Water Hammer

Fundamentals, Protection Equipment, & Modeling

CSWEA / A&WMA Conference on the Environment
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ICE (Water) Hammer Credit: Al Parrella (WLSSD) & http://rasterweb.net/raster/2015/01/15/the-ice-hammer/

What is water hammer?

- Waves of high and low pressure
- Surge / Hydraulic Transients / Water Hammer
  - Not a new concept:

Water Hammer and Surge

AWWA Steel Pipe Committee Report

AWWA Journal, 1961

WATER HAMMER AND SURGE TANKS[1]

By A. W. F. McQueen[2]

AWWA Journal, 1932

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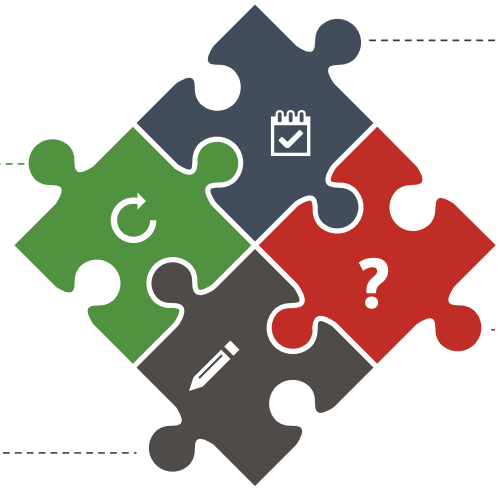
Risks of transient pressures



Service Interruption & Property Damage

External Pathogens

Damaged Pumps

Leaking Pipes, Main Breaks

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Collapsed Pipe

- Gage vs. absolute pressure.
- How low can absolute pressure go?
  - …
- How low can gage pressure go?
  - …

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Collapsed Pipe

- Gage vs. absolute pressure.
- How low can absolute pressure go?
  - 0 psi absolute pressure
- How low can gage pressure go?
  - …

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Collapsed Pipe

- Gage vs. absolute pressure.
- How low can absolute pressure go?
  - 0 psi absolute pressure
- How low can gage pressure go?
  - -14.4 psi gage pressure

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Bonus Question

- What is Atmospheric Pressure on the top of Mount Everest?
  - …

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Bonus Question

- What is Atmospheric Pressure on the top of Mount Everest?
  - 4.89 psi

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Pitted Impellers

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Heart Beat

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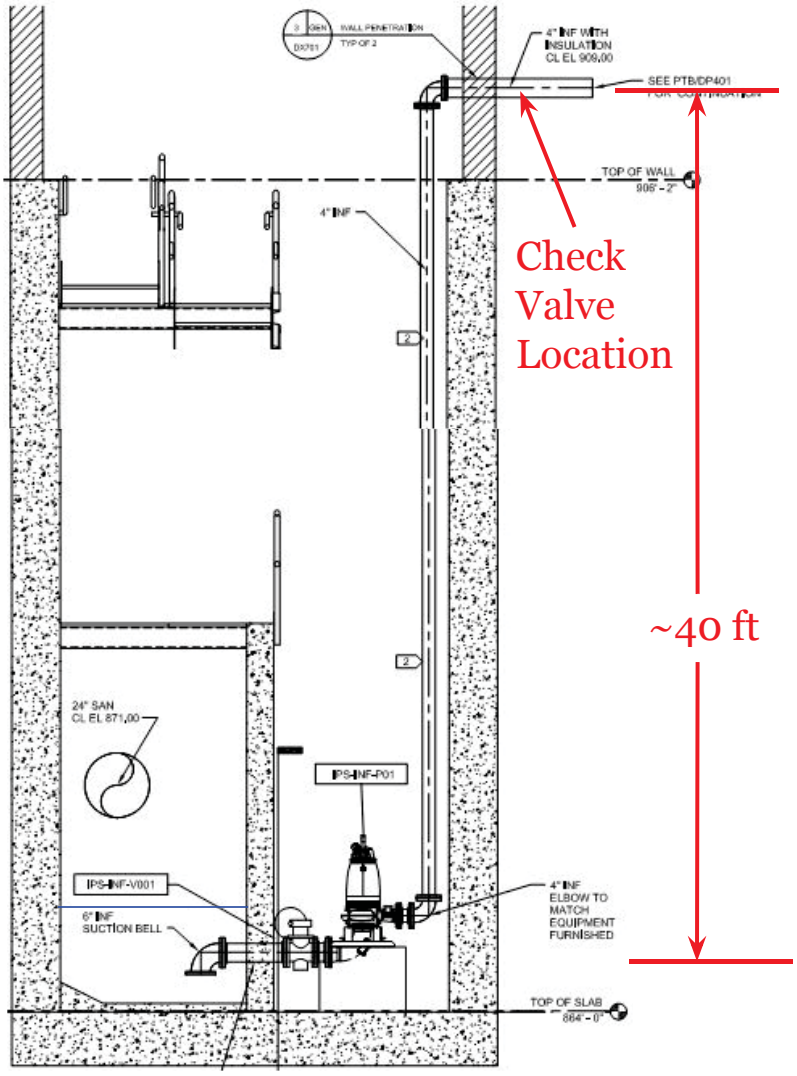
Is there a problem here?



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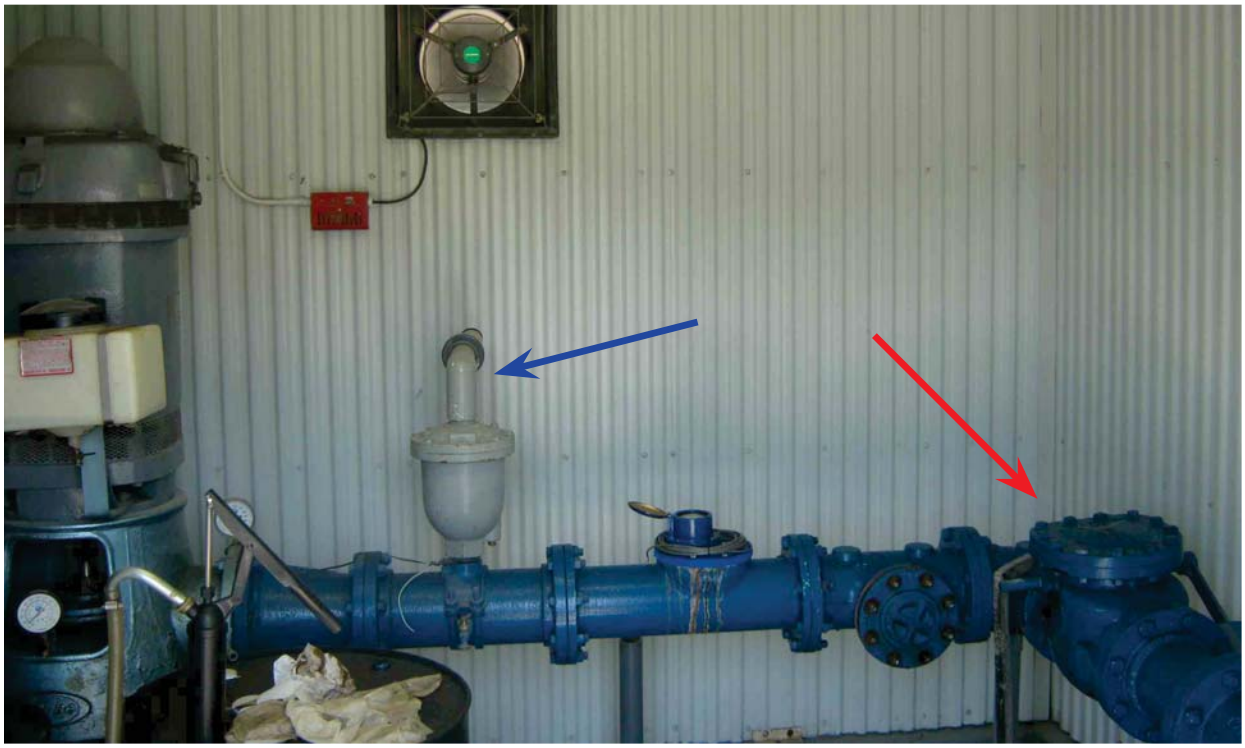
Another possible solution



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What causes water hammer?

- Main line valve closure
- Pump tripping (power outage)
- Pump start-up and shut-down
- Check valve slam
- Surge relief valve slam
- Air release valve slam

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Δ Velocity

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Water Hammer Pressures

"Potential Surge":

- Joukowsky Equation
  - $\Delta H = a\Delta v/g$
  - $508 = 4725*8/32.2/2.311$
- Elastic column theory
- No friction loss
- No dampening
- Maximum pressure rise for rapid valve closure (closure within critical closing time)
- Can be even higher on long lines with high friction due to line packing.

Table B.1 — Magnitude of pressure wave

Velocity	Delta pressure	Velocity	Delta pressure
m/s	kPa	ft/s	psi
0.3	432	1	64
0.6	863	2	127
0.9	1295	3	191
1.2	1726	4	254
1.5	2158	5	318
1.8	2589	6	381
2.1	3021	7	445
2.4	3452	8	508
2.7	3884	9	572
3.0	4316	10	635
3.4	4891	11	699
3.7	5323	12	762
4.0	5754	13	826
4.3	6186	14	889
4.6	6617	15	953

Table B.1 from ANSI/HI 9.6.6-2009
(Acknowledgement – Courtesy of Hydraulic Institute, Parsippany NJ, www.pumps.org)

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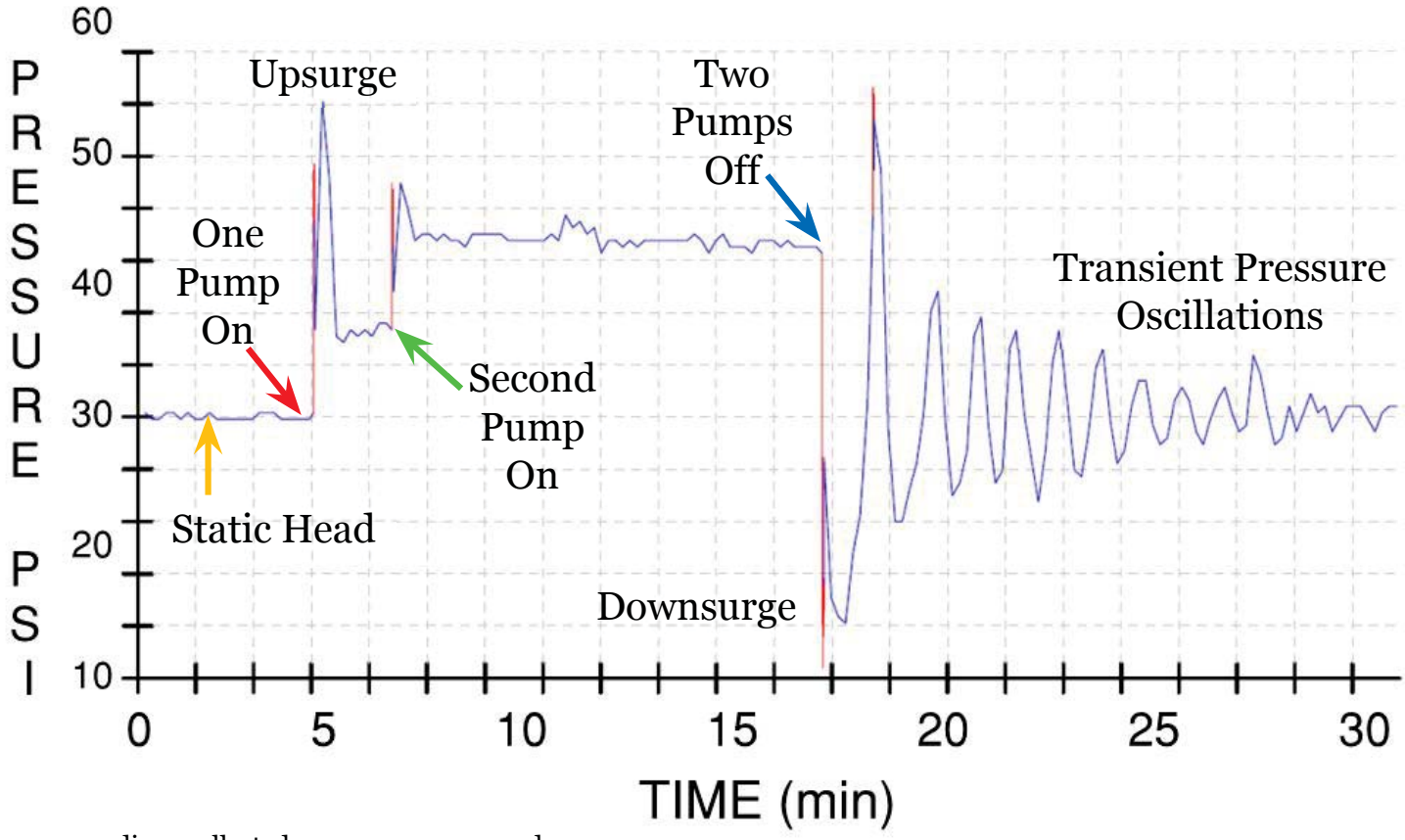
Hydraulic Transient Pressures



Pressure readings collected once every 10 seconds

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How can this be prevented?

