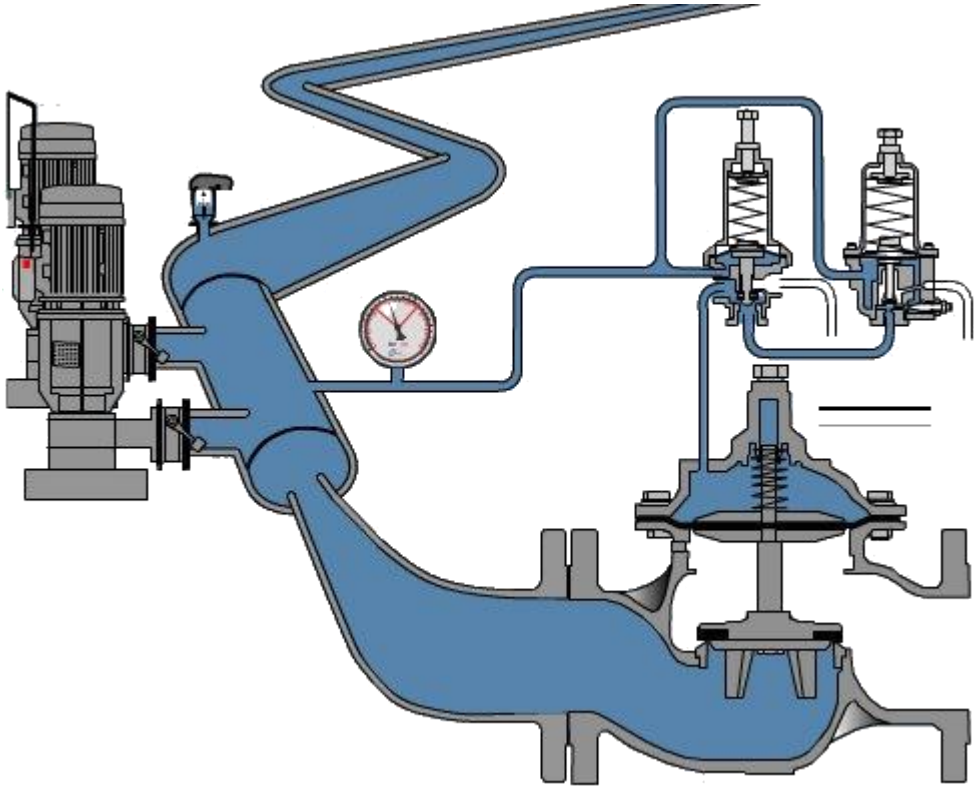



ACCURACY ± 0,60%
20 °C
FIMA

Pressure Relief Valves



Surge Anticipation Valves

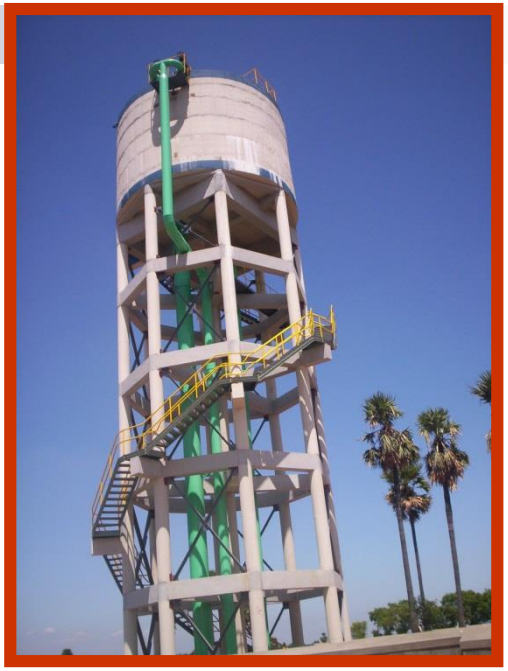


Rupture Disk

- Like a safety valve
- One-time use
- Breaks open when the pressure exceeds the set value

