Things that Go Bump in the Pipe

Causes and Consequences of Hydraulic Transients (Water Hammer)

WEST YOST ASSOCIATES

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WATER WASTEWATER STORMWATER

Presentation Overview

- What Is A Hydraulic Transient
- Some Transient Basics
- Mitigation Techniques
- Analysis Tools
- Putting It Together

Presentation Overview

What Is A Hydraulic Transient

Some Transient Basics

Mitigation Techniques

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Putting It Together

Hydraulic Transient is…

…An increase or decrease in pressure associated with a rapid velocity change

- Fast Event: Wave propagates at the speed of sound – typically 3,000 to 3,500 feet/second in system with metal pipes
- Large Change: Transient pressure changes can be very large compared with normal operating pressures

Hydraulic Transients Occur Any Time Velocity Changes Occur

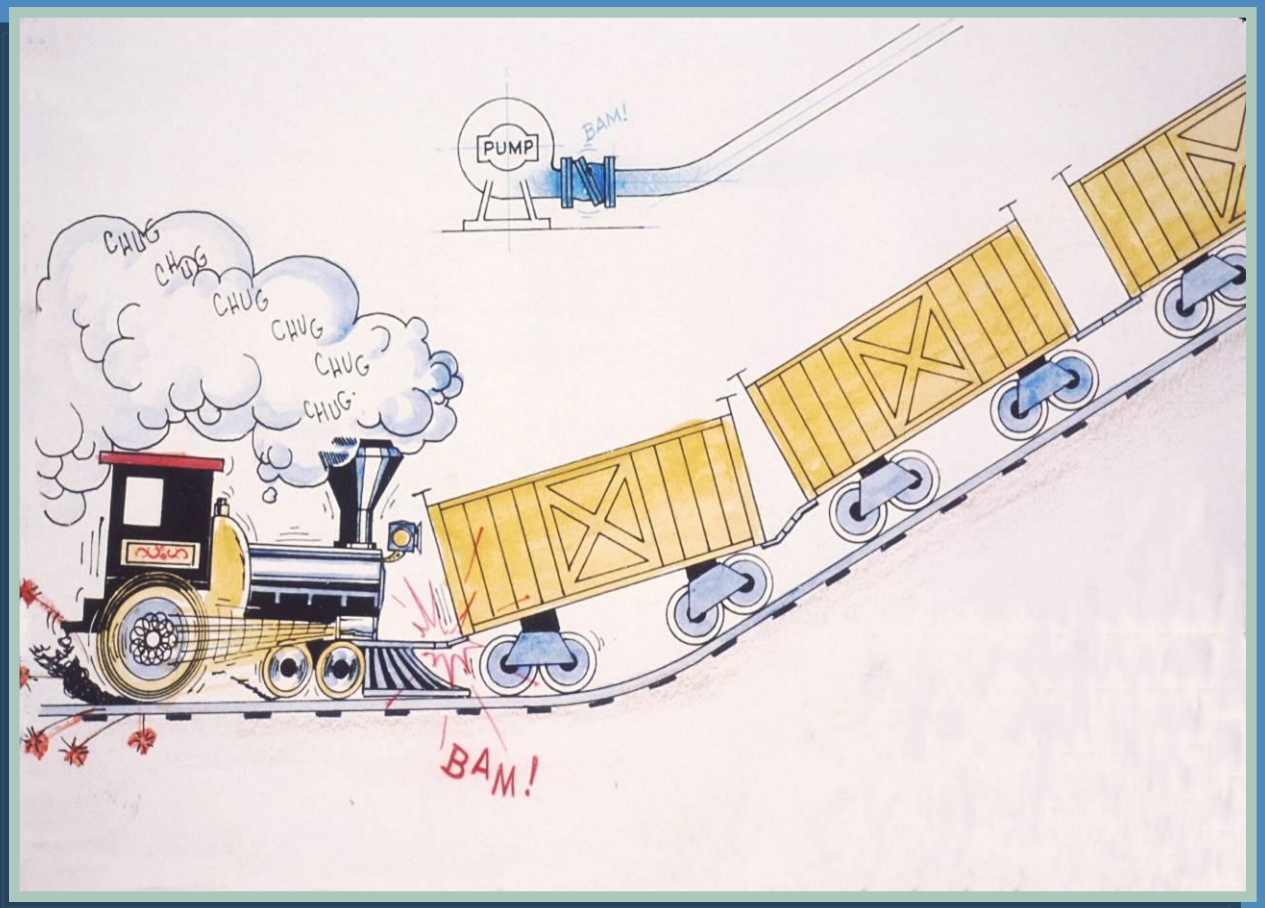
Normal System Operations

- Valve Closure or Opening
- Check Valve Operation
- Pump Normal Startup or Shutdown
- Hydrant Opening or Closing

Unexpected System Operations

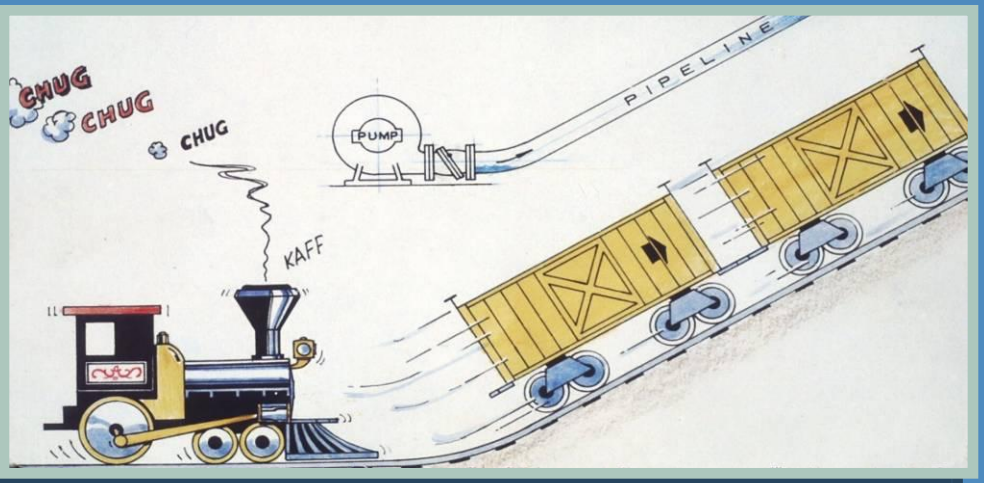
- Pump Station Power Failure
- Main Breaks

Pump Start-up Conditions



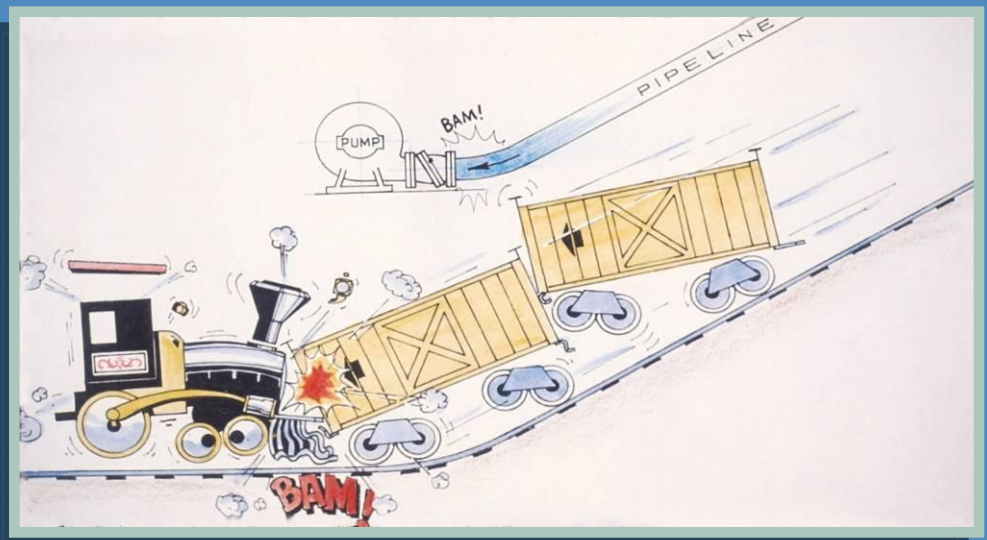
Shock pressure rise occurs when pumping operation begins abruptly and fluid is supplied to a static column