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Combination Air/Vacuum and Air Release Valve

www.rfvalve.com/products/rgx (Vent-O-Mat)
www.arivalves.com/products/wastewater/item/d-020-combination-air-valve-for-wastewater
www.dezurik.com
www.h-tec.us/

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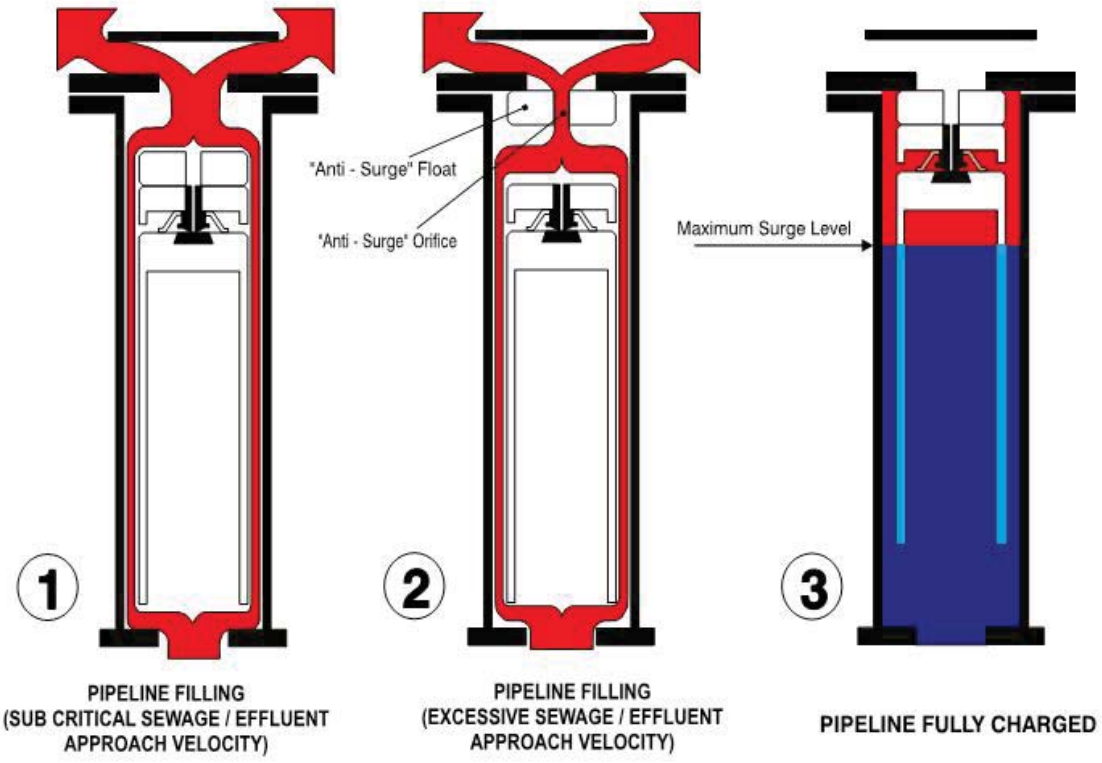
Combination Air/Vacuum and Air Release Valve

www.crispinvalve.com/airvalves/av-pw/ (UL, C, and Dual Series)

www.h-tec.us/

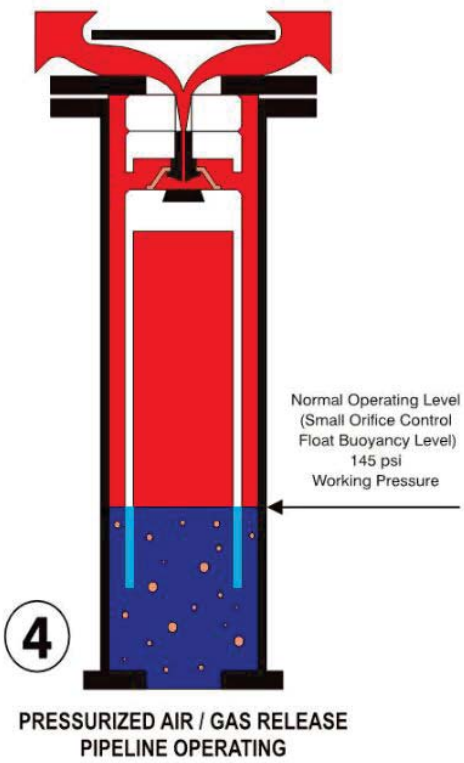
www.rfvalve.com/products/rgx (Vent-O-Mat)

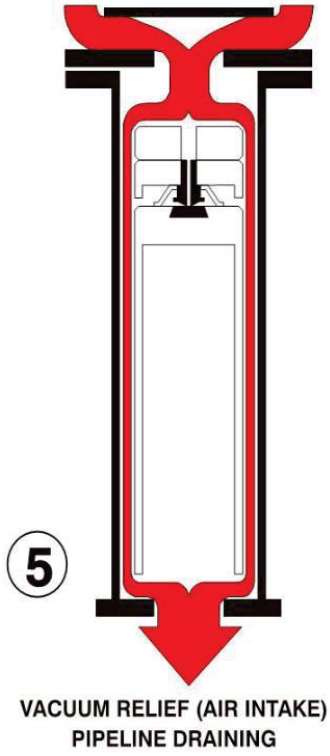
Combination Air/Vacuum and Air Release Valve



www.rfvalve.com/products/rgx (Vent-O-Mat)

Combination Air/Vacuum and Air Release Valve





www.rfvalve.com/products/rgx (Vent-O-Mat)

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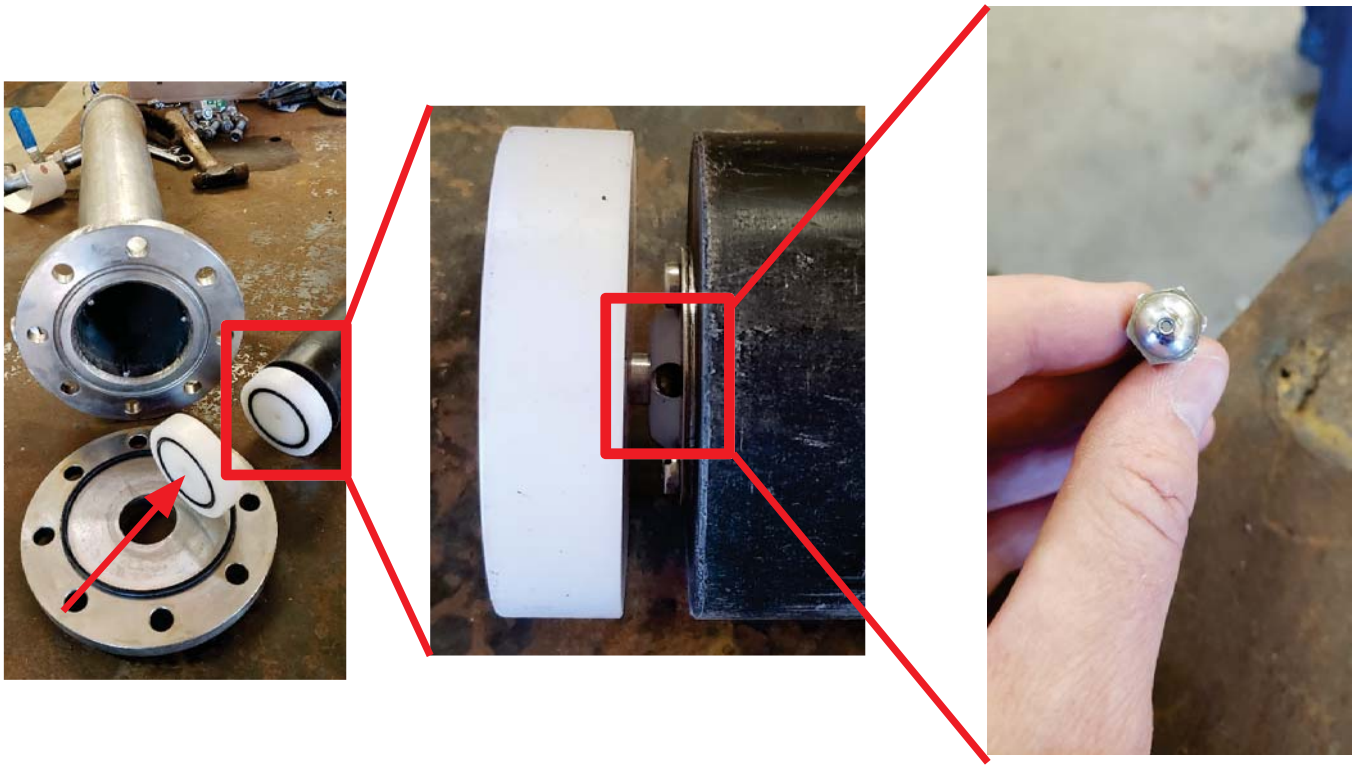
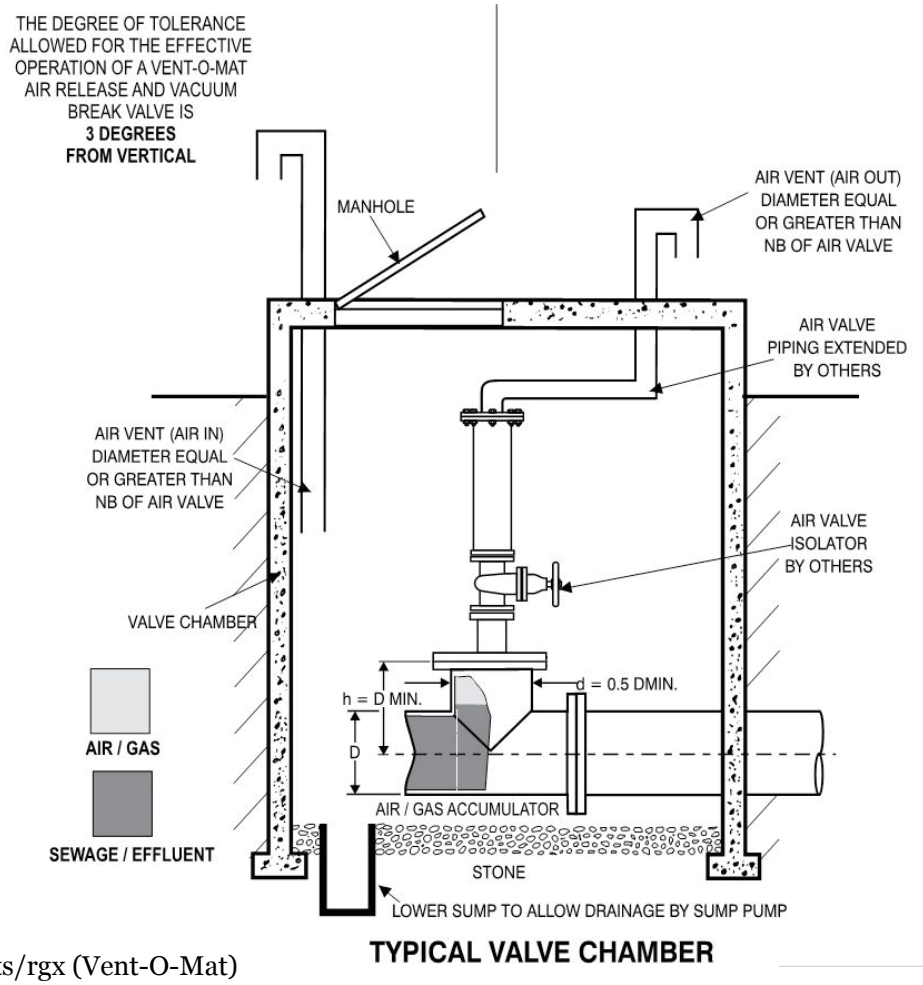
Combination Air/Vacuum and Air Release Valve



www.rfvalve.com/products/rgx (Vent-O-Mat)

Combination Valve MH



www.rfvalve.com/products/rgx (Vent-O-Mat)

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Maintenance

Carefully raise the upper part **(5+6)** until you have lifted the large stainless steel float **(16)** out of the valve.
Check the O-ring **(8)** **for** possible damage, then a re-insert it correctly into the O-ring chamber.
Clean the interior of the valve casing **(18)** e.g. by absorption/sucking. Then perform a visual inspection of the housing interior.

Clean the large, stainless steel float **16)** and check it for possible damage.

