Susceptibility of Distribution Systems to Negative Pressure Transients

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Moderator: Jian Zhang
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AwwaRF

Knowledge Webcast

Project info online: www.awwarf.org | Research | Project Center
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Susceptibility of Distribution Systems Low/Negative Pressure Transients

Kala Fleming & Mark LeChevallier
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Distribution System Challenges

- Increased water quality regulations, security concerns, and cross-connection control while managing an aging infrastructure

- Maintenance of pressure is a critical activity for protection of quality and service delivery

- Spatial and temporal complexity requires collecting and managing data from many points in the distribution system

- Cost-effective approaches, based on sound decision-making processes that add value to the customer, are required
Presentation Overview

- **Transient Pressures:**
  - Steady state pressure vs. transient pressure
  - Description of transient pressure origins

- **Project #3008 Review:**
  - How susceptible are distribution systems to low/negative transient pressures?

- **Consequences & Control of Transient Pressures**
Pump station 5-min Pressure Recording

Pressure (psi)

Time

0

10

20

30

40

50


American Water®
Distribution System Pressure @ 1 per sec

- Pump start-up
- Pump shutdown
Pump Drawdown Testing @ 1 per sec

Transients within transmission main, ~5-15 sec duration

near WTP

Dist. System
Negative for > 16 sec; as low as −10.1 psi (-69 kPa)

Transient Pressure From Sudden Flow Change

- Pressure wave travels through distribution system
- Can cause temporary low or negative pressure
- May last for several seconds
- Waves may be additive
Transient Pressure From Sudden Flow Change

\[ \Delta H = \left(\frac{c}{g}\right) \Delta V \]

- Longitudinal pressure wave initiated by change in water flow velocity

- **Note**: A wave is a disturbance that transmits energy and momentum from one point to another through a medium without significant displacement of matter between the two points.
Pressure Wave in Single Pipeline

- HGL-steady state
- HGL-pumping
- Wave front 7 sec after power failure
- 9 sec after failure
- 12 sec after failure
- Reflection increases pressure after ~14 sec

- ∆H = (c / g) ∆V
- Wave speed is 3,500 ft/s or ~0.66 mile/sec
- g = 32.174 ft/s² & V = 2 ft/s

Adapted from Thorley 2006. *Fluid Transients in Pipelines*. 
Pressure Wave in Single Pipeline

- Pump run down in 7 seconds
- Additional headloss until reflected wave approaches

TIME (seconds)

PRESSURE HEAD (feet)

HGL 7 sec after power failure

\[ \Delta H \]

450 ft

232 ft

\[ h_L \]
In more complex systems, reflections occur with changes in diameter, changes in pipe material and at dead ends or other discontinuities.

Need Models for Network of Pipes

Pressure Key
- negative pressure
- 0 to 20 psi
- pressure > 20 psi
Sources of Pressure Transients

Service interruptions
- Power failure
- Main breaks

Sudden change in demand
- Flushing operations
- Opening and closing a fire hydrant

Routine distribution system operation
- Pump startup and shut down
- Feed tank draining
- Surge tank draining
- Valve operation: open/close
How susceptible are distribution systems to transient low and negative pressures?
AwwaRF Project # 3008 Overview

16 participating systems

Variables:

- system size: 0.1 – 39 mgd
- topography/elevation (flat, moderate, hilly)
- number of pumped sources (1 to 29)
- distribution storage facilities (0 – 18 floating tanks)
- pressure zones (1 to 24)
- Surge relief features
Hydraulic Modeling in Project # 3008

1. Distribution System Maps
2. Steady State Model
   - Key step for all other modeling steps
   - Establishes physical system
   - Snapshot of only one time
3. EPS Model
   - Extended period simulations typically capture system operation over 24 hours
4. Surge Model
   - Determines how sudden changes in flow impact system pressures
Project # 3008 Significant Findings

- In the absence of surge mitigation at pump stations, **all** distribution systems were susceptible to low/negative pressure fluctuations.

- Susceptibilities ranged from 1% to 98%
  
  - Water velocity, number of floating storage facilities, number of source inputs and system configuration influence system vulnerability.

  - Velocities greater than 3 ft/s downstream of pump stations increase the risk of low/negative transient pressures.
Storage Reduces Susceptibility

Percent Nodes with Negative Pressure

- □ at time of max flow to storage
- ■ at time of max flow from storage

Miles of Main per Floating Storage

0% 10% 20% 30% 40% 50% 60%

0 20 40 60 80 100 120
Other Factors Influencing Susceptibility

- Smaller systems showed increased susceptibility.
- Presence of fewer floating storage facilities per miles of distribution system mains may explain the observation.