Pump Shut-down Conditions

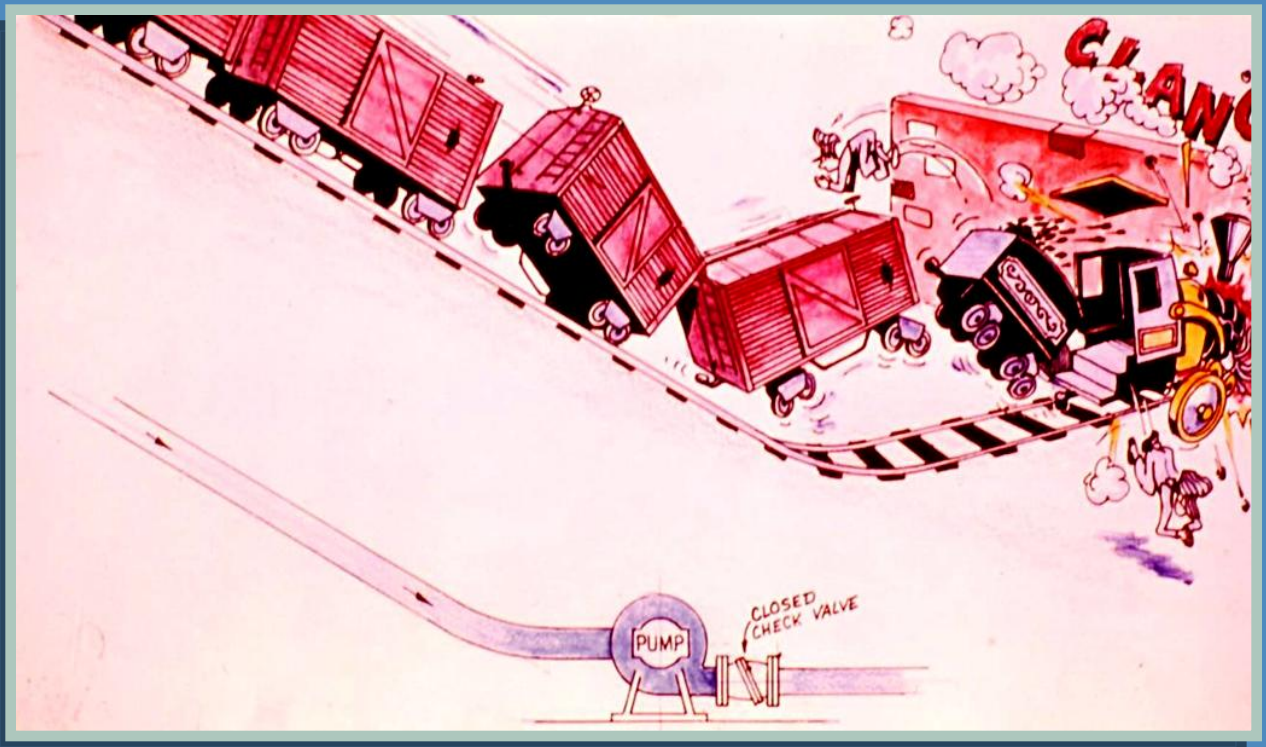


Too rapid pump shut down results in column separation and low pressure

Water column returns and shock pressure rise occurs

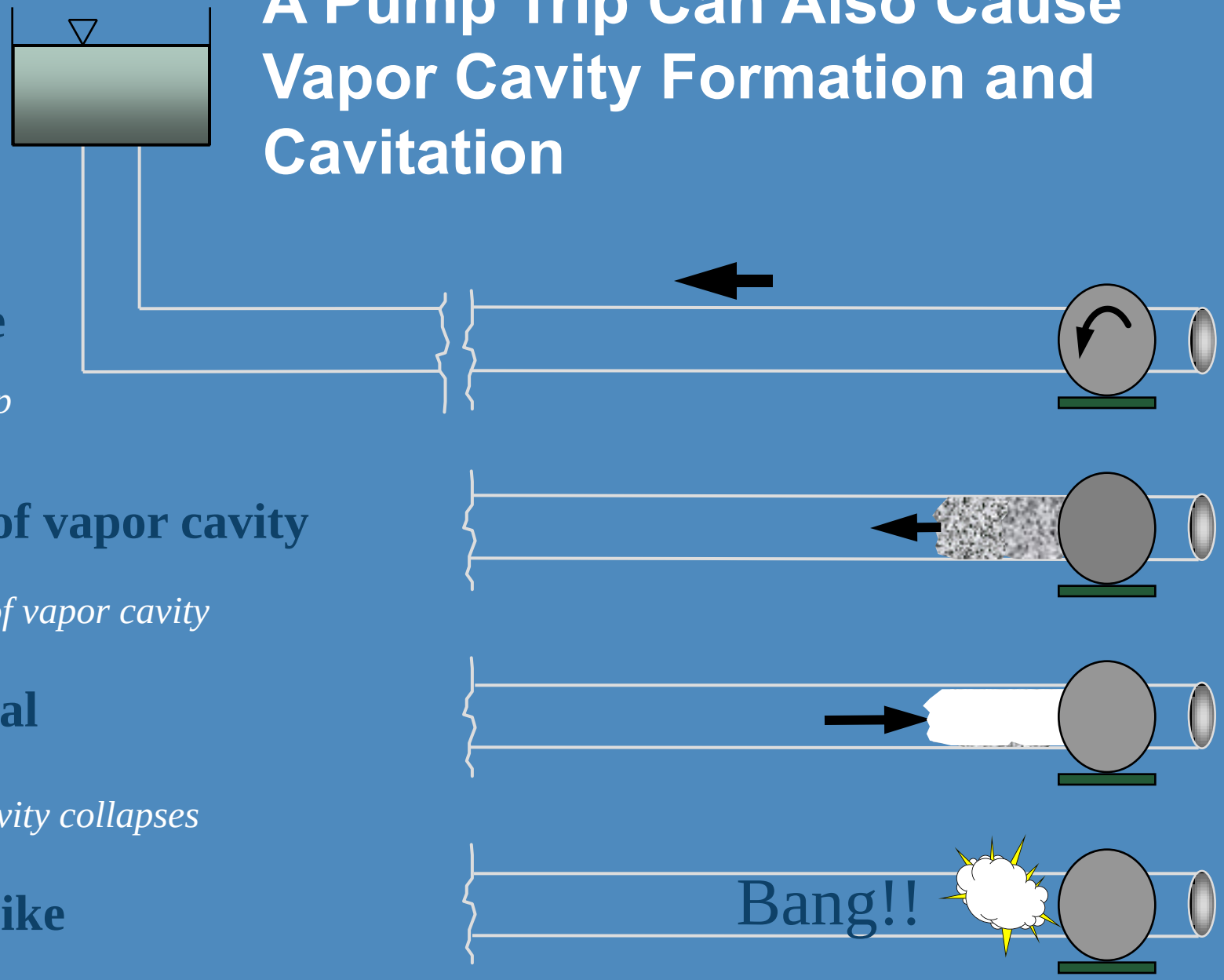


Valve Closure Conditions



Shock pressures occur following abrupt stoppage of water column at closed valve

A Pump Trip Can Also Cause Vapor Cavity Formation and Cavitation



Steady state

Pump trip

Formation of vapor cavity

Growth of vapor cavity

Flow reversal

Vapor cavity collapses

Pressure Spike

Potential Consequences If High Pressures Not Mitigated

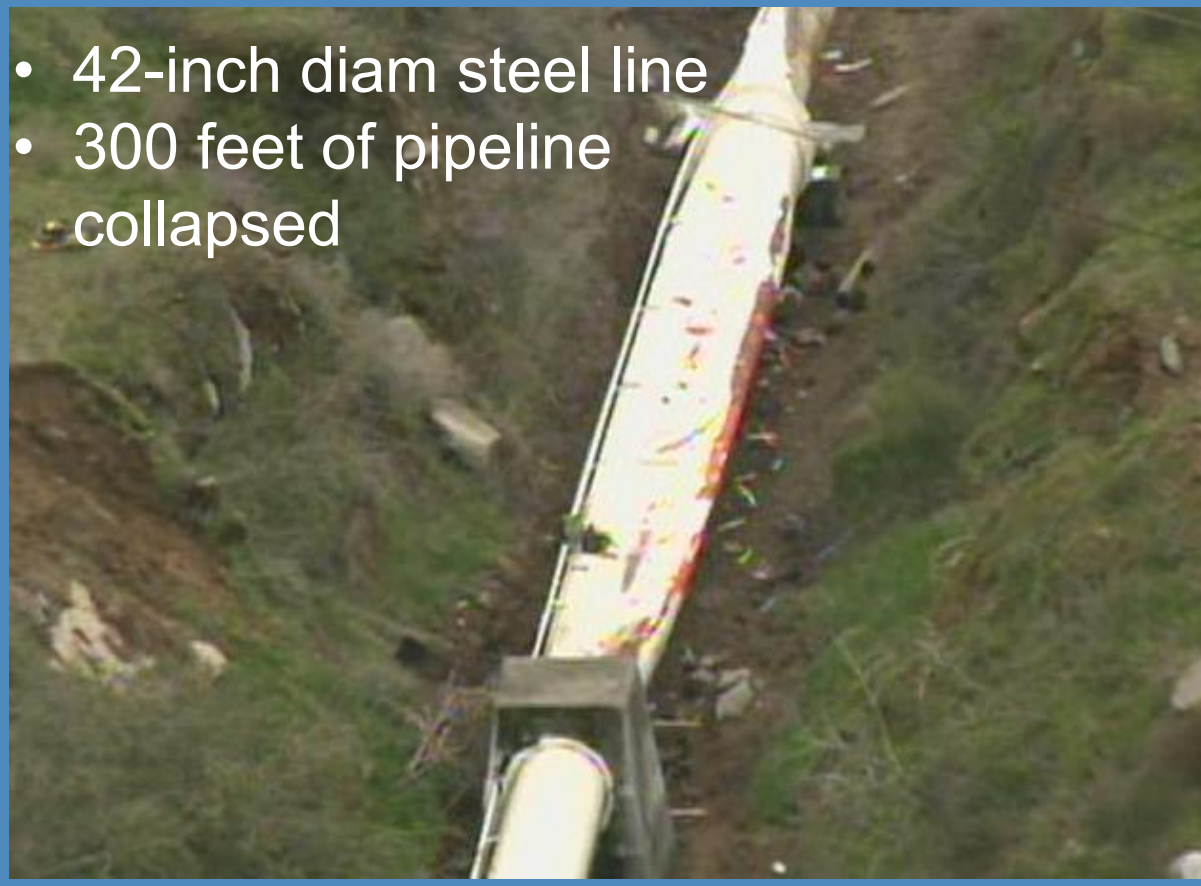
- Main breaks or leaks
- Damage to
  - Pumps or motors
  - Fittings
  - Customer piping or equipment

Potential Consequences If Low Pressures Not Mitigated

Folsom WTP Raw Water Line

Pipeline Collapse During Contractor Dewatering Operations

Vacuum Conditions When Vacuum Relief Valve Didn't Operate



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What Is A Hydraulic Transient

Some Transient Basics

Mitigation Techniques

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Putting It Together

Some Transient Basics

- The Basic Physics
- Theoretical Pressure Rise or Drop
- System Period
- Rapid Event

The Basic Physics

- When a rapid flow change occurs, the resulting change in momentum is manifested as a pressure change
- The pressure change propagates through the system at the speed of sound
- Pressure changes can be quite large

Potential Head Rise or Drop

Joukowsky head change:

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

Where,

ΔH = head rise or drop

c = wave propagation speed (typically 3,000 to 3,500 ft/second in metal pipe)

g = gravitational acceleration

ΔV = change in velocity

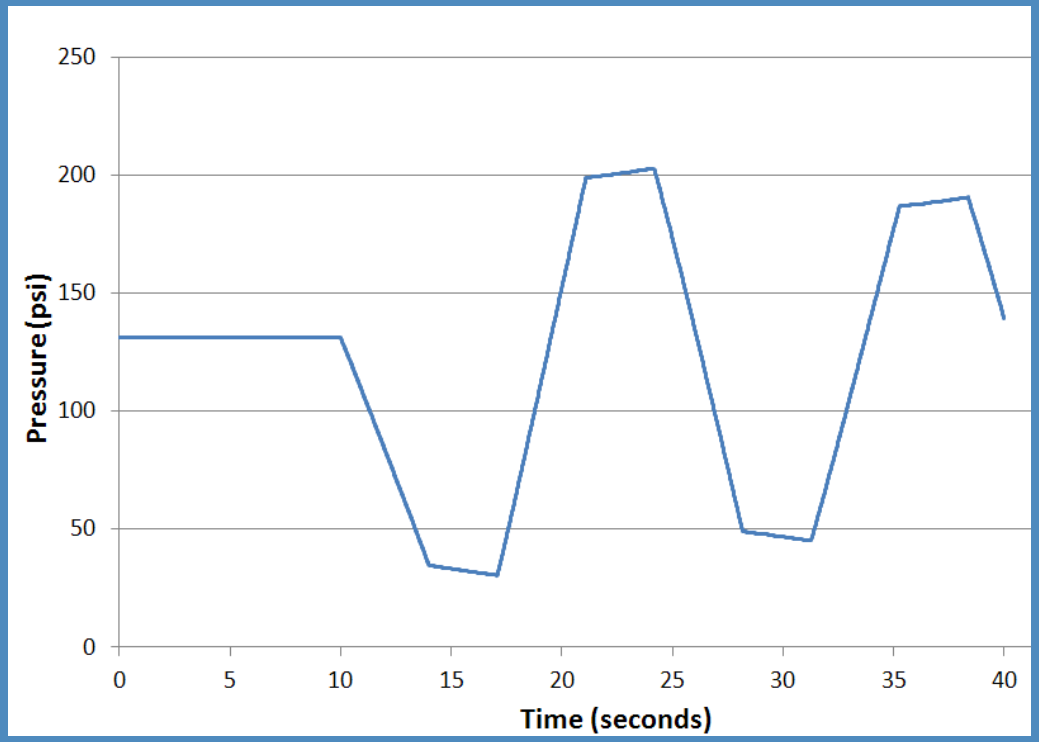
Example: Potential Head Rise or Drop

- c/g ~ 100
- Initial velocity is 4 feet/second
- Final velocity is zero

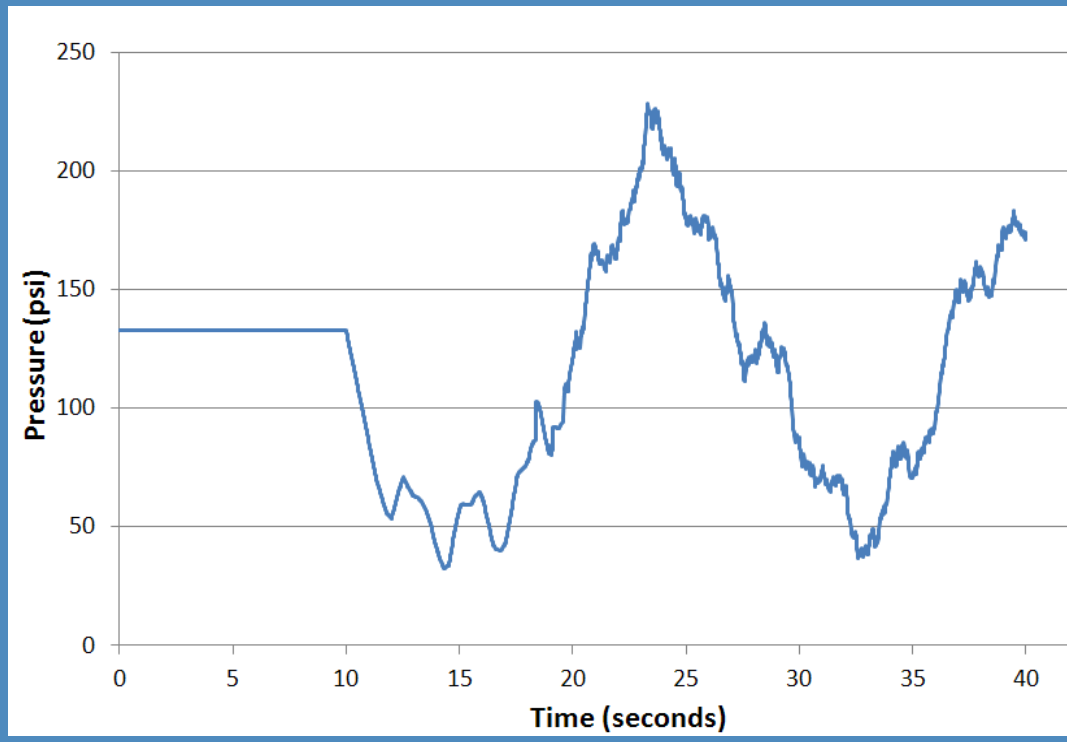
100 feet x 4 feet/second = 400 feet or 170 psi

System Discontinuities Cause Pressure Wave Reflections

Single Pipeline

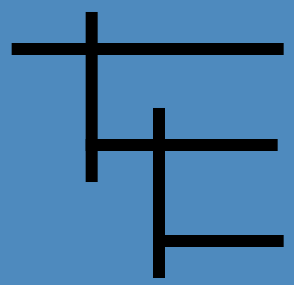


Same Pipeline – 4 branches



The System Period Defines whether Rapid or Slow Event

- System Period: Time for wave to travel through system to a boundary (e.g. open reservoir) and back to originating source
- $T = 2\ L/c$



T = System Period
L = Length of System
C = Wave Speed

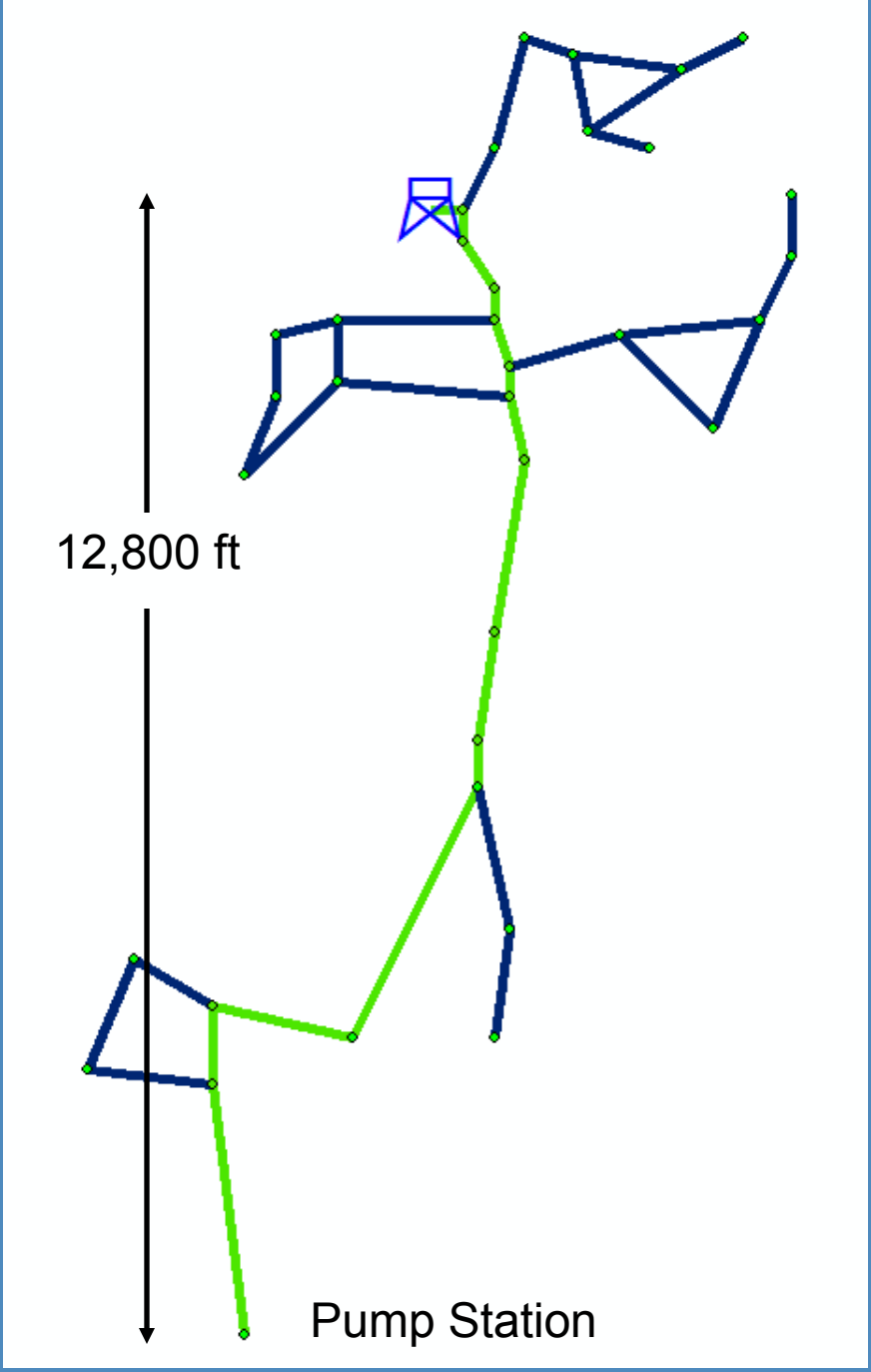
Rapid Event Occurs when Full Joukowsky Head Rise or Drop is Generated

If Transient Event Time is Shorter than the System Period, Full Velocity Change Occurs Before Wave Returns to Originating Source and Full Joukowsky Head is Generated