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Surge / Pressure Relief Valves

http://www.dezurik.com/products/brands-product/surge-relief-valves-sra/2/9/44/
https://www.cla-val.com/waterworks-pressure-relief-valves
http://www.gaindustries.com/products/detail-product/product/Surge-Relief-Anticipator-Valve.html

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Pressure Relief & Surge Anticipator Valves

http://www.cla-val.com/52-03-652-03-pressure-relief-surge-anticipator-valve-p-81.html

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What is this for?

https://www.rpmwashingtondc.com/washington-dc-water-heater-maintenance-clean-air-filter
https://www.amtrol.com/

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Residential “Thermal Expansion Tanks”

https://www.rpmwashingtondc.com/washington-dc-water-heater-maintenance-clean-air-filter
https://www.amtrol.com/

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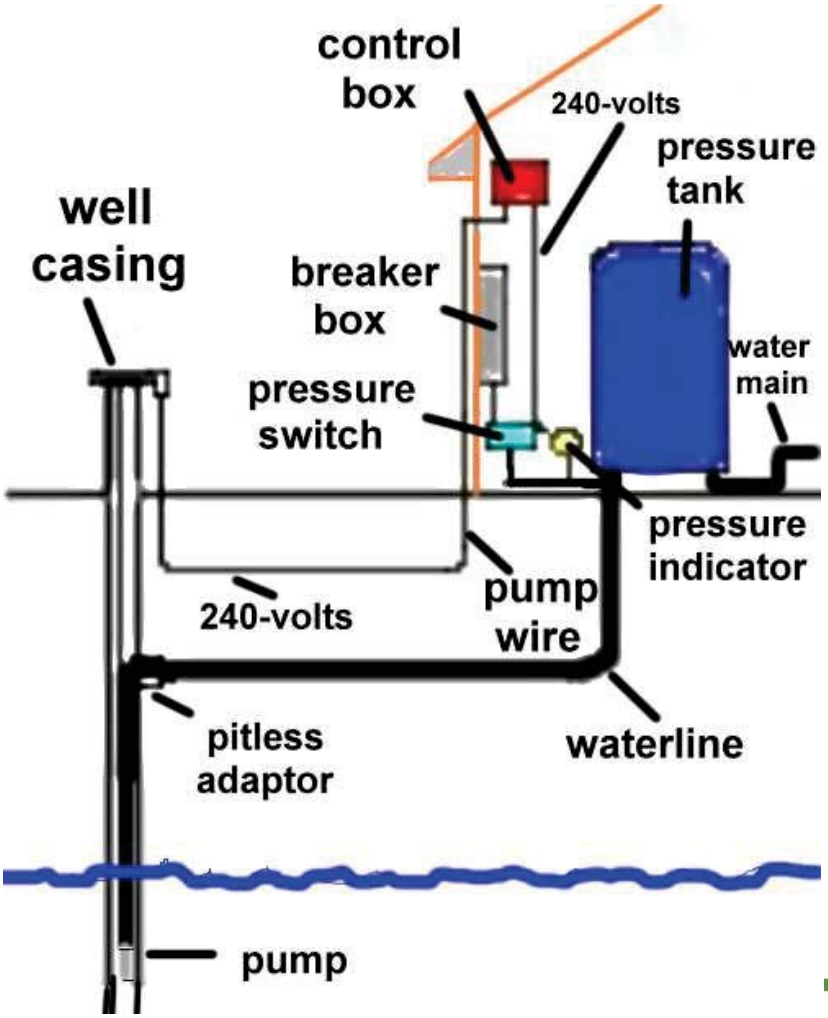
What is this for?



http://waterheatertimer.org/Two-water-heaters.html

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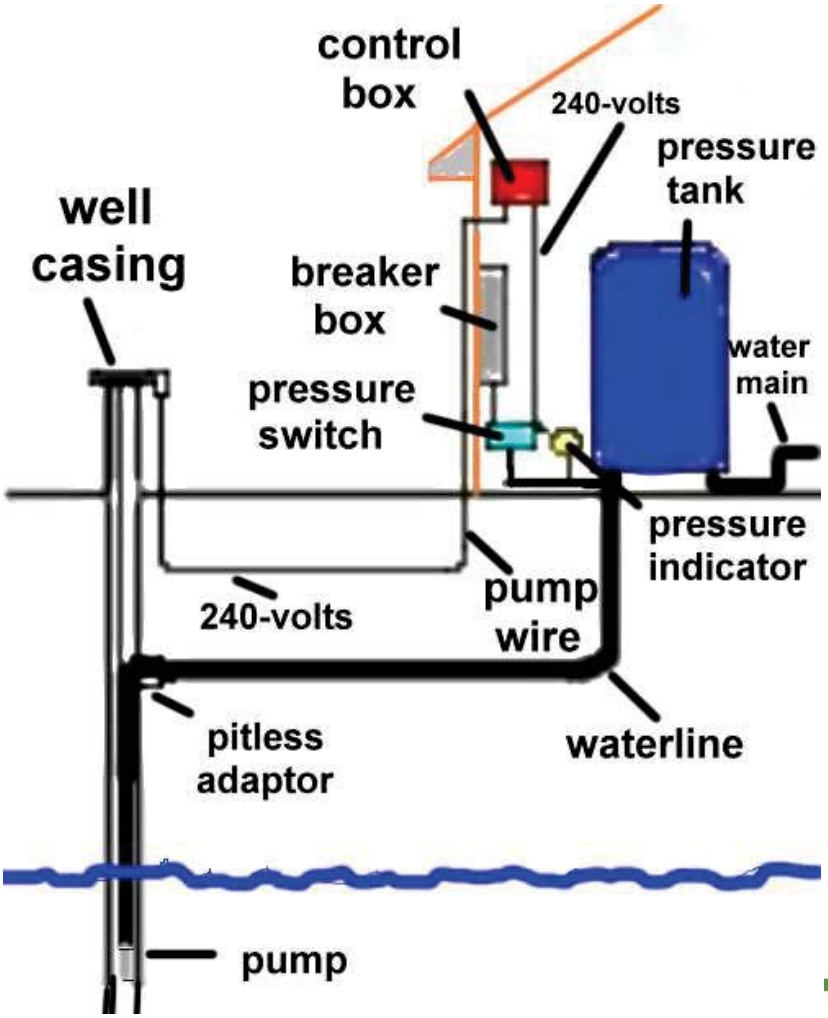
Residential "Pressure Tanks"



http://waterheatertimer.org/Two-water-heaters.html

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What are these for?”

http://www.siouxchief.com/

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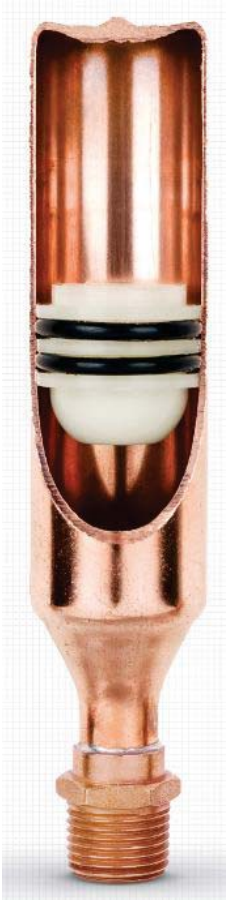
Residential “Water Hammer Arrestors” or “Surge Tanks”



http://www.siouxchief.com/

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Surge Tanks

Photos: Blacoh bladder surge tank (left) Charlatte Bladder Surge Tanks (right)

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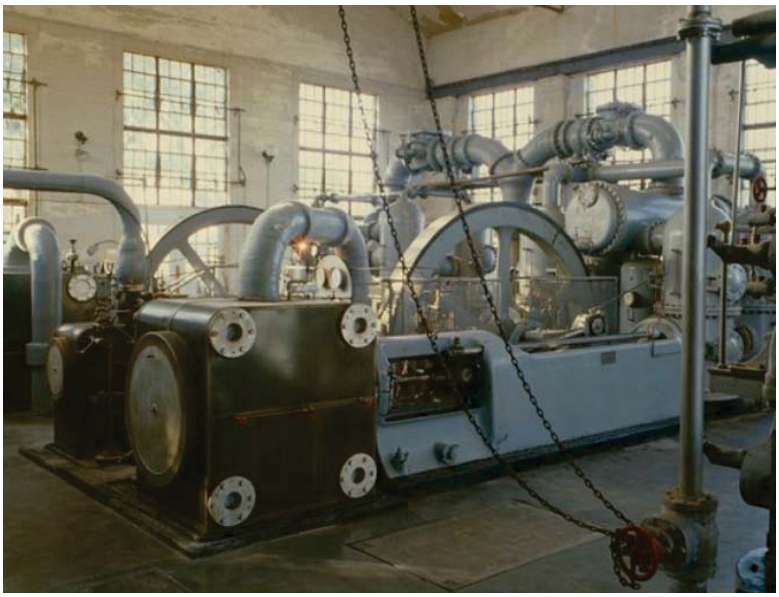
Flywheels



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Solenoid Valve

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High Efficiency Washing Machine Solenoid Valve

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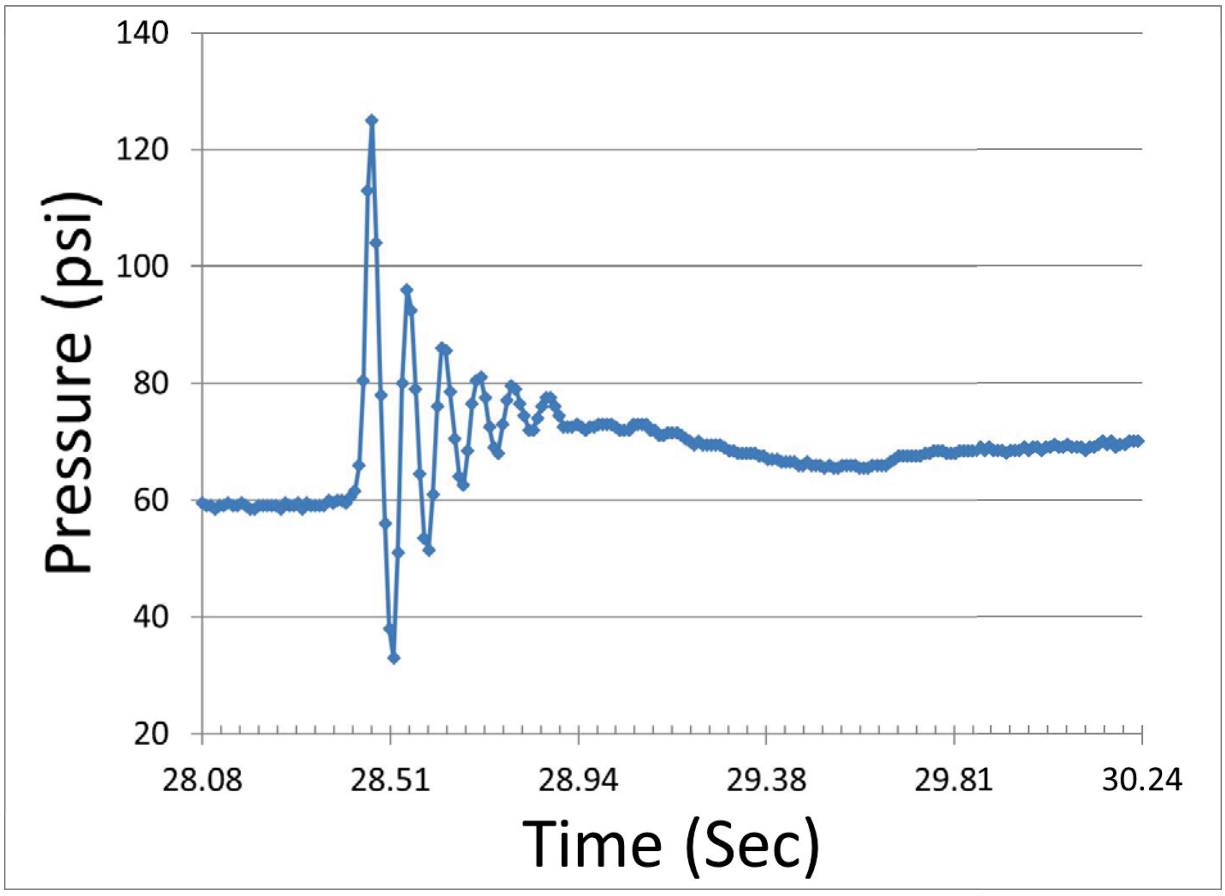
Water Hammer Arrestor