Surge Tanks

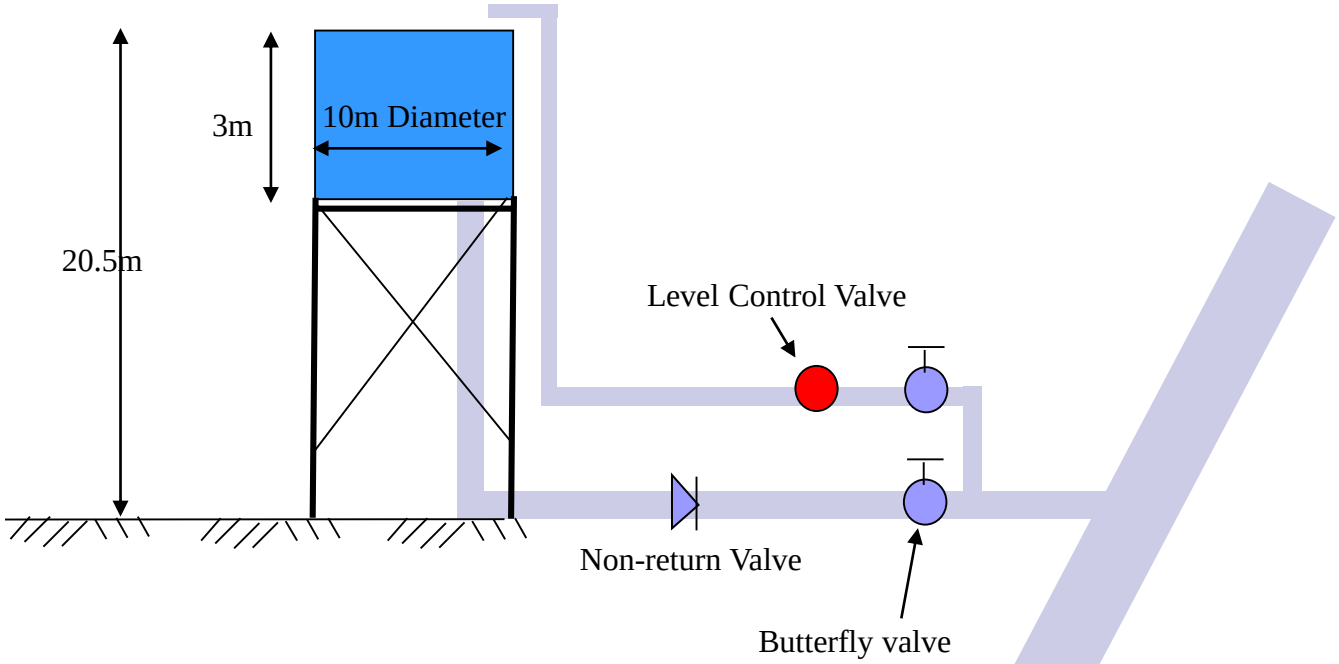
Surge Tanks



Surge Tanks

- One-way open tanks
- Open surge tanks or stand pipes
- Closed surge tanks or air vessels
  - Compressor vessels
  - Bladder vessels
  - Hybrid surge tanks

Schematic of an One-way surge tank (OST)



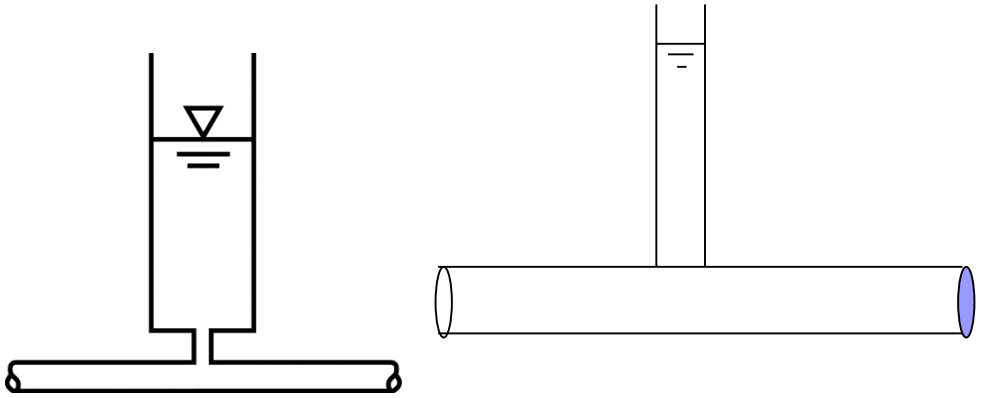
Pipe Connecting One-way Tank to Transmission Main:

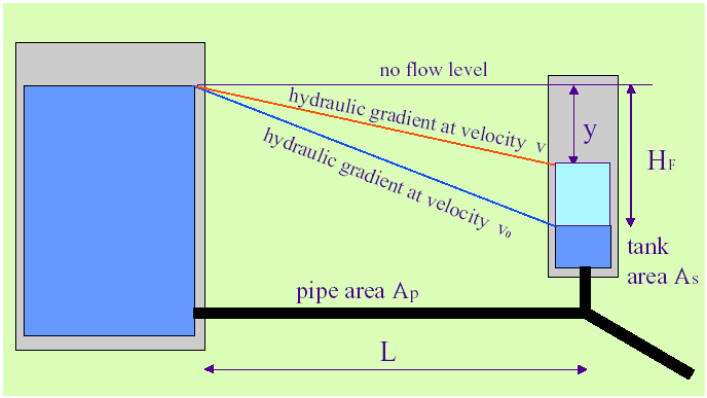
- Diameter = 1000mm
- Length = 30m (max)
- # of Elbows = 2
- NRV closure time = fast acting

Pipe for charging One-way Tank:

- Diameter = 250mm
- Length = 35m
- # of Elbows = 3
- Level control valve

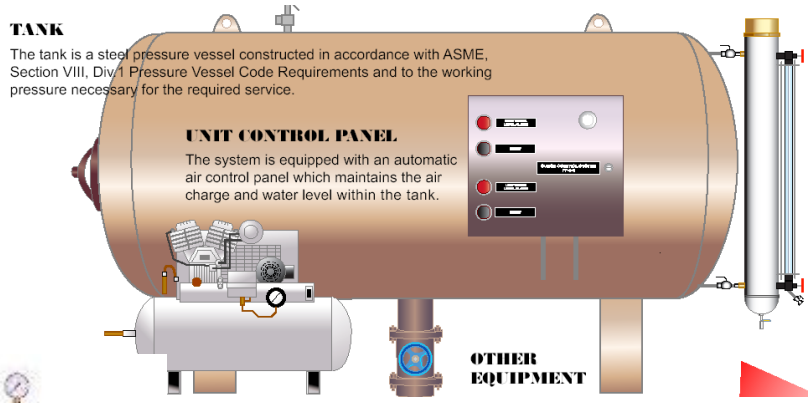
Open surge tanks or stand pipes

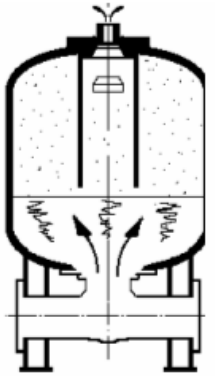




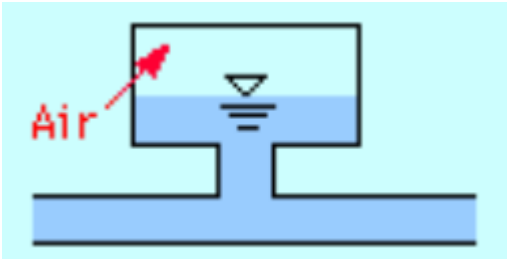
Closed surge tanks or air vessels

- Compressor vessels
- Bladder vessels
- Hybrid surge tanks

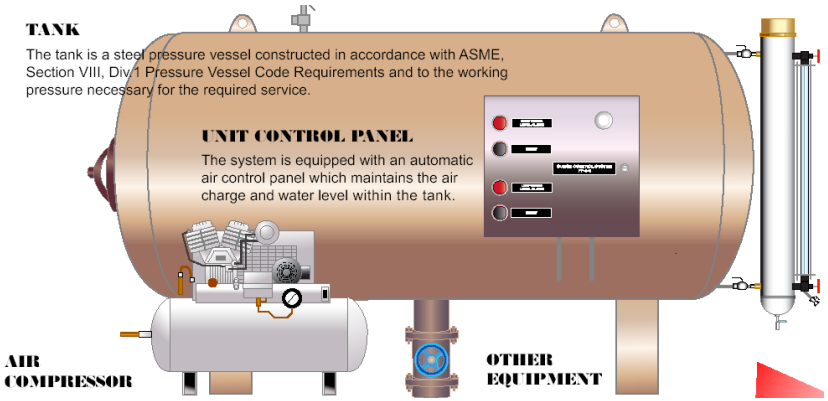