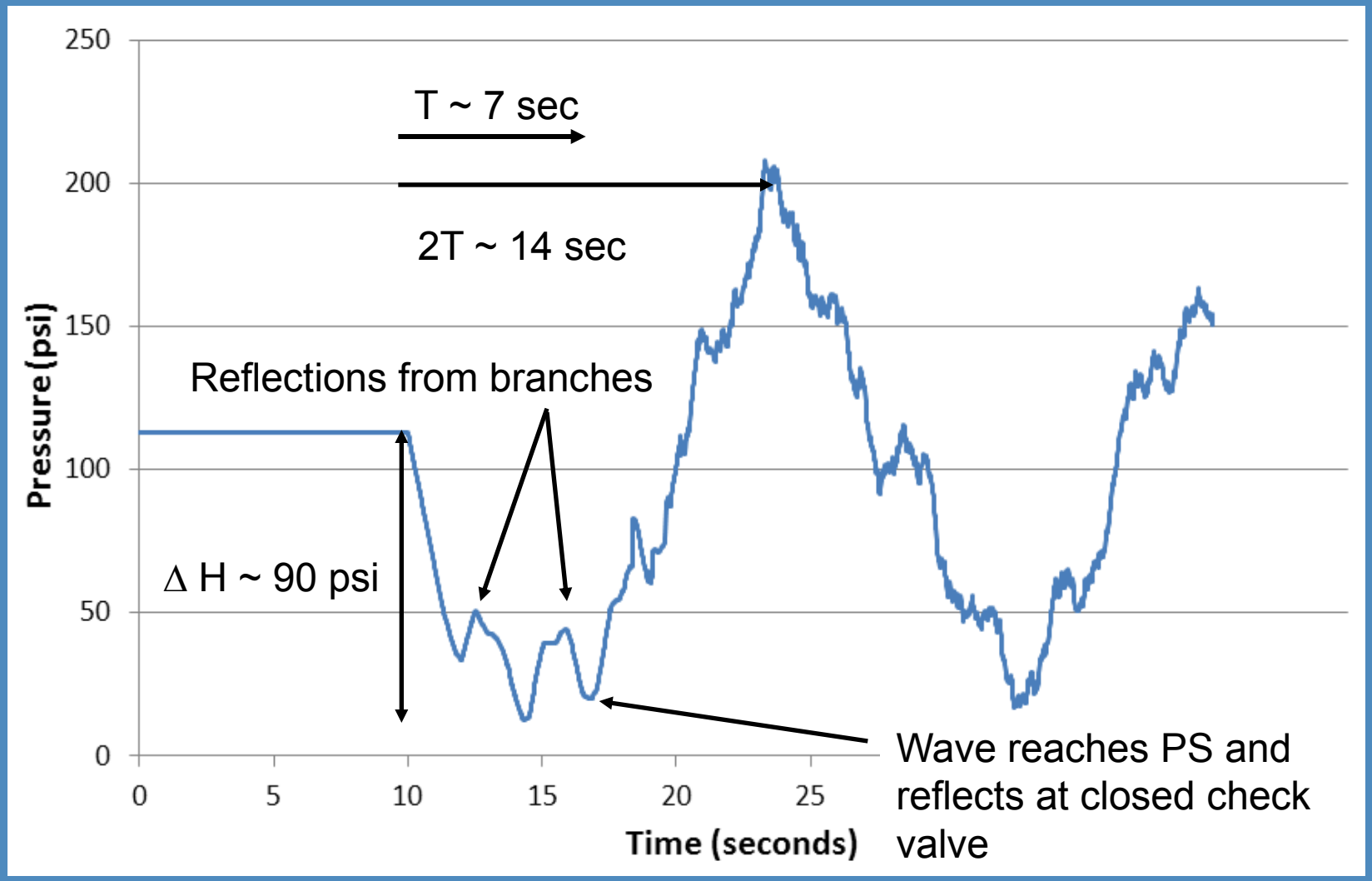
If Transient Event is Longer than System Period, Full Velocity Change Does Not Occur and Head Drop or Rise is Much Less

Pump Station Power Failure

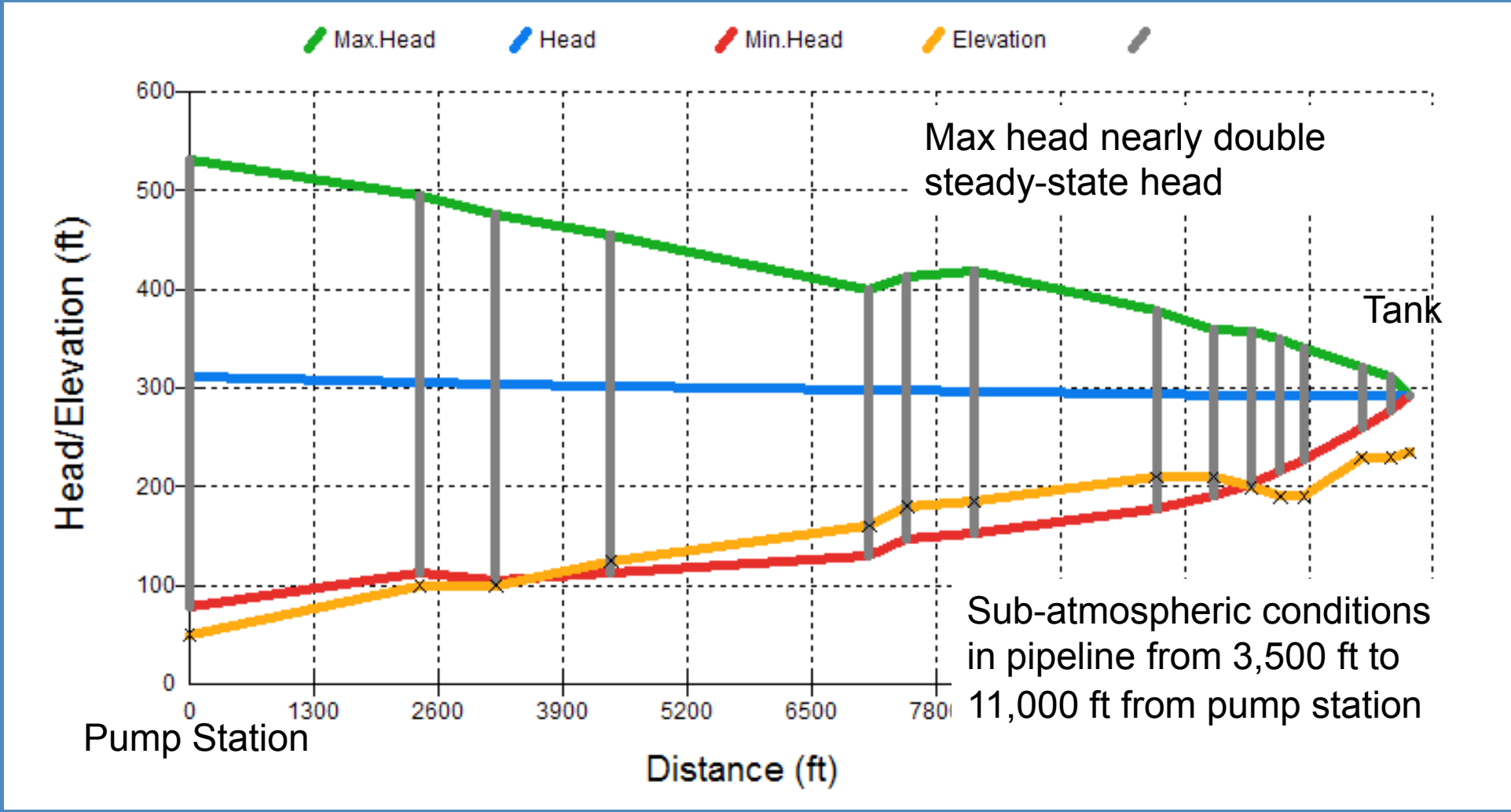
- Flowrate: 1 MGD
- Pump trips and spins down in 2 seconds
- Initial Line Velocity = 1.9 ft/s
  - Δ H = 3,600/32.2 * 1.9 = 212 ft (92 psi)
- T = 2 L/c = 2 * 12,800 / 3,600 = 7 sec



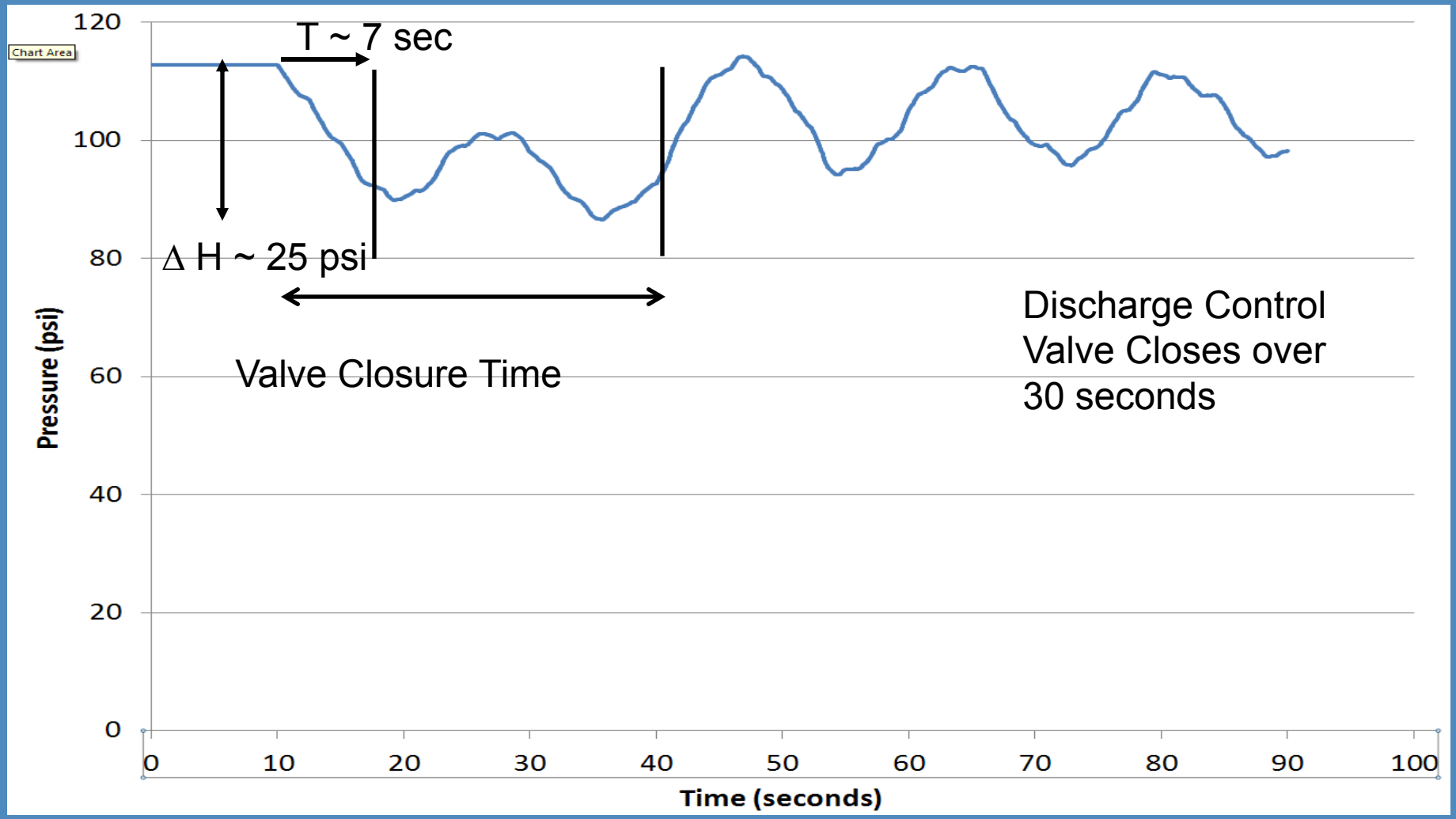
Pressure Response at Pump Station Following Pump Station Loss of Power