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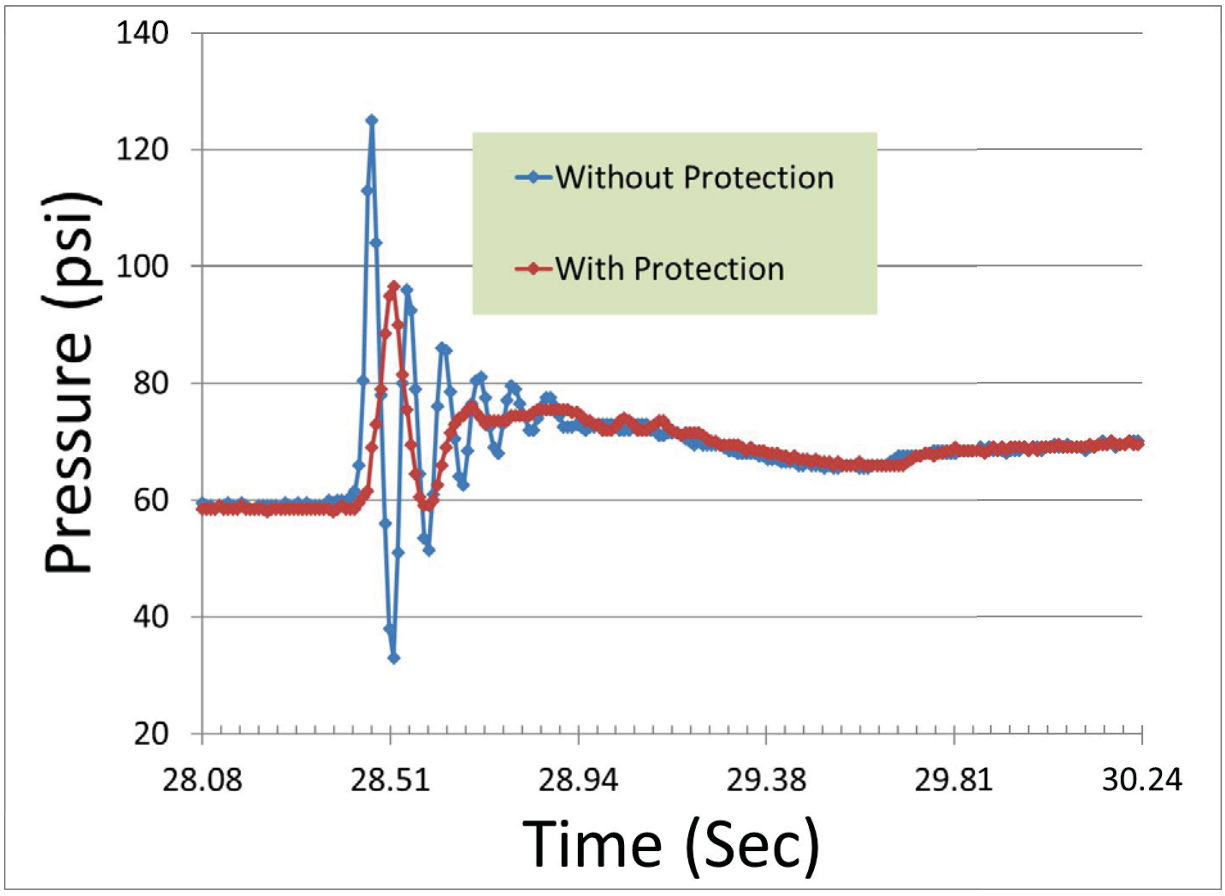
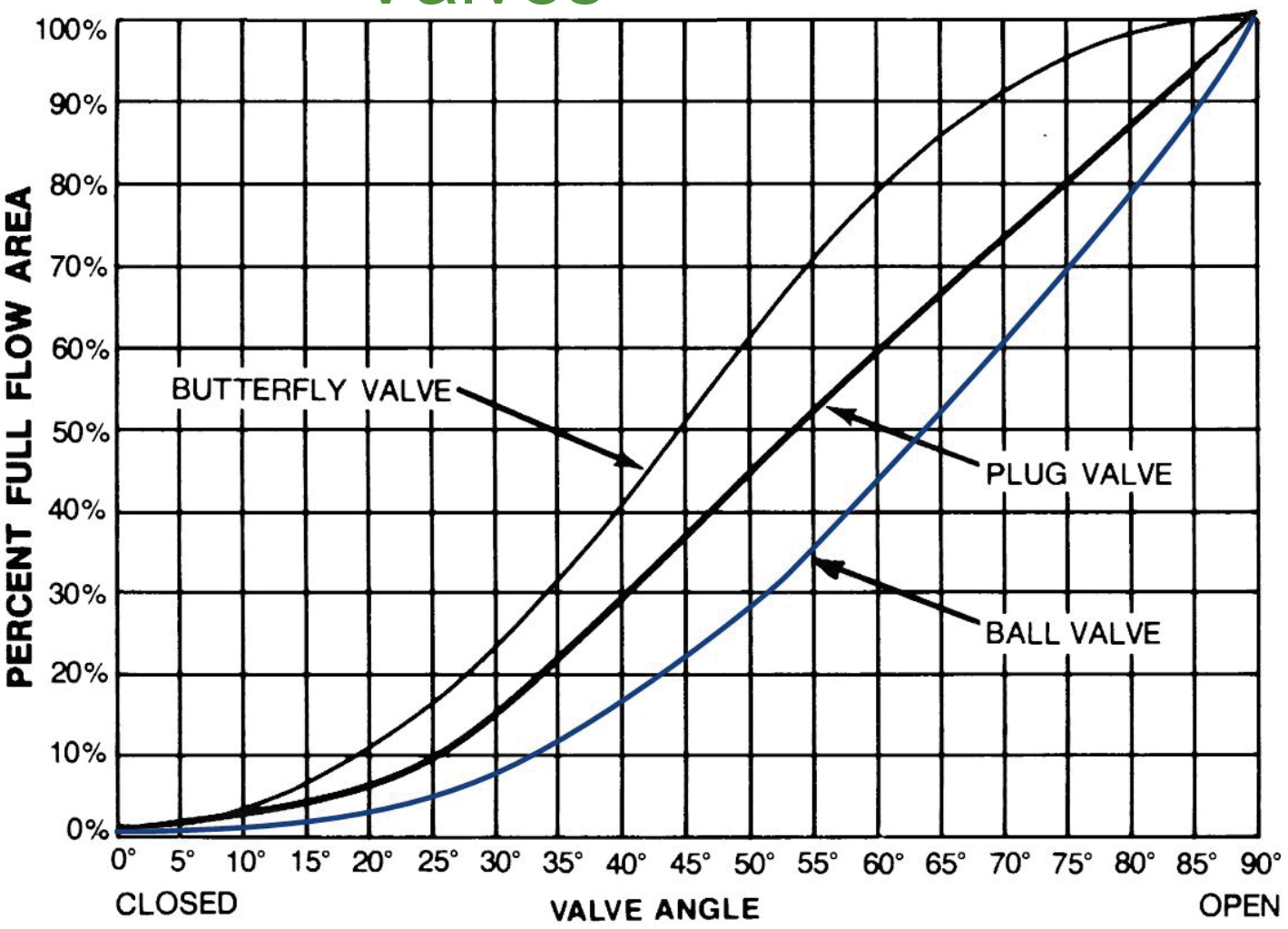
Water Hammer Arrestor



Valves



Source: PRATT AWWA Rubber Seated Ball Valve Brochure, www.henrypratt.com

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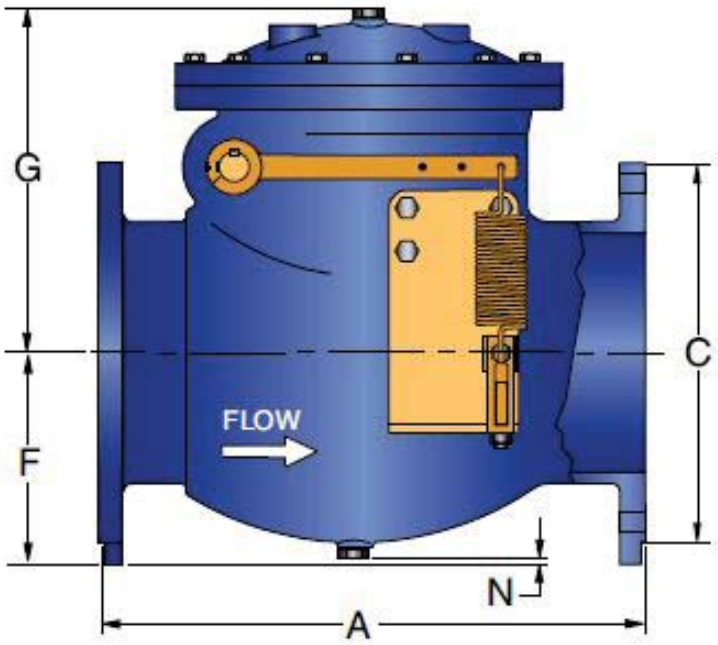
Swing Check Valves with Lever Arms

Weighted and Oil Dampened & Spring



http://www.dezurik.com/products/apco-swing-check-valves-cvs.jpg
http://www.valmatic.com/brochures/SwingCheck_7000.pdf

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Rubber Flapper Swing Check Valves

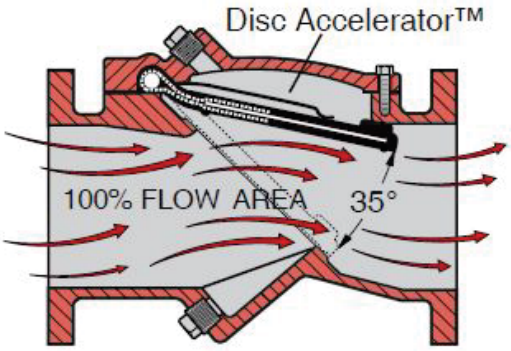

Figure 1. Val-Matic Surgebuster® Valve

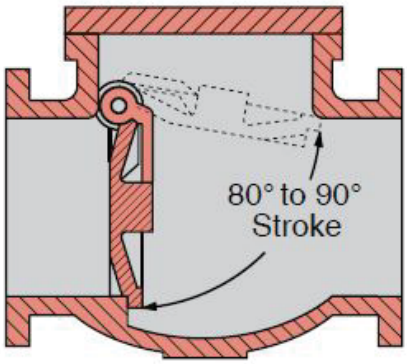

Figure 2. Conventional Swing Check Valve

http://www.valmatic.com/brochures/SurgeBuster_7200.pdf

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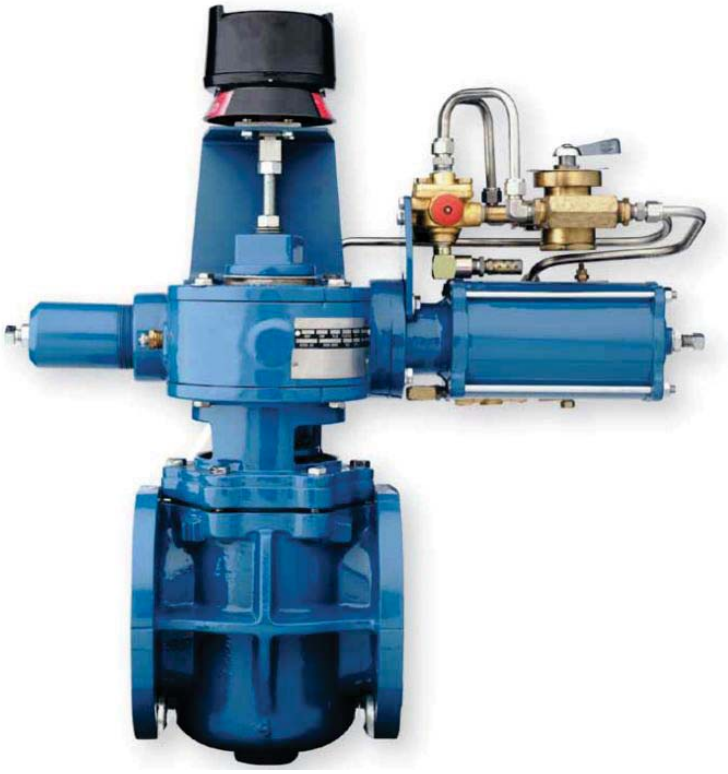
Pump Control Valves



http://www.dezurik.com

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What causes water hammer?

- Main line valve closure
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Δ Velocity

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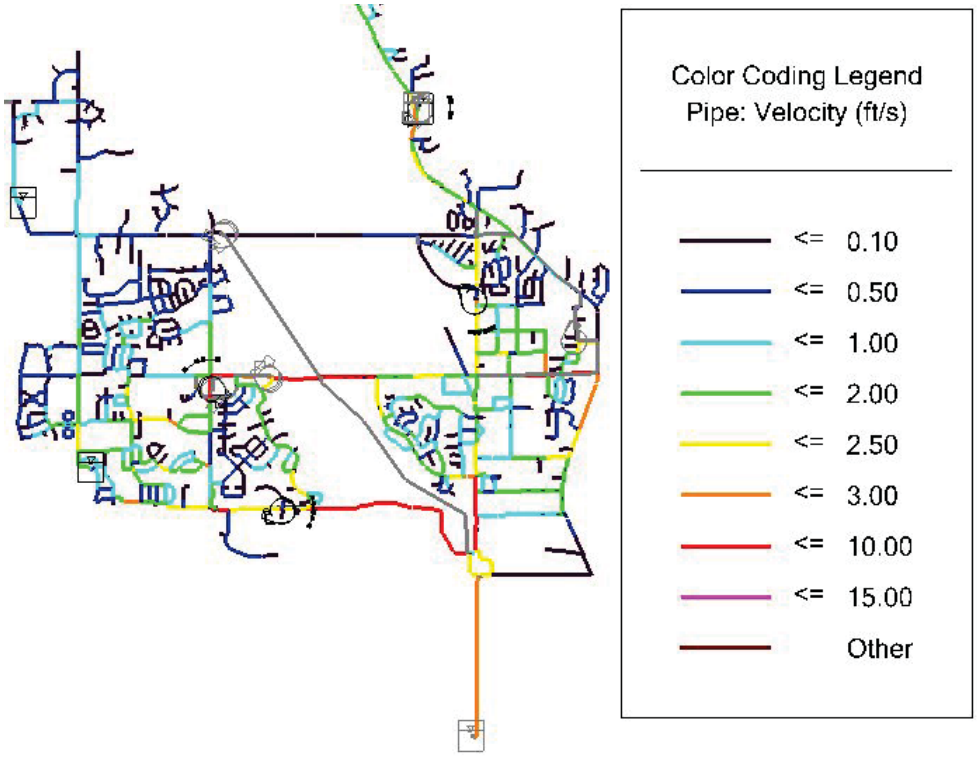
Pipe Network Velocities