Compressor vessels

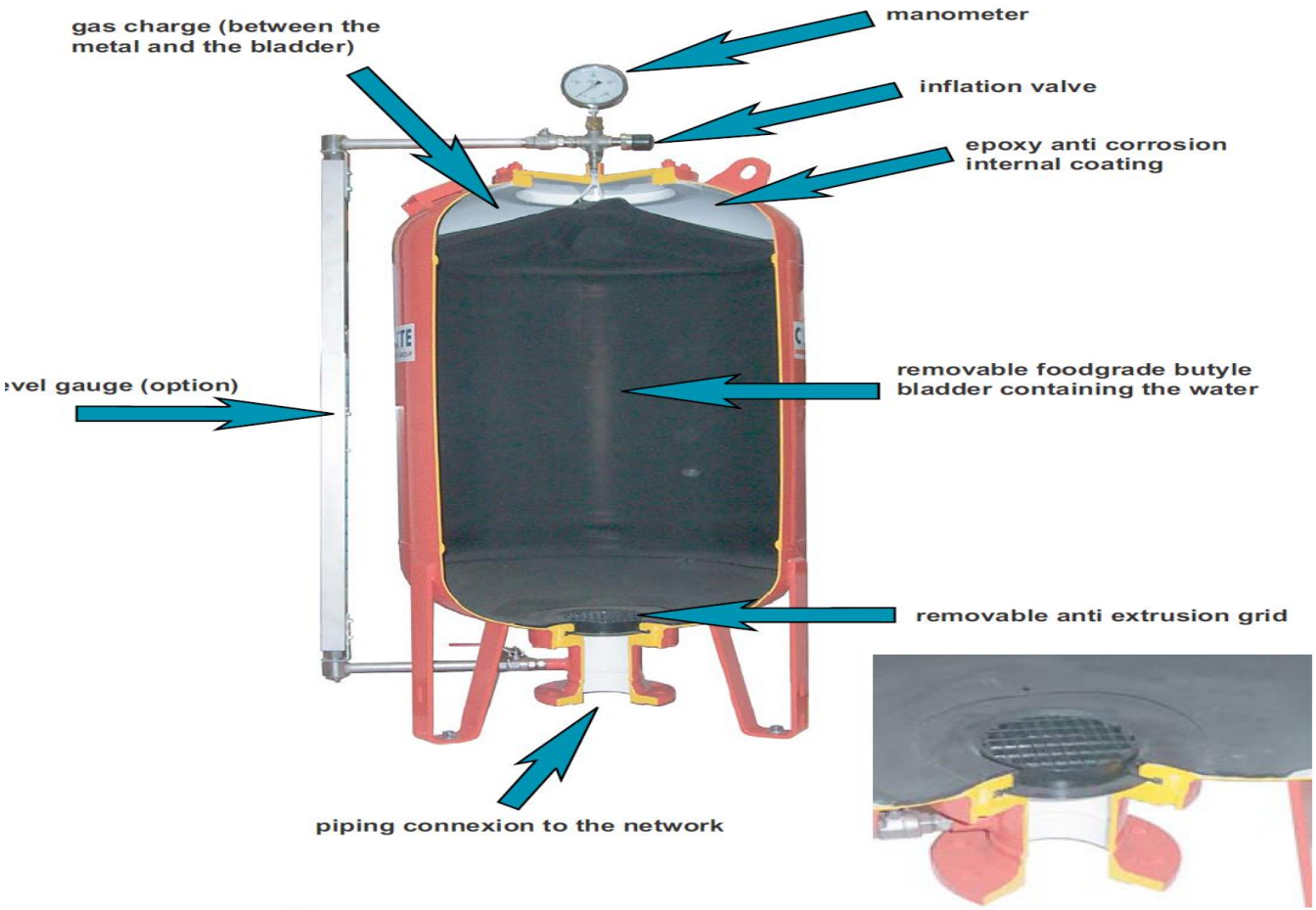


- Dissolution of air
- Necessitates compressor
- Need for electricity
- Backup generator
- Complicated System of Controls
  - Compressor
  - Air receiver
  - Measuring equipment
  - Alarm systems
  - Control panel



- Dissolved air will show up elsewhere in the system
- Vessel is highly prone for corrosion due to air-water interface
- Highly restricted locations
- **Maintenance intensive Electro-mechanical solution**

Bladder Tank



Foodgrade butyle bladder surge vessel