Pipeline HGL profile from PS to Res



Pressure Response at Pump Station Following Normal Shutdown



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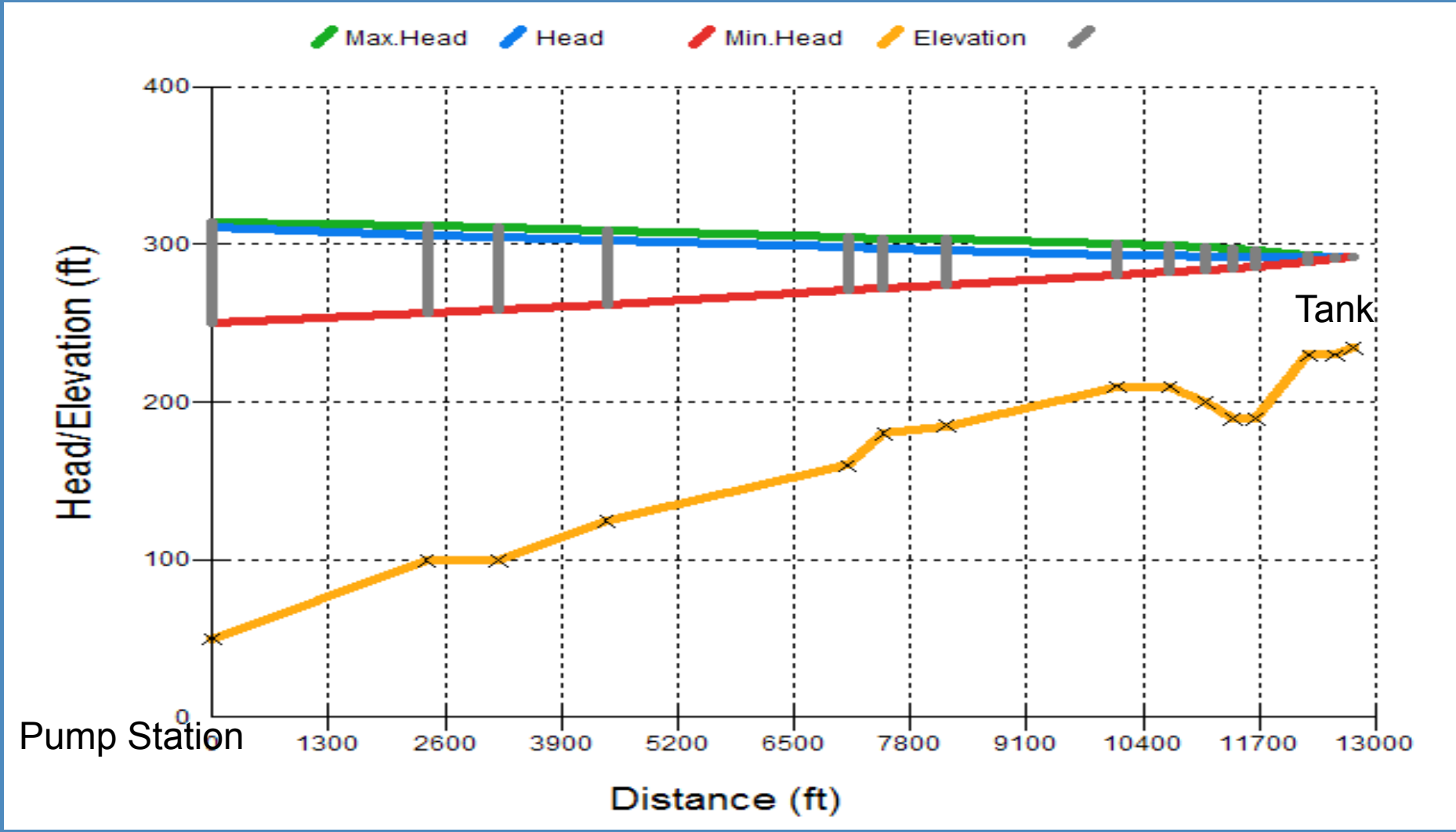

System Conditions Where Pressure Transients Are More Likely

Steep Pipeline Alignment	✓
Low Static Head	✓
High Pipeline Velocity	✓
Low/No Customer Demands	✓

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Types of Surge Mitigation

For Controlled Events
(e.g. normal pump starts and stops, valve opening/closing)

Slow it down!

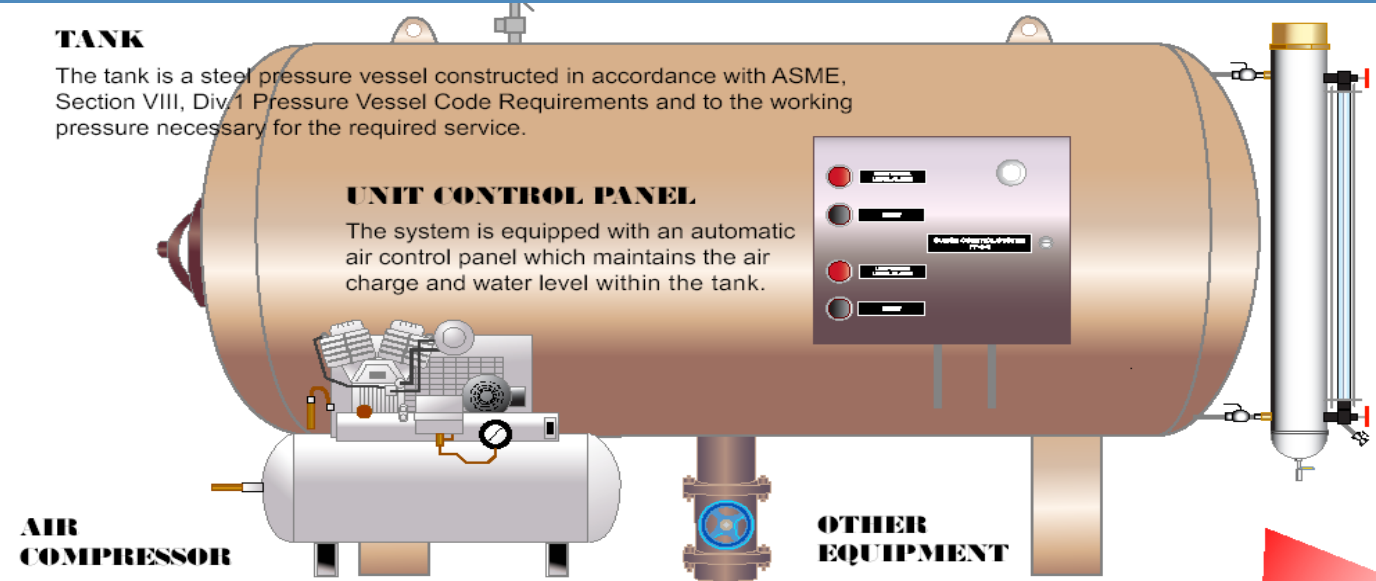
For uncontrolled events
(e.g. pump station power failure)

Surge mitigation devices

- Surge Tanks
- Surge Anticipator Valves
- Pressure Relief Valves
- Vacuum Relief Valves

Hydropneumatic Surge Tanks

- Typically used on discharge side of pumps
- Pressurized vessel (part air/part water) with compressor to maintain the desired initial water level (and air volume) under normal operating conditions
- Supplies water to system when pump stops operating

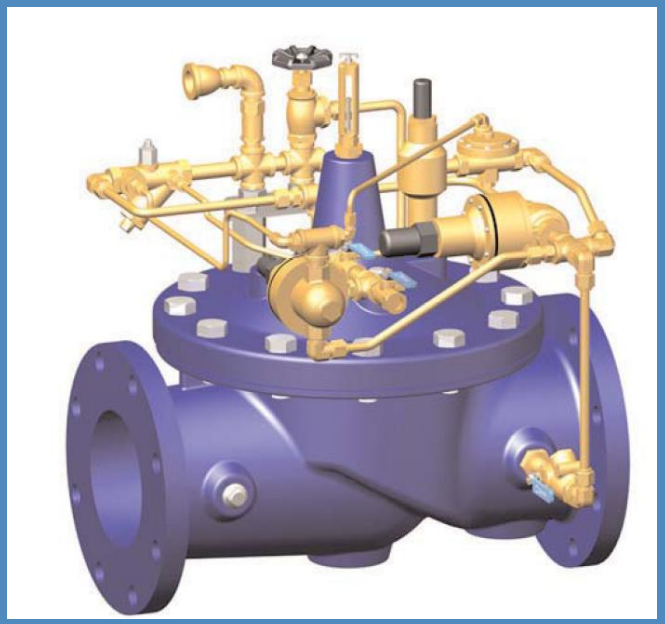


Bladder Tanks

- The tank contains a bladder which is precharged to a predetermined pressure to maintain the desired air volume under normal operating conditions.
- When pump loses power, tank provides flow to system.
- A compressor is not required.