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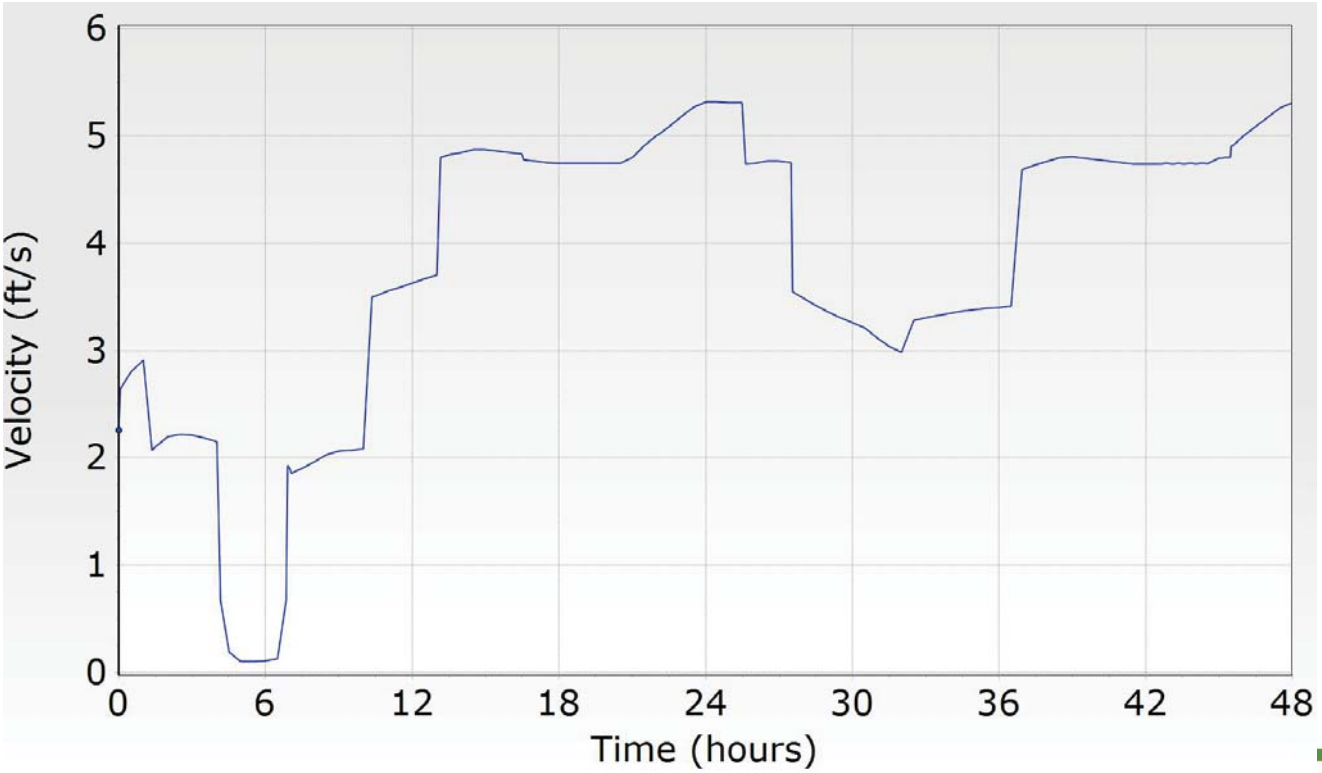
Pipe Velocity Trace



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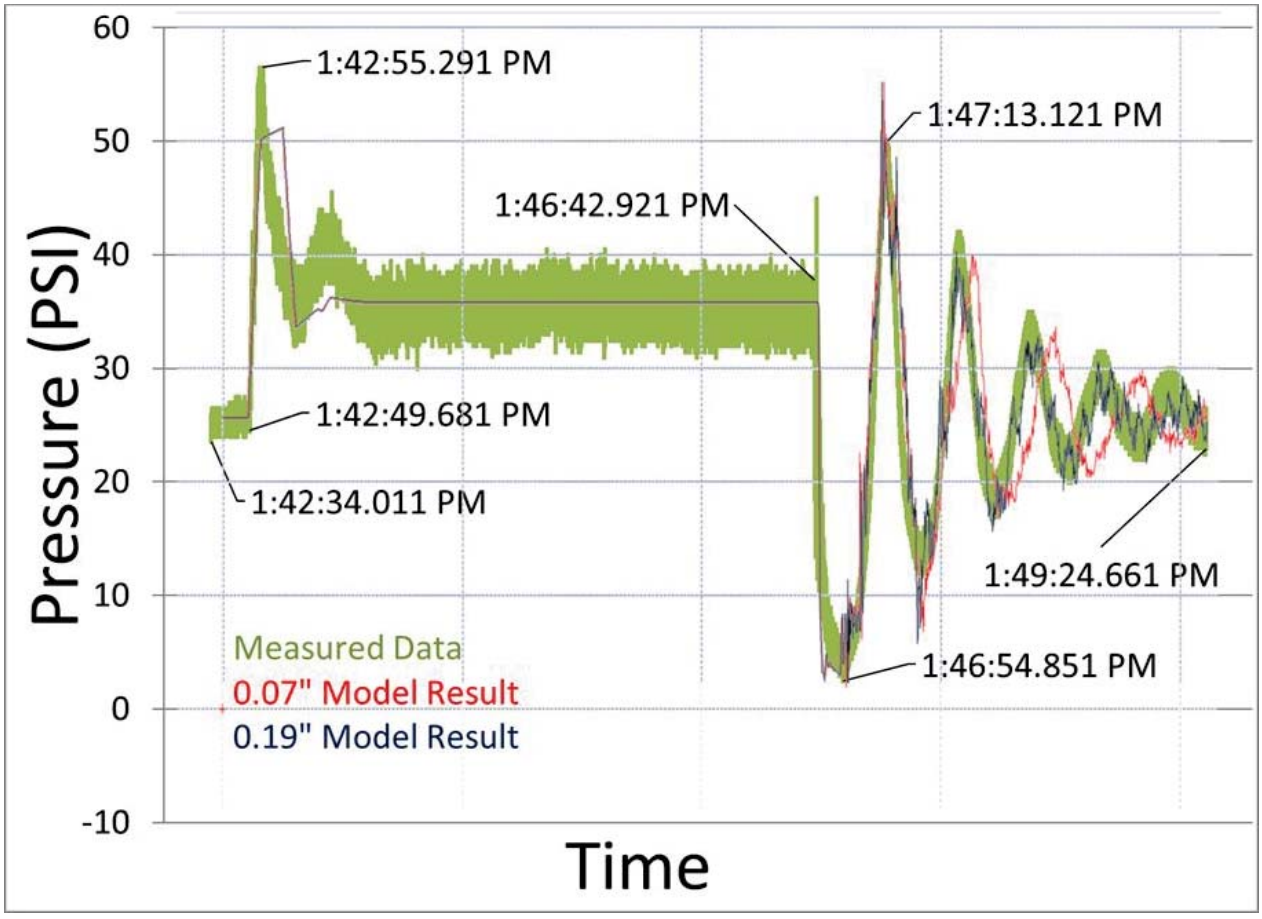
Importance of Model Calibration



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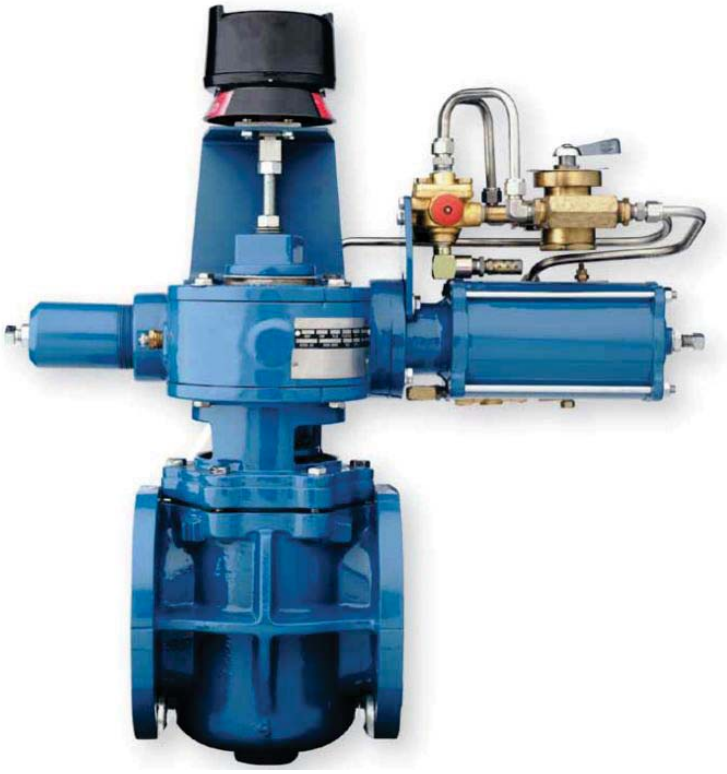
Value of Modeling



http://www.dezurik.com

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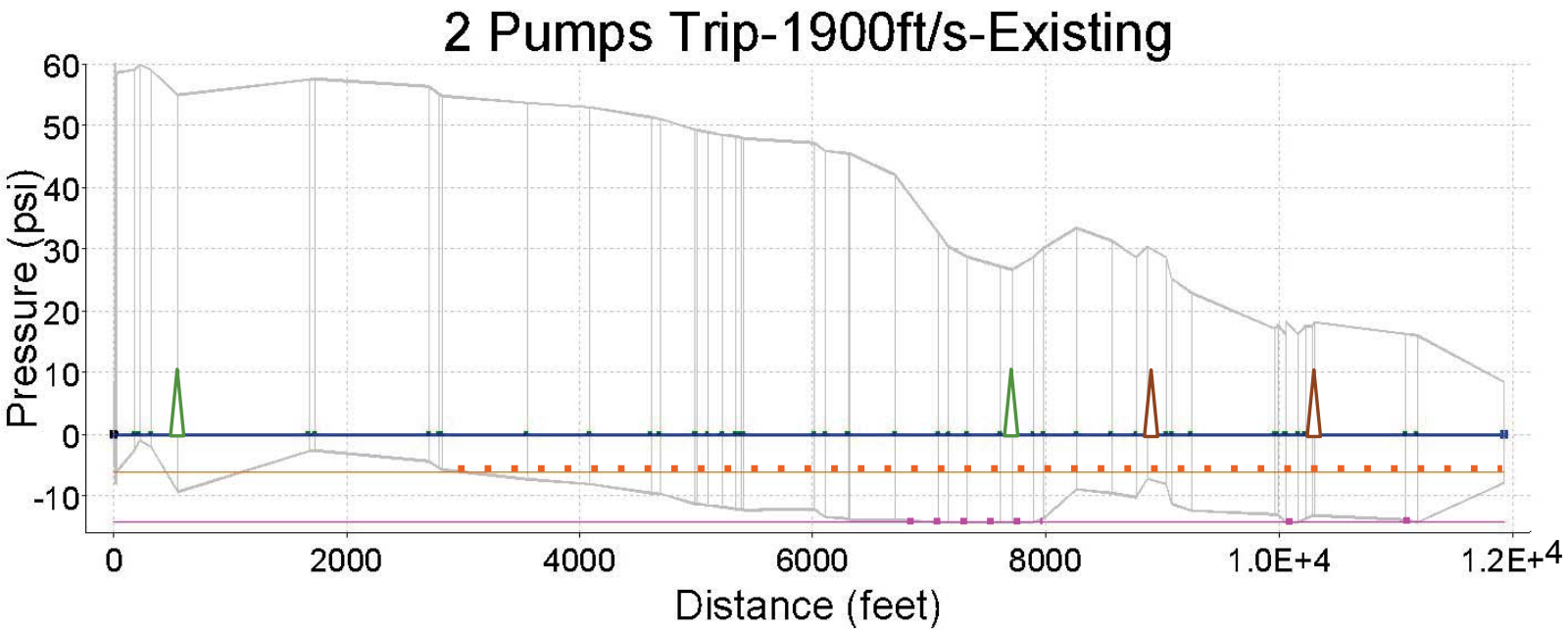
Value of Modeling



Legend: Pressure envelope Pipe -6 psi -14.7 psi

Combo Valve-active Combo Valve-inactive Combo Valve-add new

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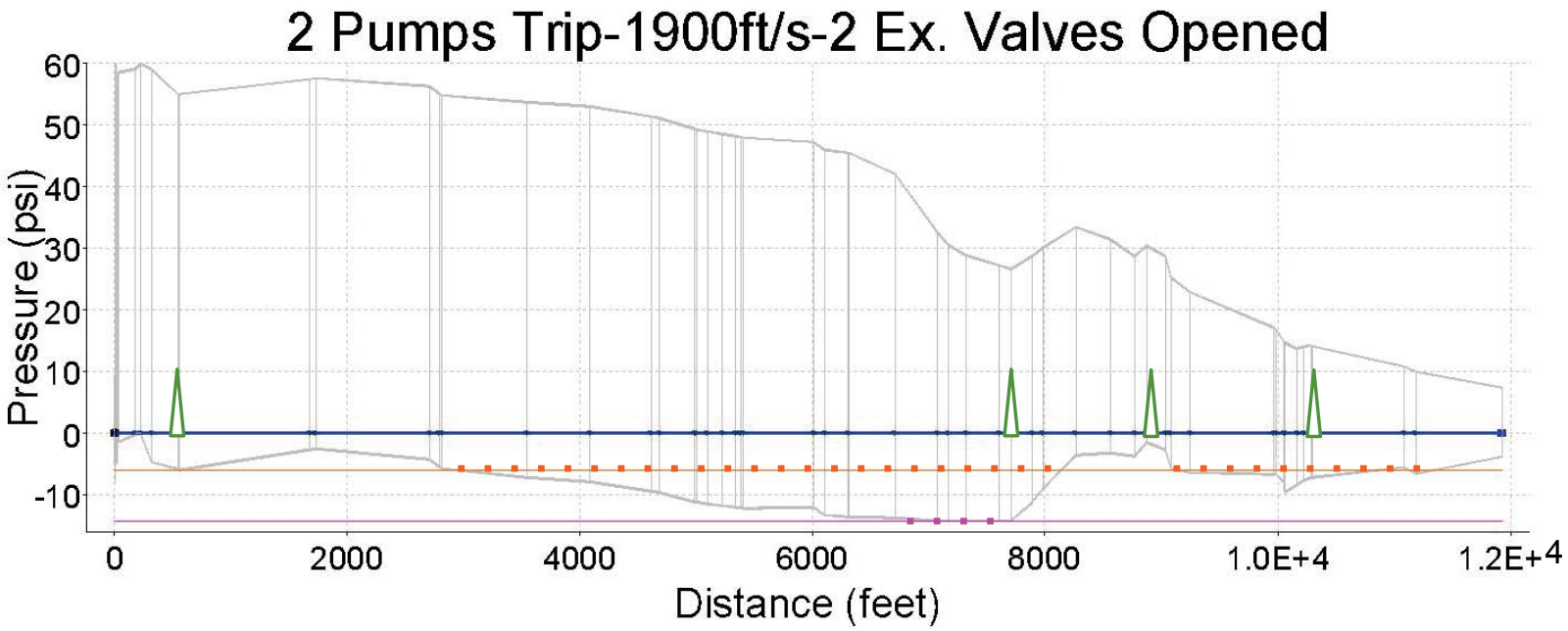
Value of Modeling