The diagram shows the percentage of nodes with negative pressure versus average system delivery (MGD), with a median value of 27%.
Other Factors Influencing Susceptibility

- Smaller systems showed increased susceptibility
- Presence of fewer floating storage facilities per miles of distribution system mains may explain the observation

- Groundwater systems may have an increased susceptibility to low/negative pressure transients
Surface vs Ground Water Source

Median value = 27%
Other Factors Influencing Susceptibility

- **System Size**
  - Smaller systems showed increased susceptibility
  - Presence of fewer floating storage facilities per miles of distribution system mains may explain the observation

- **Surface vs Ground**
  - Groundwater systems may have an increased susceptibility to low/negative pressure transients

- **System Config.**
  - Hilly distribution systems (> 150 ft elevation difference) showed less susceptibility
  - Locations at or near dead ends were more susceptible to negative pressures
System Configuration

Percent Nodes with Negative Pressure

- Flat
- Moderately Hilly
- Hilly

median value = 27%
Project # 3008 Significant Findings

- Modeling tools are available for utilities to perform routine surge analyses.

- Modeling can be used to identify susceptible distribution system locations and identify appropriate mitigation strategies.
  - In modeling simulations, relatively small hydropneumatic tanks (1,000 gal or less) reduced the magnitude of down surges in many systems.
Hydropneumatic Tanks

pipeline under steady-state conditions

compressor

air

water

pipeline experiencing downsurge

compressor

air

water leaves tank to maintain pipeline pressure
Hydropneumatic tanks as a surge mitigation option

Hydropneumatic tanks installed on 4/5/05
Transient pressures can cause backflow of contaminants into the distribution system
Pathogen Intrusion

- Intrusion of outside water into the distribution system may potentially occur during periods of low or negative pressures if there is an opening in the pipe (e.g., a hole or crack) and the external head > internal head.

- Studies (Karim et al. *JAWWA* 95(5): 134-146, 2003) have shown that soil and non-potable water surrounding distribution pipes can contain a variety of microbiological pathogens, including fecal indicators and culturable human viruses.
Overall 63% (20/32) of samples were positive for viruses: enteroviruses (Sabin strain), Norwalk, and Hepatitis A virus.
## Microbe Concentrations

<table>
<thead>
<tr>
<th>Microbes</th>
<th>Water CFU or PFU/100 ml</th>
<th>Soil CFU or PFU/100 gm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total coliform</td>
<td>2 - &gt; 1.6 x 10^3</td>
<td>20 - &gt; 1.6 x 10^4</td>
</tr>
<tr>
<td>Fecal coliform</td>
<td>2 - 5 x 10^2</td>
<td>20 - &gt; 1.6 x 10^4</td>
</tr>
<tr>
<td><em>Clostridium</em></td>
<td>5 x 10^2 - 2.5 x 10^3</td>
<td>5 x 10^3 - 1 x 10^5</td>
</tr>
<tr>
<td><em>Bacillus</em></td>
<td>5 x 10^2 - 4.6 x 10^6</td>
<td>6 x 10^4 - 1.2 x 10^8</td>
</tr>
<tr>
<td>Phages</td>
<td>2.5 x 10^2 - 1 x 10^4</td>
<td>0</td>
</tr>
</tbody>
</table>

Separation from Sewer Lines

- Typical separation distance: 10 feet (3 m)
- Standards allow for minimum of 18 in. (0.5 m) separation
Leakage Facilitates Intrusion

\[
\text{distribution water loss (\%)} = 100 \left( \frac{\text{volume distributed} - (\text{volume billed} + \text{volume unbilled but authorized})}{\text{volume distributed}} \right)
\]

**Distribution System Water Loss**

(Median Range, 25\textsuperscript{th} – 75\textsuperscript{th} Percentile)

- West
- South
- Midwest
- Northeast
- > 500,000
- 100,001 – 500,000
- 50,001 – 100,000
- 10,000 – 50,000
- < 10,000

Source: AWWA 2005 – Benchmarking Performance Indicators for Water and WasteWater Utilities

*121 Participants*
Intrusion Summary

Pathogens near but external to pipe

Transient low/negative pressure

leaking pipe

sewer main

leaking pipe
Several measures reduce susceptibility to transient pressures and transitory contamination
Be Cognizant of Risks

- Recognize that intrusion can occur
- Maintain effective disinfectant residual throughout distribution system
- Identify regions of system where negative pressures develop, and prioritize O&M activities in these areas
Modeling & Monitoring are Important

- Determine effect of routine operations on system pressures
- Use models to determine system vulnerability and place monitoring devices
- Use models to determine most appropriate mitigation measure
  - slow valve closure times, air vessels, surge tanks, pressure relief valves, surge anticipation valves, air release valves, combination two-way air valves, vacuum break valves, surge suppressors, and by-pass lines with check valves
Conclusions

- **Control of variations in pressure requires additional attention by water utilities:**
  - Low pressures may cause backflow
  - Pressure variations may impact infrastructure reliability

- **Important research questions need to be addressed:**
  - What are the health risks posed by intruded water?
  - How effective are disinfectant residuals? Are chloraminated systems more susceptible to transitory contamination?
  - What is impact of sewer exfiltration on pathogen occurrence?
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