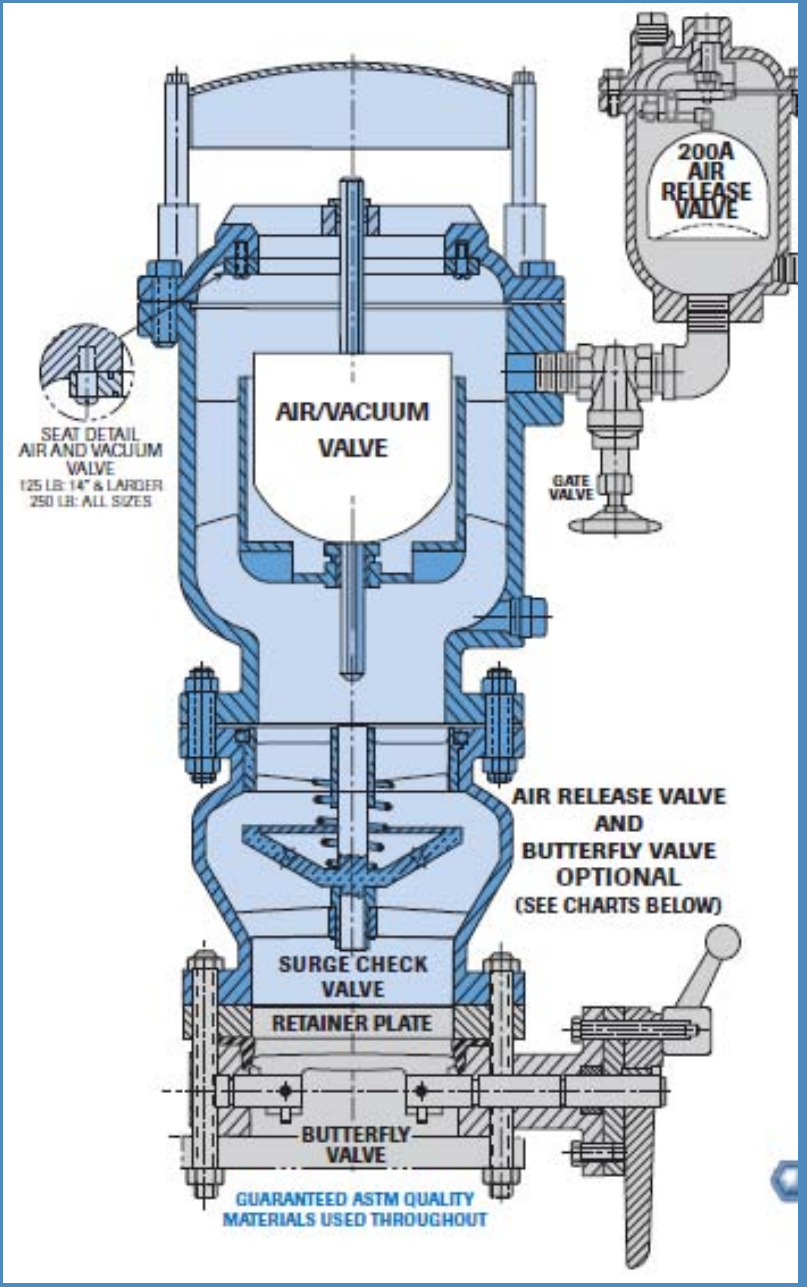
Surge Anticipation Valves

- Typically used on discharge side of pumps
- Open on a down surge in pressure (sensed at a specified location) in anticipation of an upsurge to follow
- Does not modify the downsurge, only affects the subsequent upsurge



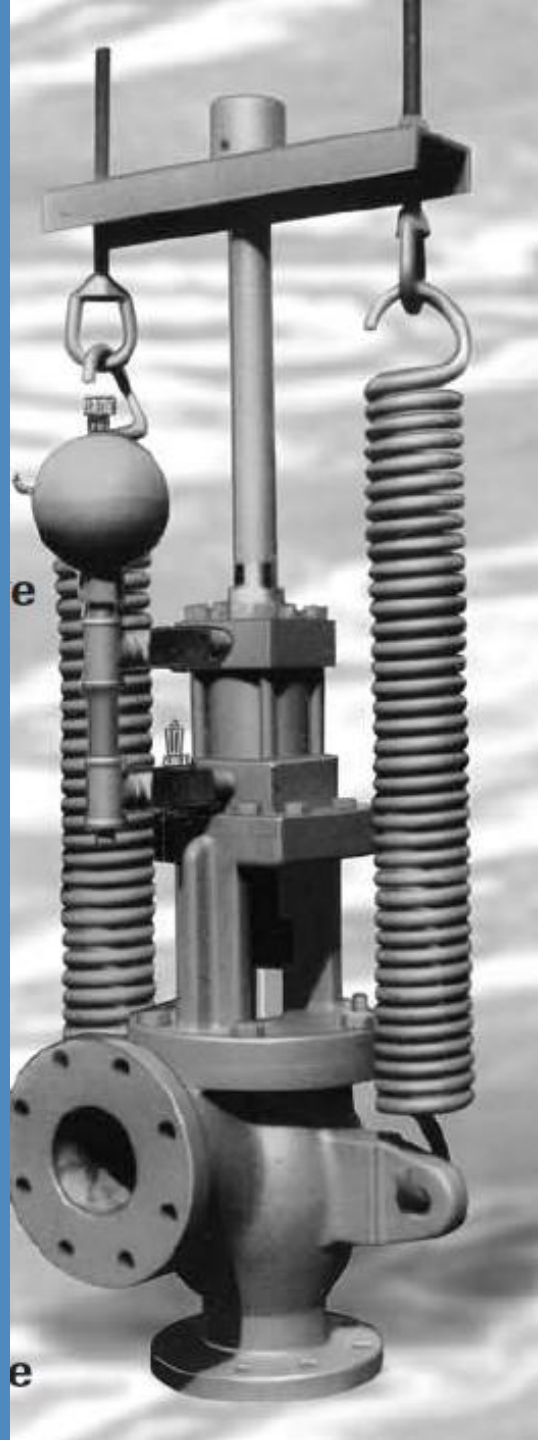
Vacuum Relief Valves

- Installed at pump station header or pipeline high points
- Prevents vacuum conditions by allowing air into the pipe when the line pressure drops to atmospheric
- Air expelled when the line re-pressurizes
- Controlled venting required for transient applications



Pressure Relief Valves

- Typically installed at locations in system where high pressures are undesirable
- Ejects water out a side orifice to prevent high-pressure surges.
- Activated when line pressure reaches a preset value.



Considerations for Mitigation

System Requirements	Site Factors	Utility Preference
Potable, Non-Potable?	Available Space	? ? ? ?
Are there Customers?	Weather	

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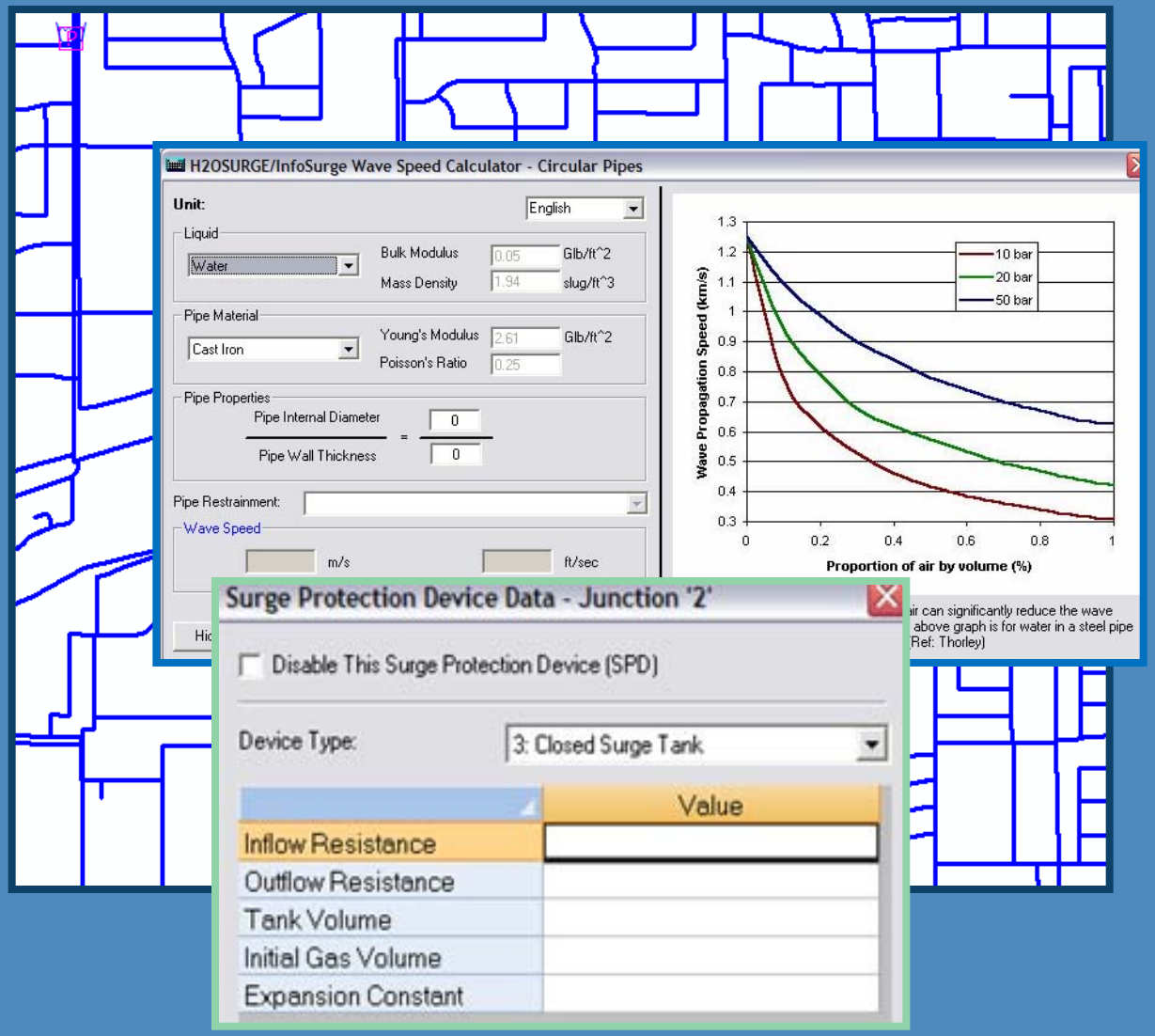
Current Commercial Codes Have Add On Packages

Pipe 2010: KYPIPE	→	Pipe 2010: Surge
Innovyze: InfoWater	→	InfoSurge
Bentley: WaterGEMs	→	Hammer

Build On Hydraulic Model To Evaluate Surge



Start with Hydraulic Model

Add Information Specific to Surge:

- Wave Speed
- Transient Characteristics
- Surge Mitigation Devices

Data Requirements for Analysis

- System Information
  - Pipeline layout, profile, pipeline materials
  - Operating description

- Facility Design Info
  - Mechanical piping layouts, pump/motor equipment selections,
  - Pump curves, number of stages, rated speed
  - Ancillary equipment – check valves, existing surge equipment, etc.
  - Manufacturer information – pump inertial characteristics, valve curves

Quick Checks to Assess Potential for Damaging Transients

- Calculate Joukowsky Head Rise or Drop
- Estimate System Period using Generalized Wave Speed of 3,600 ft/second and compare to Pump Spin Down Speed
- If Pump Spin Down is Shorter than System Period and Head Change of Concern, Plan for Computer Analysis