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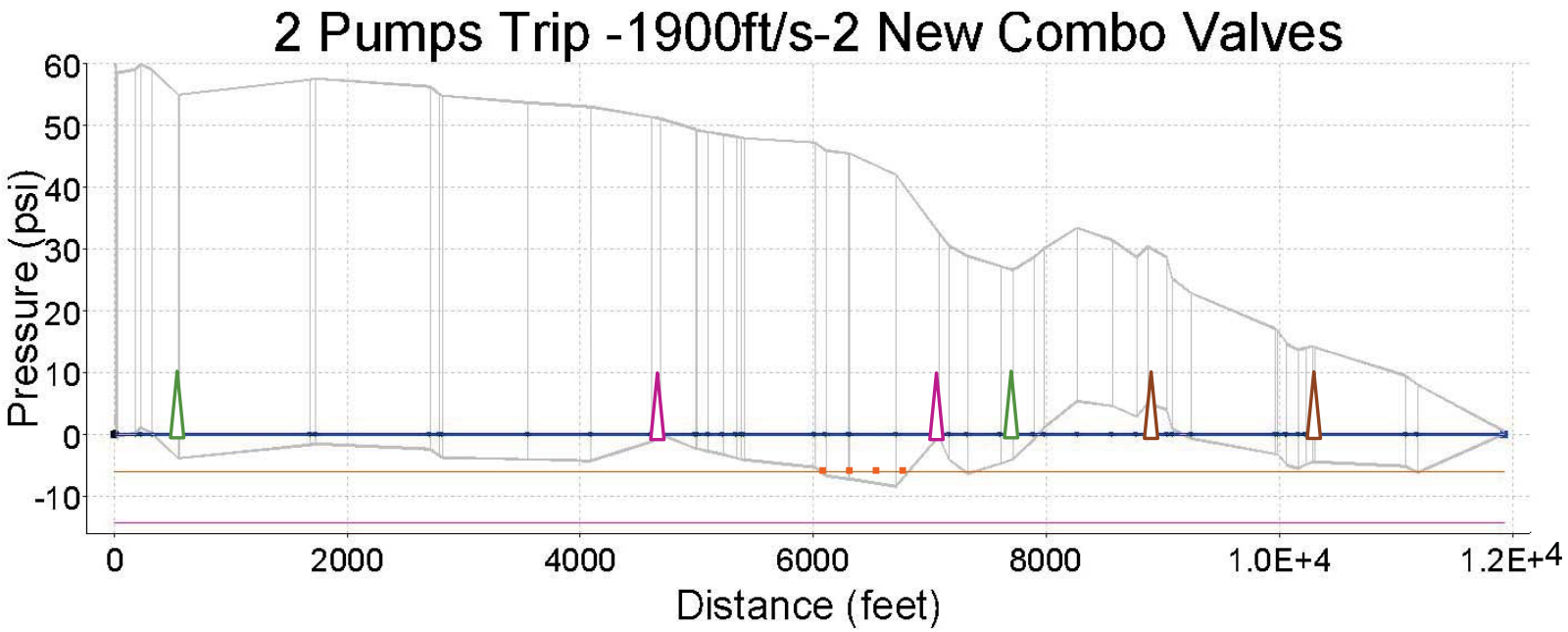
Value of Modeling



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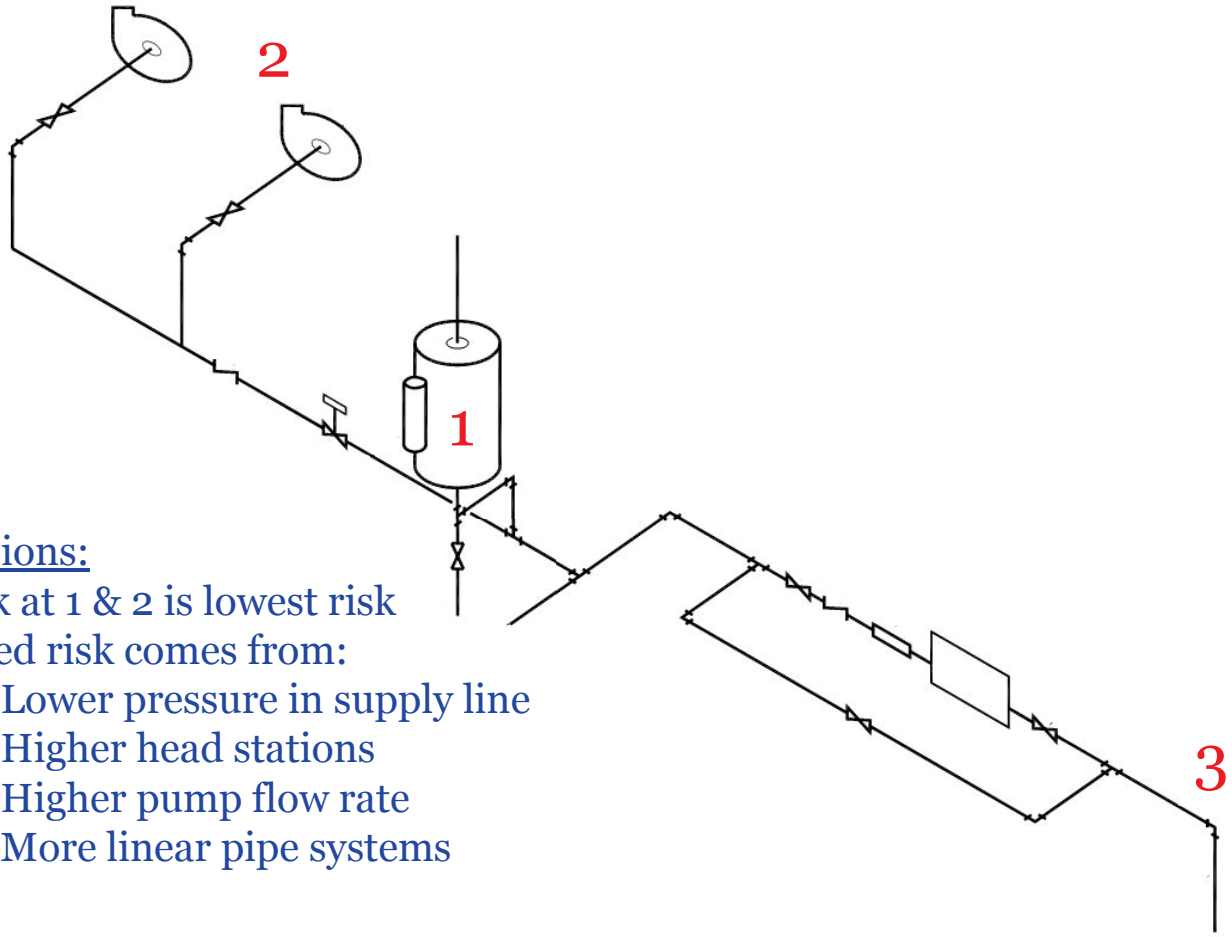

Conclusions:

1. Tank at 1 & 2 is lowest risk
2. Added risk comes from:
   - Lower pressure in supply line
   - Higher head stations
   - Higher pump flow rate
   - More linear pipe systems

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Thank You's

- Benjamin Wylie
- Jim Liou
- Gwenn Phalempin
- Jana Faith
- Frank Knowles Smith
- Jim Rasmussen
- Mike Halde
- Andrew Marsh
- Josh Scanlon
- Costa Dimitracopoulos
- Adam Salo
- Mark Stone
- Alison Sumption
- Matt Wildman
- Ashley Hammerbeck
- Jackie Strait
- Mo Brua
- Justin Conner

- Certainly others who I have pestered with questions over the years.

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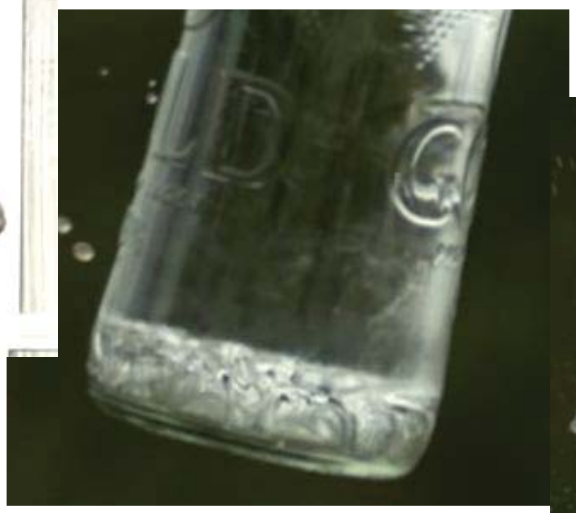
Do try this at home or later tonight!



youtube: The Slo Mo guys, water hammer beer bottle trick

Questions?

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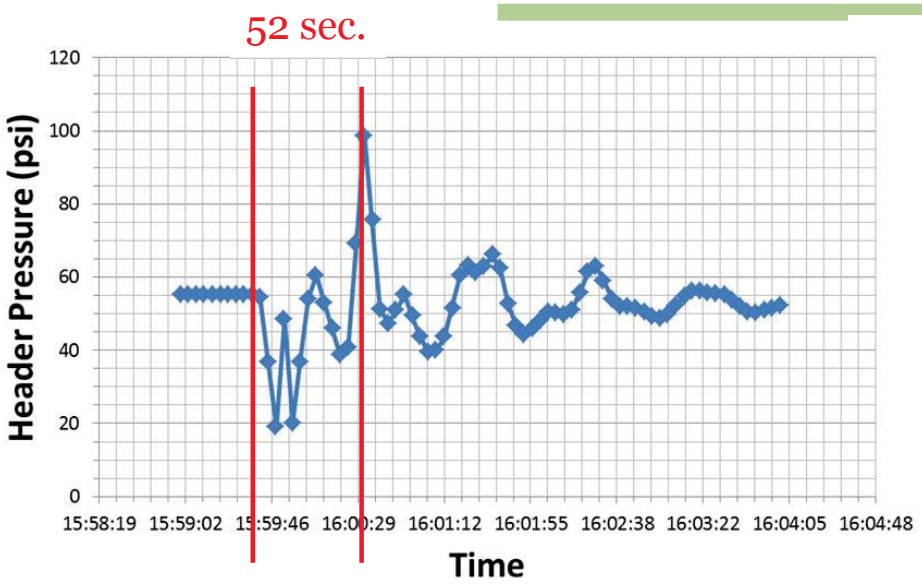
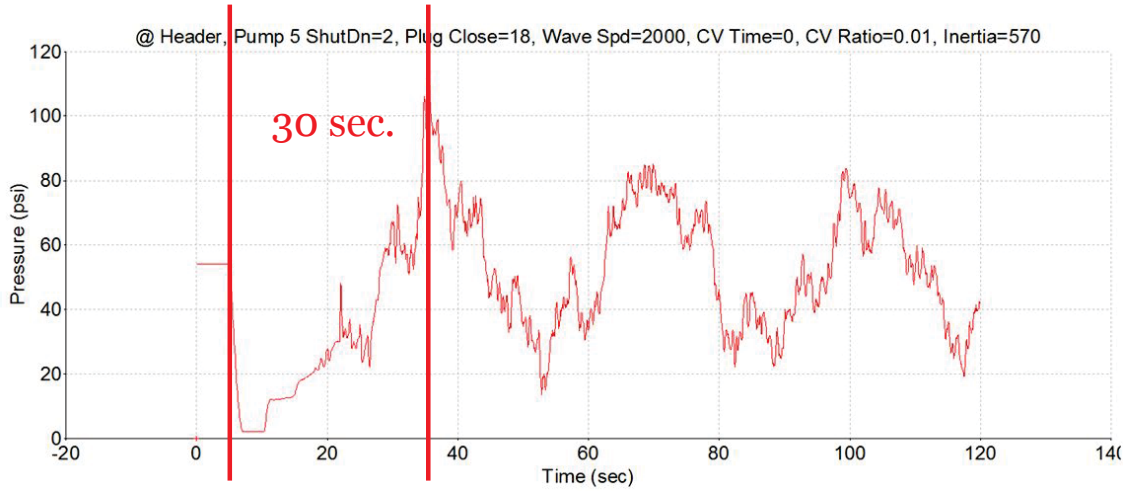
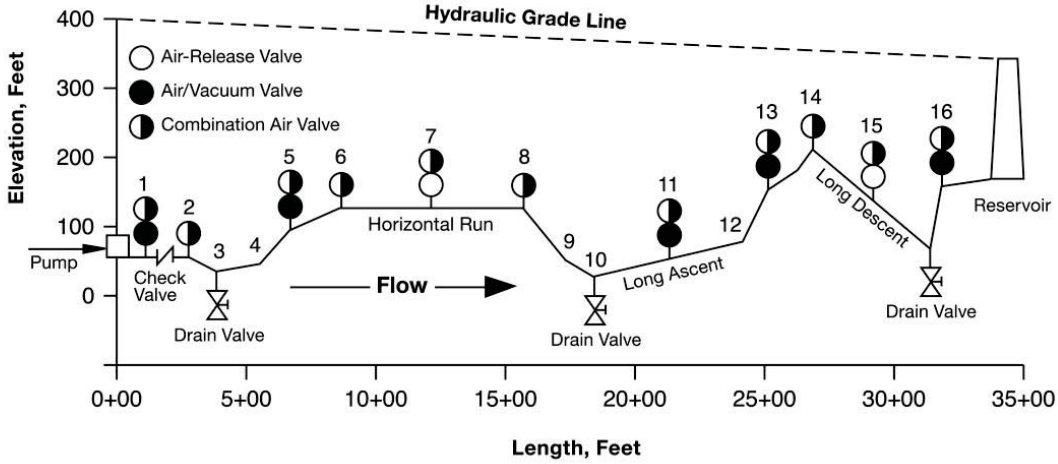
Actual Hydraulic Transient Measurement