Bladder tanks

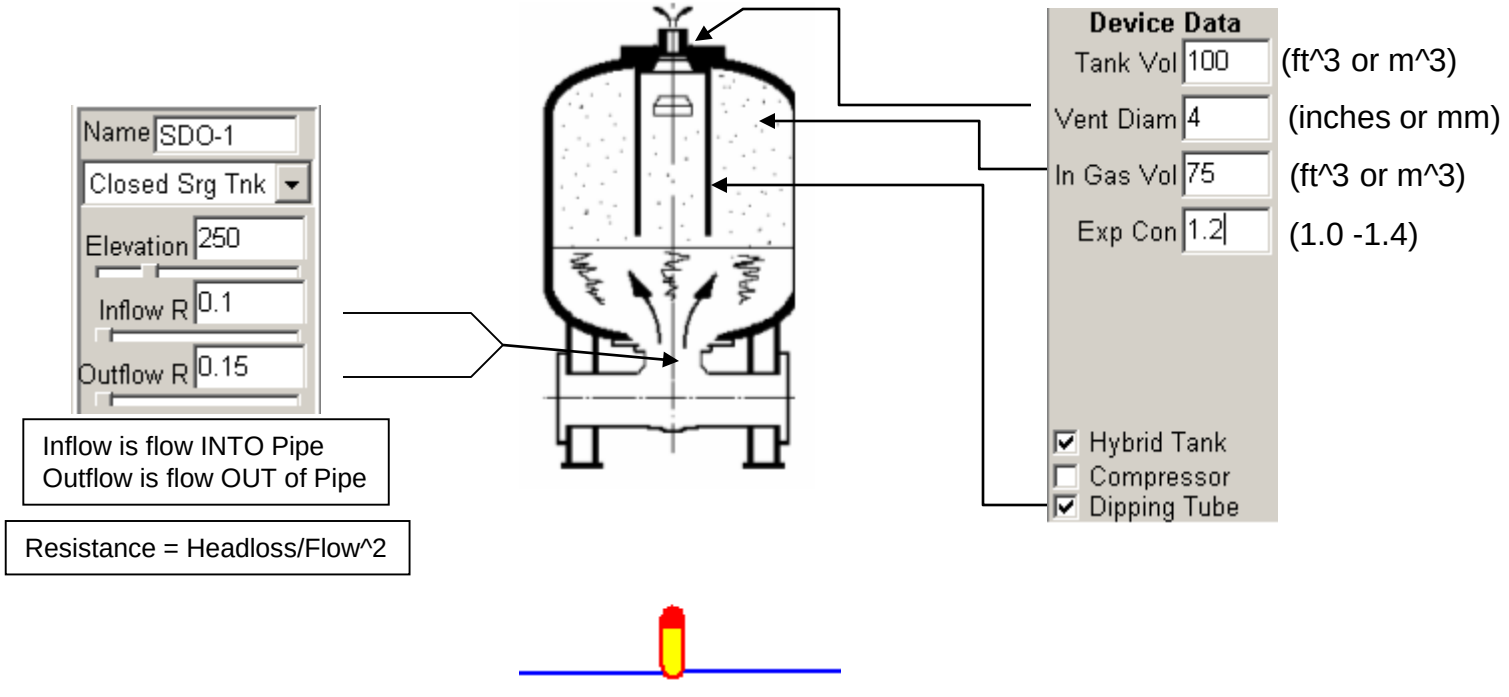
- Liquid and gas are separated by a bladder
- Butyl rubber bladder approved for drinking water
- No permanent regulation system
- Portable compressor will be sufficient to maintain pre-charge pressure in case of necessity
- Little or no corrosion of vessel interior as water is NOT in contact with the vessel.
- Corrosion can be completely eliminated by using Nitrogen in place of air
- Flexible selection of location for the vessel
- **More reliable Hydro-pneumatic solution**