Pump Station Power Failure

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- Pump trips and spins down in 2 seconds
- Initial Line Velocity = 1.9 ft/s

  Joukowsky Head Change:

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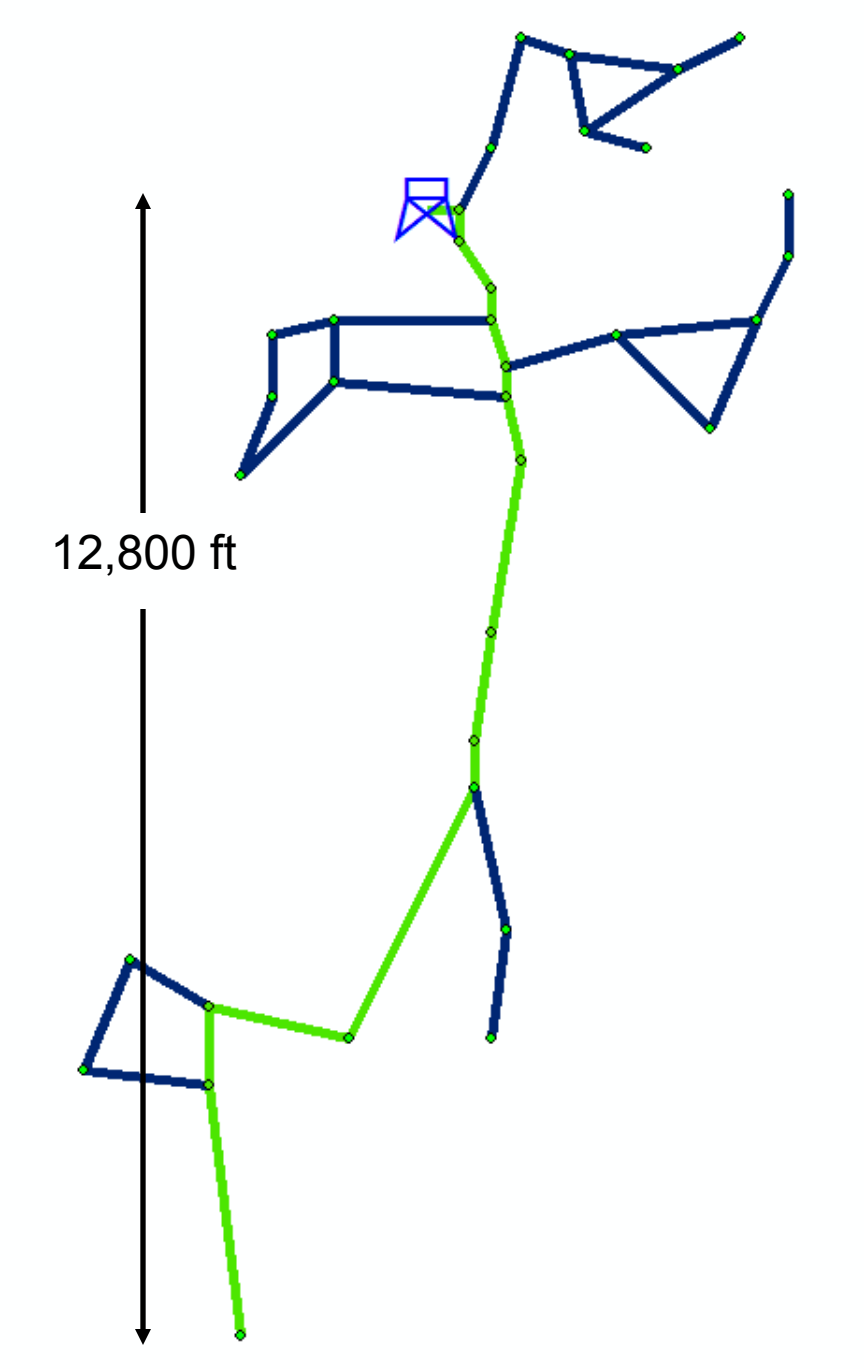

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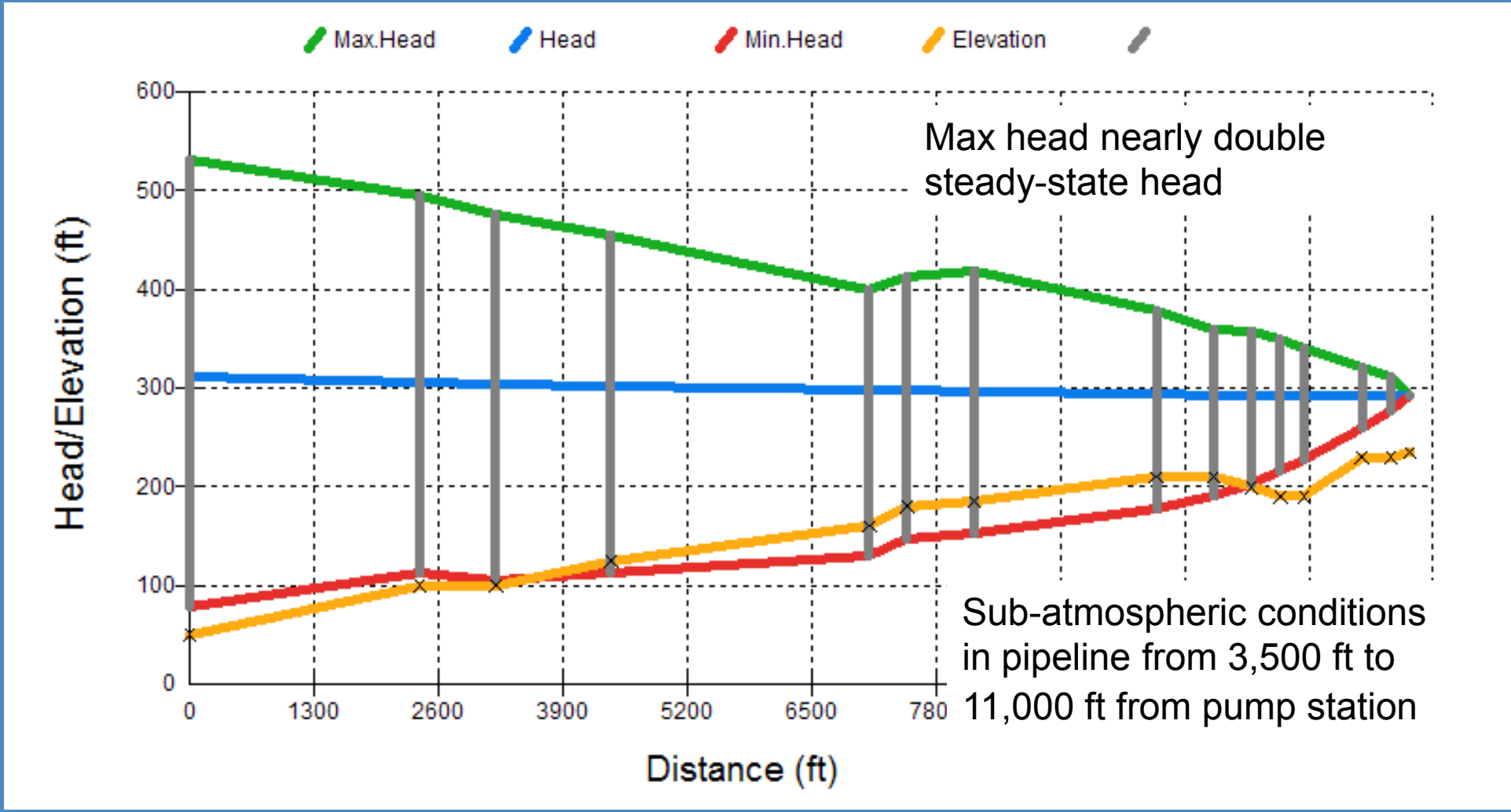
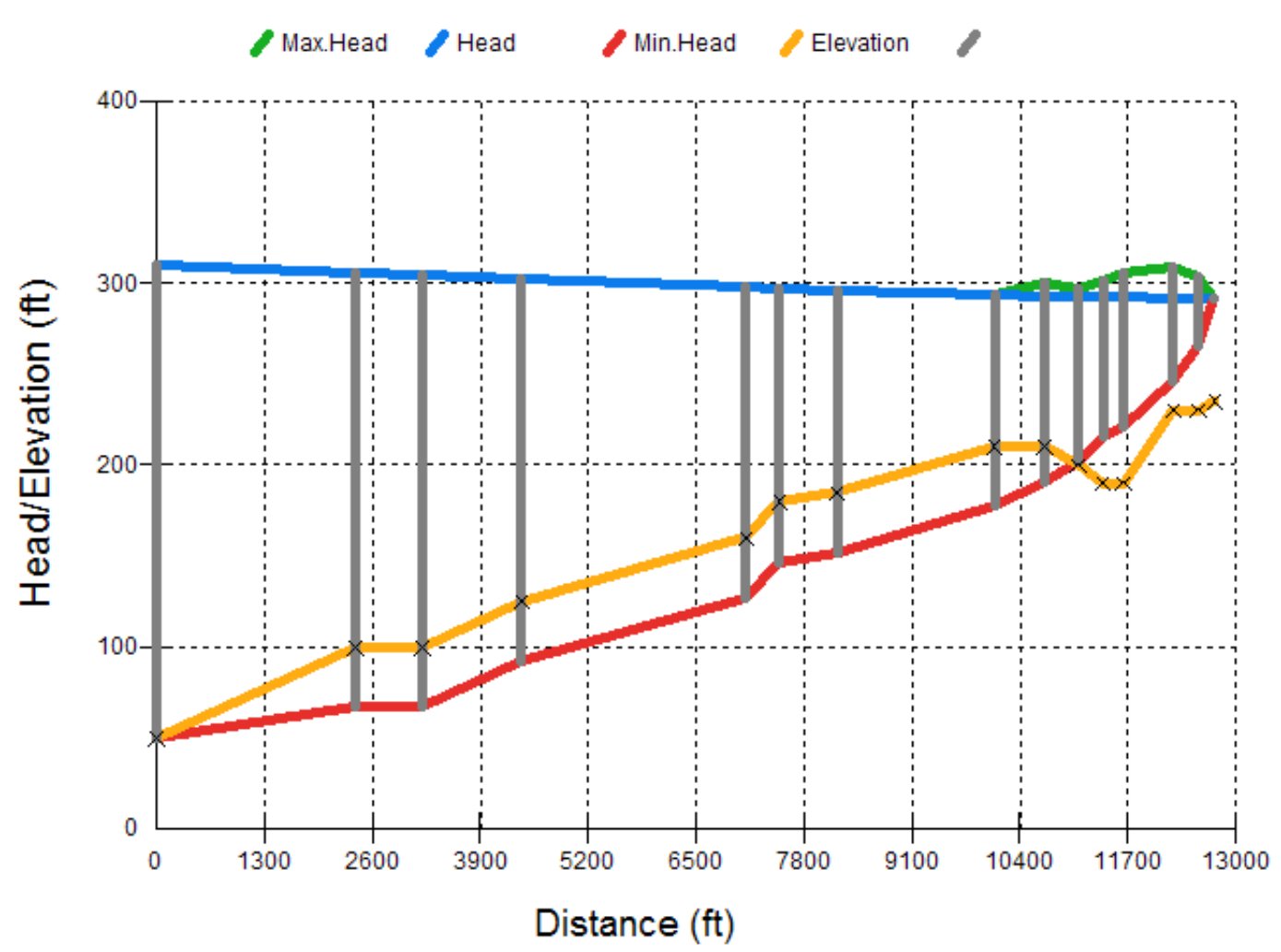