Model Output Post Calibration



Air Release, Vacuum & Combination Valves



No.	Description	Recommended Types	No.	Description	Recommended Types
1	Pump discharge	Air/Vac or combination	9	Decrease downslope	No valve required
2	Increase downslope	Combination	10	Low point	No valve required
3	Low point	No valve required	11	Long ascent	Air/Vac or combination
4	Increase upslope	No valve required	12	Increase upslope	No valve required
5	Decrease upslope	Air/Vac or combination	13	Decrease upslope	Air/Vac or combination
6	Begin horizontal	Combination	14	High point	Combination
7	Horizontal	Air-Release or combination	15	Long descent	Air-Release or combination
8	End horizontal	Combination	16	Decrease upslope	Air/Vac or combination

AWWA M51 (2nd Edition) – Air Valves : Air-Release, Air/Vacuum & Combination

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Hydraulically Operated Check Valves

https://www.cla-val.com/81-01-681-01-check-valve-p-126.html

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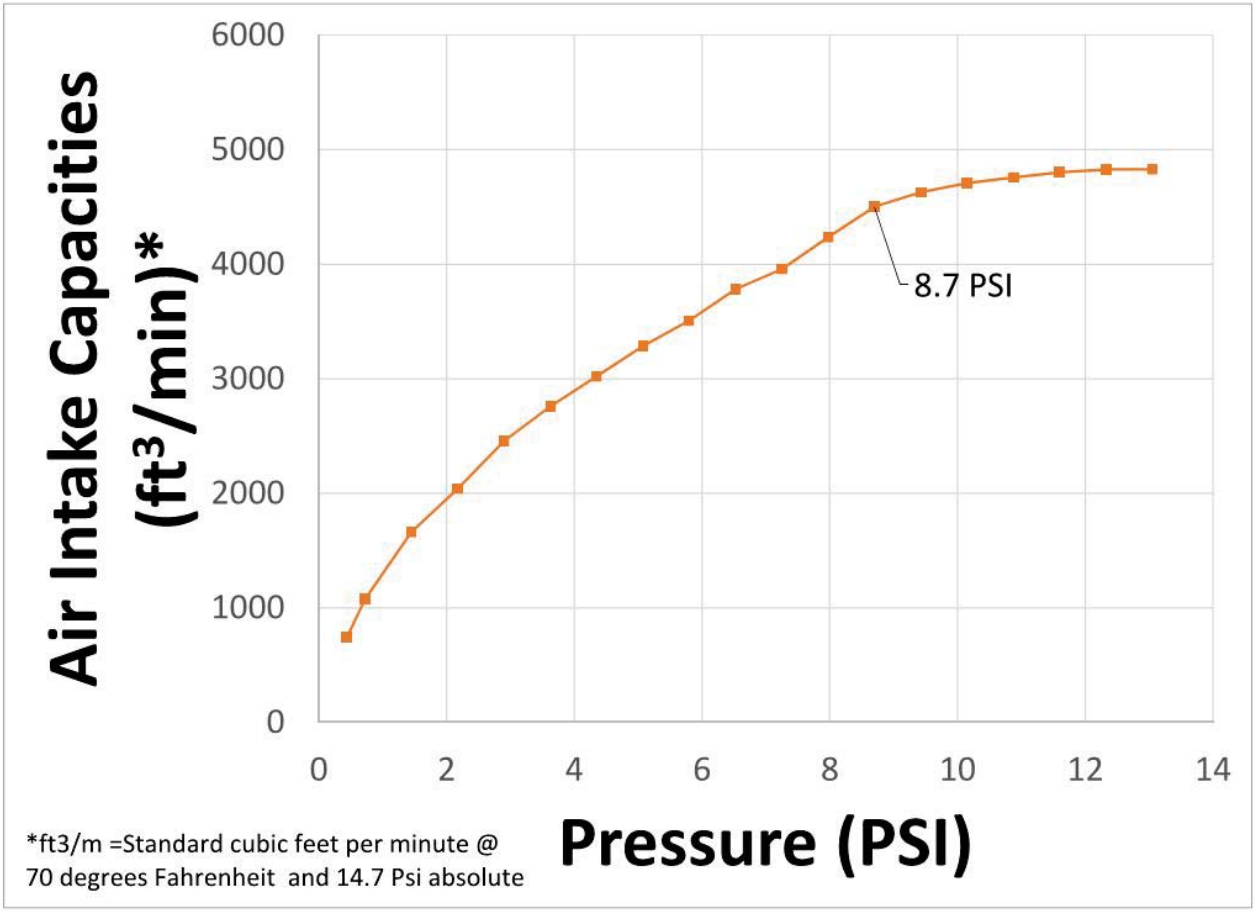
Performance Under Vacuum



www.rfvalve.com/products/rgx (Vent-O-Mat)

	TECHNICAL SPECIFICATION	Quality Assurance
CHARLATTE AMERICA HYDRAULIC VESSEL DIVISION	ARAA DIPPING TUBE VESSEL Operational Specification	SHEET 1/3

CONCEPTION OF THE ARAA VESSEL:

The ARAA is a vertical vessel, connected to the pipe work by a large connection pipe at the bottom; the top of this vessel has a compression chamber limited by the dipping tube or ventilation tube with a shut off float valve. This special Charlatte patented vessel has three different operations:

1 - Compressed air vessel as the compression chamber traps air.
2 - Standpipe when the float is open in the dipping tube.
3 - Air valve if all the water volume has been delivered to the pipe work.

As there is no bladder in the vessel, the connection pipe is completely open and there is absolutely no risk of obstruction if used in a sewage system. With this surge vessel there is absolute control of the amount of air as it is renewed at any pump stop, and therefore no need for a compressor. Obviously it is preferable to stop the pumps once a day in order to refresh the air and compensate the dissolution by performing one cycle.

WHERE OR WHEN SHOULD ONE USE AN ARAA VESSEL?

As a general rule of thumb, if the system you are dealing with has the following characteristics, it may be a good application for an ARAA type vessel:

- Very long pipe (more than 15,000 feet long).
- Very flat pipe profile (less than 50ft in elevation change).

This type of device is recommended over bladder vessels for relatively flat profiles with low geometric head.

When dealing with a flat pipe profile, there is very low static head. The energy that prevents the water column from moving in the pipe comes mostly from friction with the pipe, and there is very little resistance due to static pressure.

As a result, when the pump(s) stop, because of the small resisting force, it takes a very long time for the water column to come to a complete stop. Using a traditional compressor tank, or a bladder tank would require a very large volume in order to provide the required amount of water to fill the void left by the water column moving away from the pumps.

A correctly sized dipping tube vessel will provide the right amount of water, and the right amount of energy to prevent a sudden pressure drop due to a pump stop. Since there is no bladder, it is not a problem if the tank drains totally.

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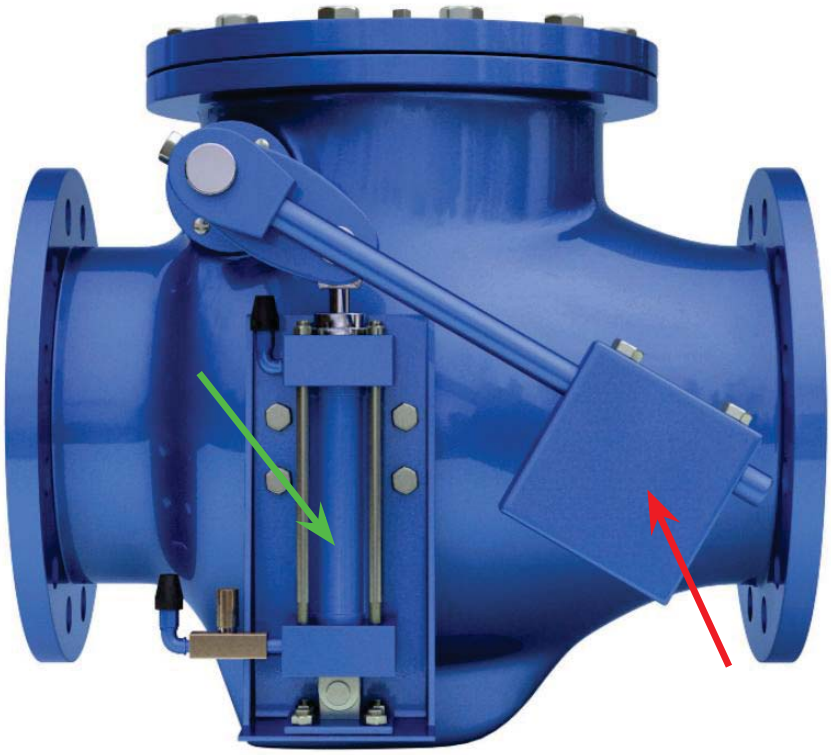
Swing Check Valves

Weighted and Oil Dampened



http://www.dezurik.com/products/apco-swing-check-valves-cvs.jpg

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Rubber Flapper Swing Check Valves

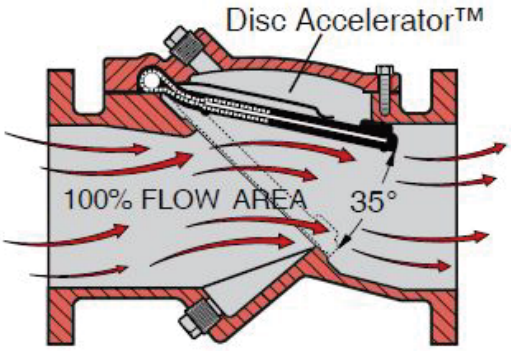


Figure 1. Val-Matic Surgebuster® Valve

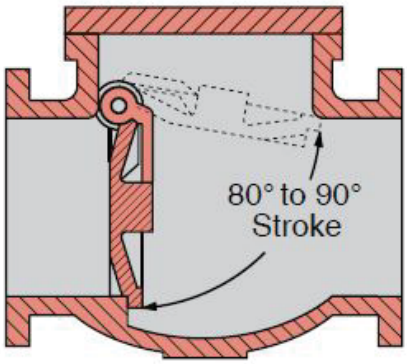
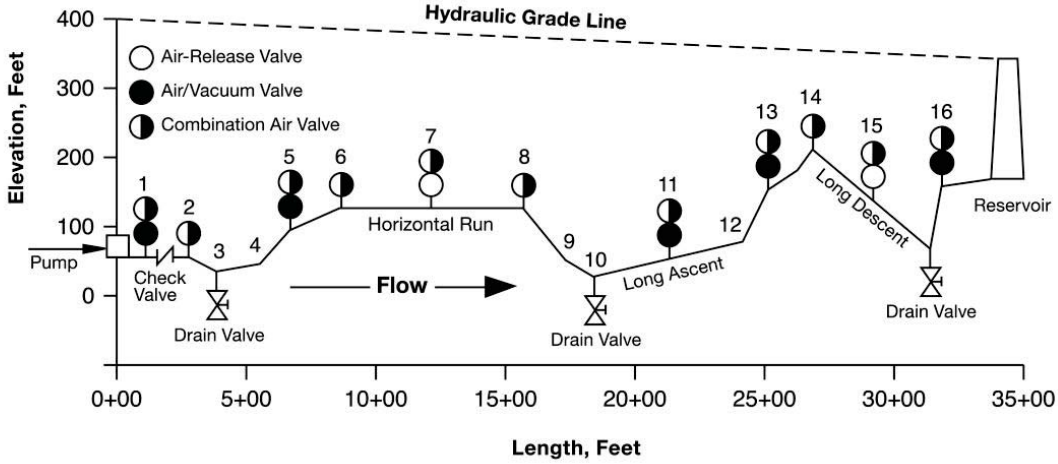