Advantages of Bladder Vessels

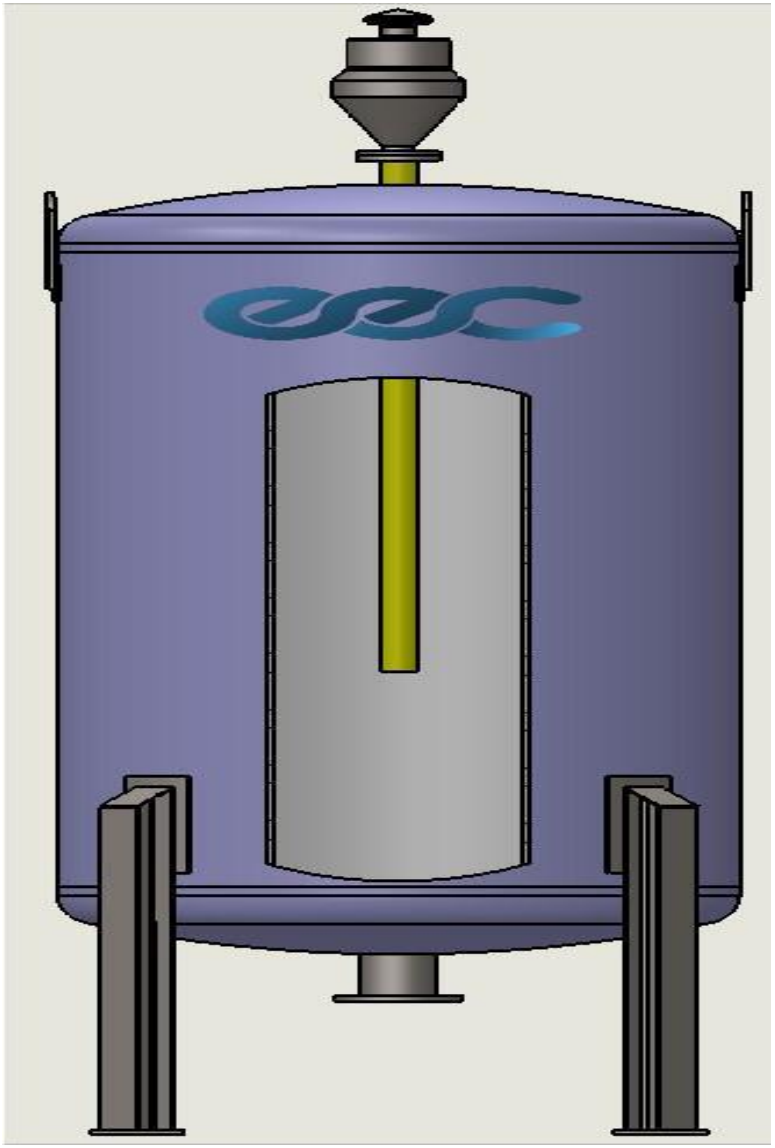
- Air Vessels
  - Dissolution of air
  - Necessitates compressor
  - Need for electricity
  - Backup generator
  - Complicated System of Controls
    - Compressor
    - Air receiver
    - Measuring equipment
    - Alarm systems
    - Control panel
  - Dissolved air will show up elsewhere in the system
  - Vessel is highly prone for corrosion due to air-water interface
  - Needs wide area
  - **Maintenance intensive Electro-mechanical solution**