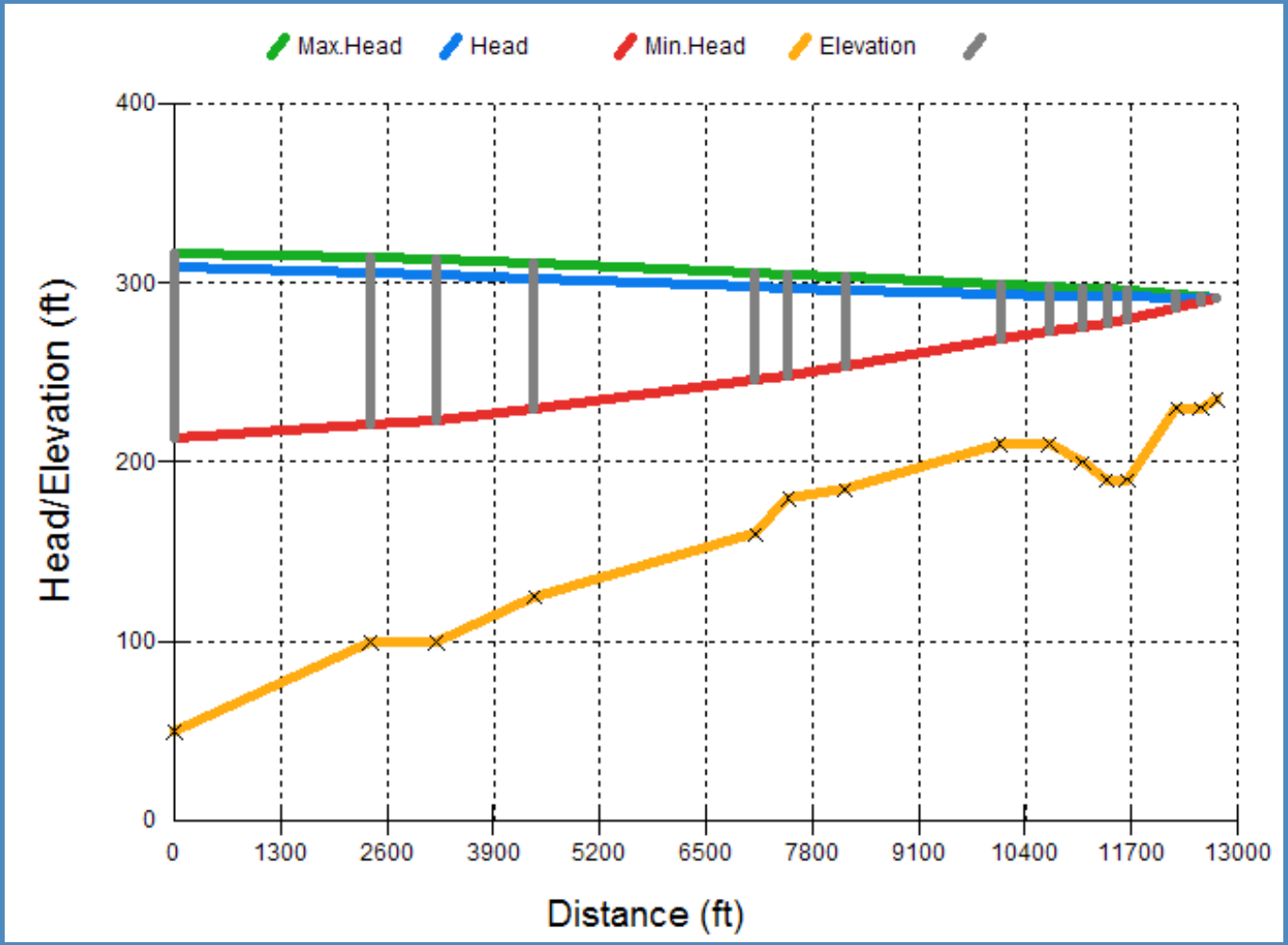
Surge Anticipator Valve

- Opens on down surge, in anticipation of high pressure return wave
- Solves High Pressure
- Doesn't Help Low Pressure



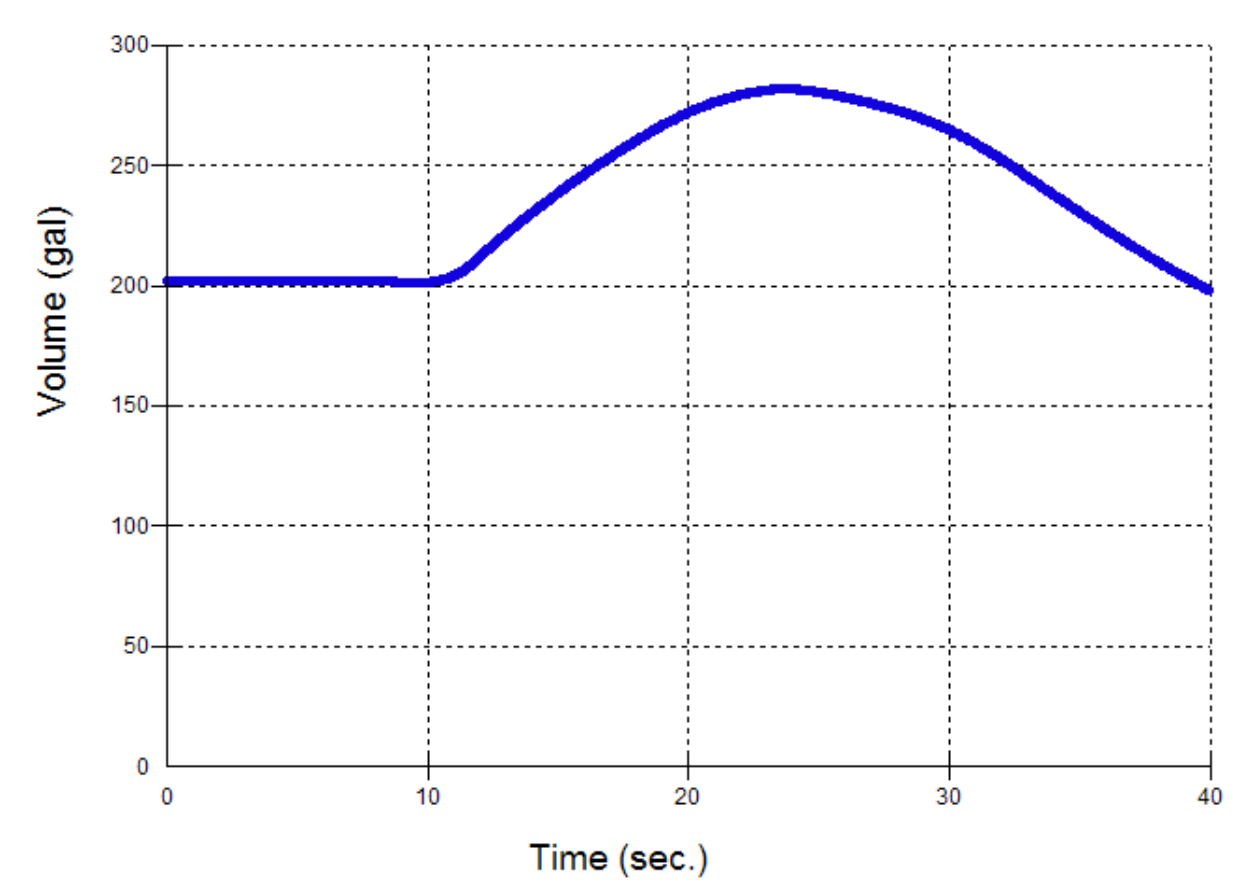
400 Gal Surge Tank

- Mitigates both high and low pressure problems
- Size appropriate for bladder tank



Check Tank Operation

- 50 Percent Air/ 50 Percent Water
- Still at Least 20 Percent Water in Tank Following PS Power Failure



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Example Analysis

Putting It Together

Be Aware of Situations that Can Cause Hydraulic Transients

Any Velocity Change Generates Hydraulic Transients

For Normal Operations, Slow It Down!

For Unplanned Events, Make Sure Mitigation is In Place

Use Simple Calculations to Assess Risk

What is the potential Joukowsky head change?

$\Delta H = \sim 100 * \Delta V$

Is it a rapid event, faster than the system period?

Event time $< T = 2 L/c$

Plan For Hydraulic Transient Analysis IF

Designing New Facilities or Expanding Existing Facilities

Recommending Operational Changes that Increase Risk for Transients

Budgeting Rules of Thumb

Simple System

- **Single PS**
- **Model Already Developed**

16 to 32 hrs

Moderately Complex

- **Multiple PS's**
- **Need Model but Simple System**

40 to 100 hrs

Complex System

- **Multiple Scenarios**
- **New Model**

100 + hrs

Additional Resources

Books and Journals

- Personal Favorite: Fluid Transients In Pipeline Systems, A.R.D Thorley, ISBN: 0-9517830-0-9

Short Course:

- ASCE: Water Hammer in Transmission and Distribution Systems, Benjamin Wylie & Jim C.P. Liou

Code Specific Resources:

- KYPIPE: Surge Code Tips by Don Wood (http://www.kypipe.com/new_stuff/surge_modeling_tips.pdf

Questions