Figure 2. Conventional Swing Check Valve

http://www.valmatic.com/brochures/SurgeBuster_7200.pdf

Air Release, Vacuum & Combination Valves



No.	Description	Recommended Types	No.	Description	Recommended Types
1	Pump discharge	Air/Vac or combination	9	Decrease downslope	No valve required
2	Increase downslope	Combination	10	Low point	No valve required
3	Low point	No valve required	11	Long ascent	Air/Vac or combination
4	Increase upslope	No valve required	12	Increase upslope	No valve required
5	Decrease upslope	Air/Vac or combination	13	Decrease upslope	Air/Vac or combination
6	Begin horizontal	Combination	14	High point	Combination
7	Horizontal	Air-Release or combination	15	Long descent	Air-Release or combination
8	End horizontal	Combination	16	Decrease upslope	Air/Vac or combination

AWWA M51 (2nd Edition) – Air Valves : Air-Release, Air/Vacuum & Combination

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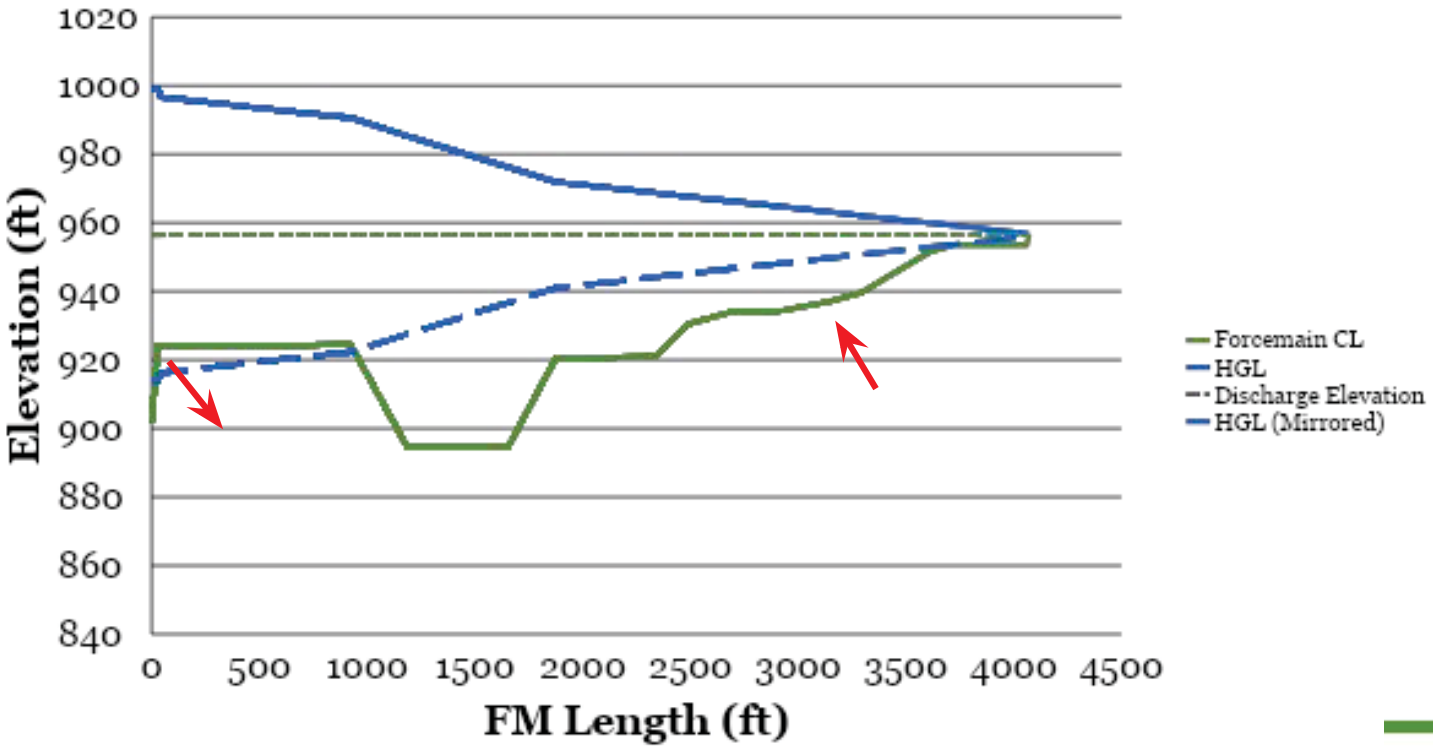
How do I know if I should be concerned?



Jones et. al., Pumping Station Design & Ashley Hammerbeck

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How do I know if I should be concerned?

- When to analyze for transient pressures (easy answer):
  - *Centrifugal pump systems with pipelines larger than 8 in and more than 1000 ft long*
- When to analyze for transient pressures (multiple triggers = more risk):
  - *TDH > 50 ft (22 psi) and Q > 500 gpm (0.7 MGD)*
  - *Flow velocities exceeding 4 ft/s*
  - *High lift pump stations with a swing check valve*
  - *Pipe line with "knees" (steep uphill then flat) or worse high points*
  - *Any pumping system that needs air venting and/or air/vacuum valves*
  - Long force mains with high dynamic head relative to static head
- Analysis may not be necessary:
  - *Flows < 100 gpm (0.14 MGD)*
  - *Flow velocities less than 2 ft/s*
  - *Distribution systems or highly branched networks*
  - *Systems with less than 30 ft (13 psi) of differential static head across pumps (unless the system is also long and/or if it has high points and knees)*

Sources:
Jones et. al., Pumping Station Design, p. 6.12-6.13
Engineering Judgement

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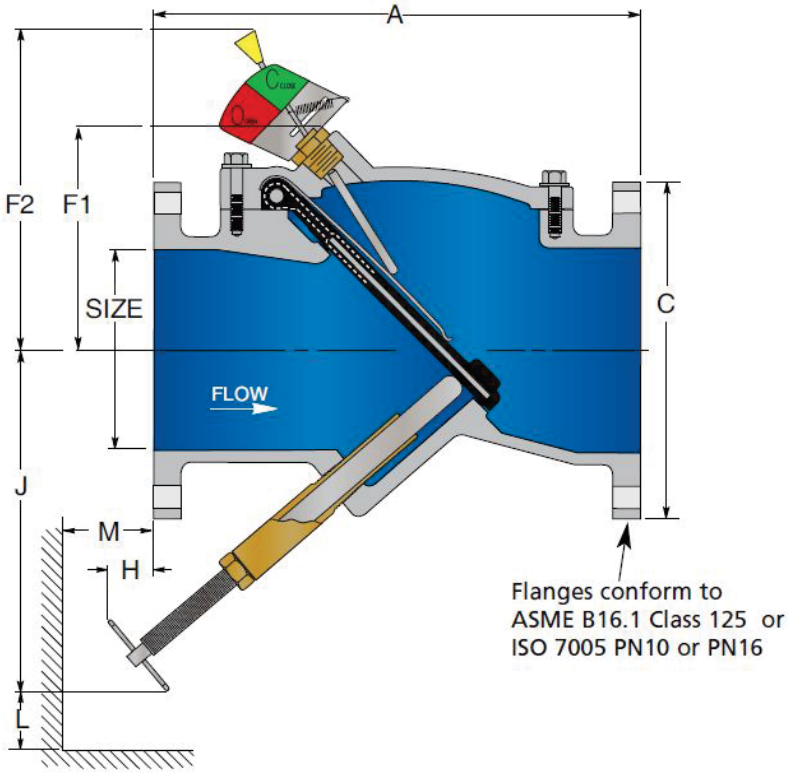
Rubber Flapper Swing Check Valves

Quick Closing / Reduces Slam



http://www.valmatic.com/brochures/SurgeBuster_7200.pdf

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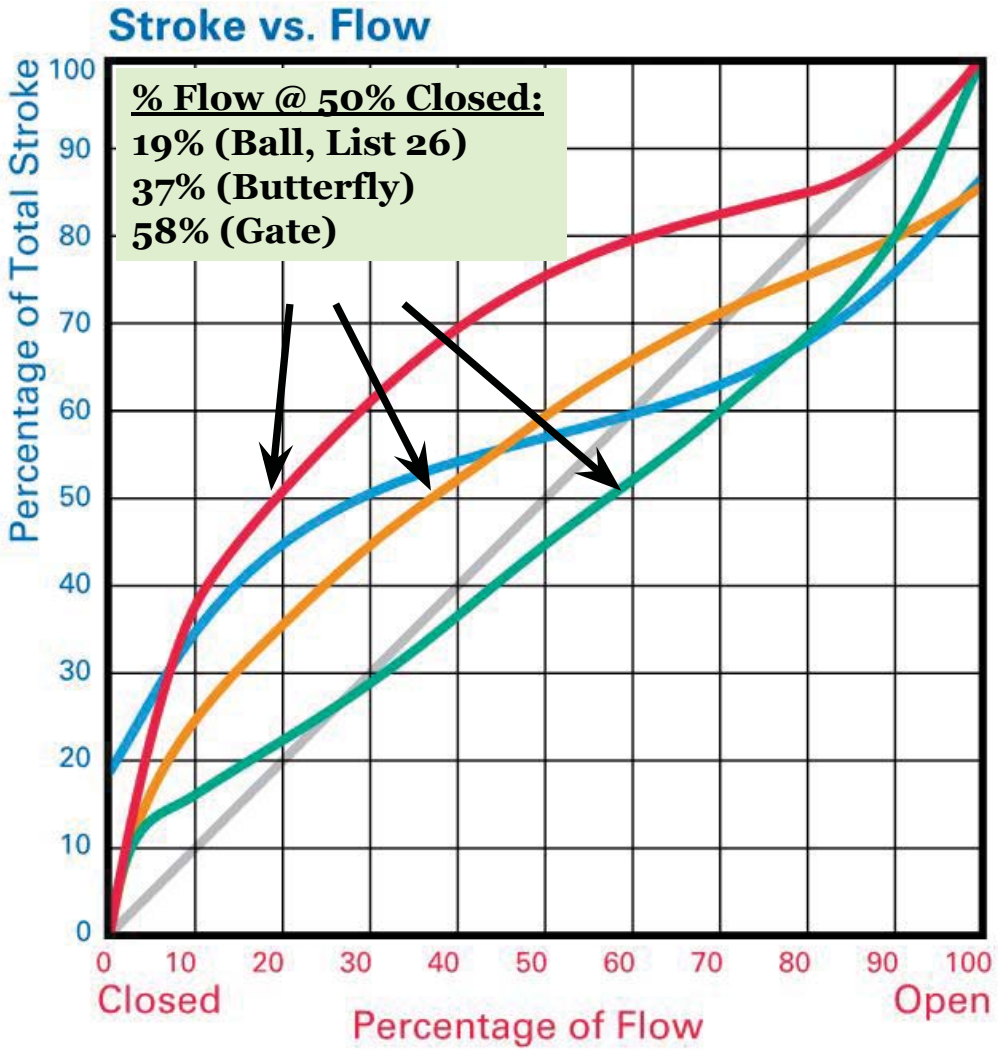

Valves

Bulletin 2200/2600
Dezurik / APCO / Willamette
www.dezurik.com

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AWWA Specifications

- AWWA C151-09 (Centrifugally Cast DIP):
  - "adequate for the rated working pressure indicated… plus a 100 psi surge allowance" (Table 7, 250 psi to 450 psi).
  - "Each pipe shall be subject to a hydrostatic test of not less than 500 psi… The pipe shall be under the full pressure for at least 5 sec… Any pipe that does not withstand the test pressure shall be rejected." (section 5.2.1).
- AWWA C110-12 (DI and Gray-Iron Fittings)
  - "fittings are adequate for the rated pressure plus a surge allowance of 100 psi or ½ of the rated pressure whichever is less [i.e., 150 psi + 150/2 psi = 225 psi (for 150 psi fittings) or 350 psi + 100 psi = 450 psi (for the 350 psi fittings)].

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AWWA Specifications

AWWA C905-10
PVC = 14" – 48"

Table 2 Pressure-test requirements

	Pressure Class		Sustained-Test Pressure		Hydrostatic-Test Pressure		Burst-Test Pressure	
DR	*psi*	*(kPa)*	*psi*	*(kPa)*	*psi*	*(kPa)*	*psi*	*(kPa)*
51	80	(550)	170	(1,180)	160	(1,110)	260	(1,800)
41	100	(690)	210	(1,450)	200	(1,380)	315	(2,180)
32.5	125	(860)	270	(1,870)	250	(1,730)	400	(2,760)
26	160	(1,100)	340	(2,350)	320	(2,210)	500	(3,450)
25	165	(1,140)	350	(2,420)	330	(2,280)	535	(3,690)
21	200	(1,380)	420	(2,900)	400	(2,760)	630	(4,350)
18	235	(1,620)	500	(3,450)	470	(3,240)	755	(5,210)
14	305	(2,100)	650	(4,490)	610	(4,210)	985	(6,800)

AWWA C900-07
PVC = 4" – 12"

Table 2 Pressure-test requirements

	Pressure Class		Sustained-Test Pressure		Burst-Test Pressure		Hydrostatic-Test Pressure	
DR	*psi*	*(kPa)*	*psi*	*(kPa)*	*psi*	*(kPa)*	*psi*	*(kPa)*
25	165	(1,140)	350	(2,420)	535	(3,690)	330	(2,280)
18	235	(1,620)	500	(3,450)	755	(5,210)	470	(3,240)
14	305	(2,100)	650	(4,490)	985	(6,800)	610	(4,210)