- Bladder Vessels
  - Liquid and gas are separated by a bladder
  - Butyl rubber bladder approved for drinking water
  - No permanent regulation system
  - Portable compressor will be sufficient to maintain pre-charge pressure in case of necessity
  - Little or no corrosion of vessel interior as water is NOT in contact with the vessel.
  - Corrosion can be completely eliminated by using Nitrogen in place of air
  - Flexible selection of location for the vessel
  - **More reliable Hydro-pneumatic solution**

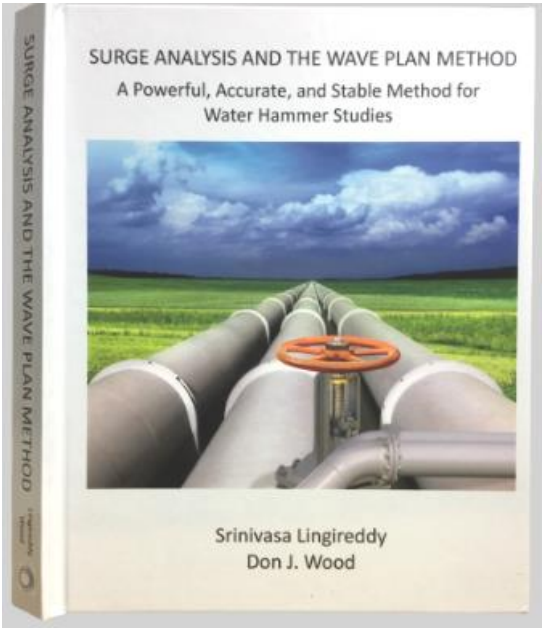
Hybrid Surge Tank
(closed surge tank)



Dipping Tube

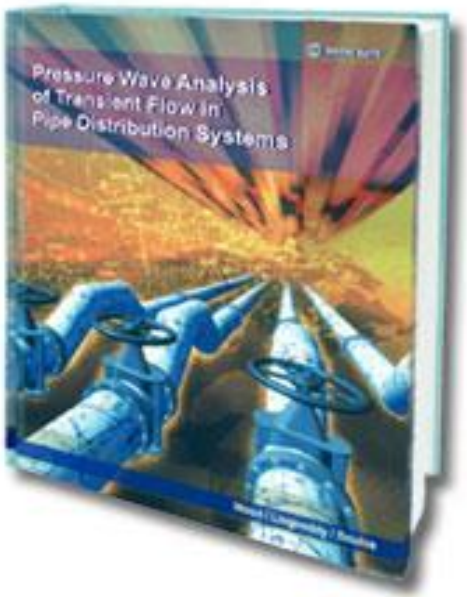


Good References



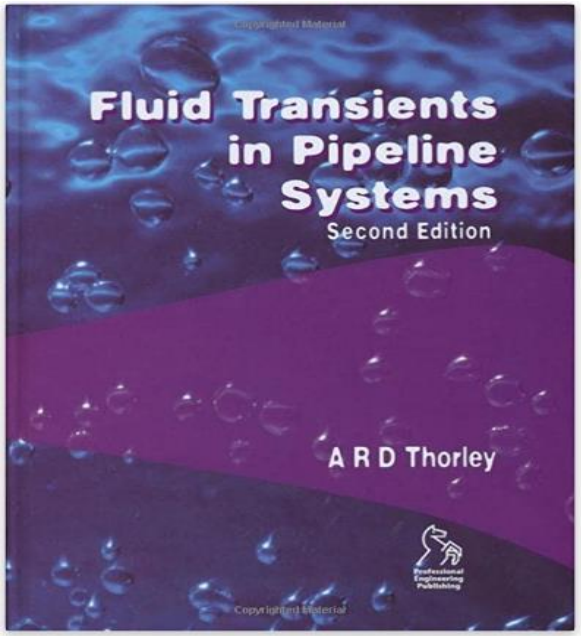
Surge Analysis and the Wave Plan Method

Srini Lingireddy-Don J. Wood



Pressure Wave Analysis of Transient Flows in Pipe Distribution Systems

Don J. Wood-Srini Lingireddy-Paul F. Boulos



Fluid Transients in Pipeline Systems

A R D Thorley

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