PNEUMATIC TESTING PRIMER

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• Overview
  • Code provisions for hydrostatic & pneumatic test
  • Explanation of pneumatic test
  • Basic concern with pneumatic test
  • Energy & energy equivalents
  • Provisions for pneumatic test procedures
  • Application to specific example
  • Fracture control plan
  • Risk management
• **Code Provisions**
  
  • Codes specify hydrostatic testing as final check of design, construction & inspection – however, not a “proof test”
  
  • Hydrostatic test at 1.3x to 1.5x Design Pressure, MAWP
  
  • Hydrotest at 30 F above minimum design metal temperature [MDMT]
  
  • Pneumatic testing may be made in lieu of hydrostatic test; but at reduced pressure
  
  • Pneumatic testing used in lieu of hydrostatic testing when
    • equipment cannot be safely filled with water
    • cannot be readily dried where testing liquid cannot be tolerated
  
  • Pneumatic test at 1.1x Design Pressure, MAWP
Why Pneumatic Testing

- Difficulties with hydrostatic testing
  - Environmental concerns
    - Supply & disposal of water, disposal of fluid additives
  - Water leak can cause equipment damage
  - Freeze susceptibility
  - Structural support limitations [large lines]
  - Contamination – chlorine levels
  - Operational impacts - process contaminant
  - Affect dry-out of internal refractory linings
- Availability – air is readily available, clean
• Why Hydrostatic Testing
• Why Hydrostatic Testing

• vessel failure occurred during hydrostatic test with “cold” water
• no injuries occurred
A Hydro-Pneumatic Failure

No injuries but many sad faces!
• Failure during Pneumatic Testing
• Failure during Pneumatic Testing
• Failure during Pneumatic Testing
• Failure during Pneumatic Testing

Pipeline fails under air pressure test - Kills worker

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Industry: Construction and Utilities
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Two workers had completed laying a 30 metre length of 300 mm diameter PVC pipe, in order to connect it to an existing steel pipe, along a suburban roadside. The pipe was then to be pneumatically tested up to a pressure of 690 kPa (100 psi).

As the air pressure in the pipeline approached the maximum test pressure, the 70 kg temporary metal cap exploded from the pipe end. One worker was killed and another injured in the blast. Debris from the metal cap, timber shoring and rock was strewn over an area of up to 100 metres, including into residential properties.

This incident highlights the hazards and risks involved in high pressure air testing of water and sewerage pipe mains.

Source: www.worksafe.vic.gov.au
• Failure during Pneumatic Testing
  
  • Nov 2005, AB – Worker injured by fragments of ESD valve failure when overpressured by nitrogen supply bottle. The nitrogen bottle did not have a pressure relief device to limit pressure to the ESD. Fragments discharged to 50 feet.

ENFORM Safety Alert #01-2006
• Failure during Pneumatic Testing

  • Feb 2006, AB – Worker hurt while holding 2 NPS valve that ruptured when water flush cycle initiated to clear well cementing mixture from piping. Valve was rated at 150 psi. Triplex pumps were used rather than precharge pump per procedure.

  ENFORM Safety Alert #013-2006

  • August 2006, AB – A 45 year old male worker, employed as a consultant, was fatally injured when a wellhead was being pressure tested with nitrogen and catastrophically failed.

  Alberta Government, Workplace Health & Safety, Fatalities Summary 2006
• Qualitative Differences

• Water is not compressible
  • Energy storage is minimal
  • Pressure changes finite amount by infinitesimal change in volume
  • Bulk modulus, \( K = \frac{-\Delta P}{\Delta V / V} \)
  • Water filled balloon does not “pop” \( \rightarrow \) no compressive energy

• Air is compressible
  • Energy storage is large
  • Pressure change “proportional” to volume change \( [P_1V_1 = P_2V_2] \)
  • Bulk modulus, \( K = 20.6 \text{ psi} \)
  • Air filled balloon “pops” \( \rightarrow \) large, instantaneous energy release
• Comparisons
  • What is the stored energy in 42 NPS pipe, 36 feet length and pressurized to 7.5 psig?

  • Hydrostatic Test

\[ W = \int P \cdot dV = \int P \cdot \frac{V}{K} \cdot dP \]

\[ = \frac{1}{2} \frac{P^2}{K} \cdot V \]

\[ = 4.44 \text{ lb}_f \cdot \text{ft} \]

  • Pneumatic Test

\[ W = \int V \cdot dP \]

\[ W = \frac{P_1 \cdot V_1}{K - 1} \cdot K \cdot \left[\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} - 1\right] \]

\[ = 294,815 \text{ lb}_f \cdot \text{ft} \]
• How To Relate to Differences?
  
  • 4.44 lb$_f$-ft is a small number that can be readily grasped

  • What about 294,815 lb-ft?
    • An SUV traveling at 42 mph [68 kph] has this amount of energy

    • Typically, sudden energy release comparisons are made to a
      TNT equivalent $\rightarrow$ 294,815 lb-ft = 0.2 lb TNT

    • TNT equivalent given as 1 kg TNT* = $4.184 \times 10^6$ J [1], or
    • 1 lb TNT* equivalent = $1.4 \times 10^6$ lb-ft
    • *Note that some sources give 1 kg TNT = $4.63 \times 10^6$ J
• What are Industry Provisions for Pneumatic Testing?
  • Do not pneumatically test
  • Pneumatic test (no issues)
  • Pneumatic test is acceptable only if test procedure has been approved by Owner
  • Maximum energy not to exceed $P \cdot V = 50,000$ [psig • ft$^3$]
    • For 42 NPS pipe test - $P \cdot V = 2,385$
  • Exclusion zone of 100’ radius around test equipment
  • Pneumatic test if hydrostatic test has been carefully reviewed and determined not to be feasible – min requirements apply
    • See ABSA Pressure News Vol 7, Issue 2 June 2002
• Safe Distances – What is Safe?

  • Two primary concerns
    • Pressure wave
    • Fragmentation debris
• Safe Distances – What is Safe?
  • Pressure Wave Criteria
    • Damage correlation

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Damage Effect</th>
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<tbody>
<tr>
<td>0.04</td>
<td>Very loud noise [143 dB], sonic boom glass failure</td>
</tr>
<tr>
<td>0.10</td>
<td>Breakage of small windows under strain</td>
</tr>
<tr>
<td>0.15</td>
<td>Typical glass pressure induced failure</td>
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<tr>
<td>0.30</td>
<td>10% of windows broken</td>
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<tr>
<td>0.50</td>
<td>Windows shattered, minor damage to house structures</td>
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<tr>
<td>0.70</td>
<td>Upper limit for reversible effects on humans</td>
</tr>
<tr>
<td>1.0</td>
<td>Partial demolition of houses</td>
</tr>
<tr>
<td>2.0</td>
<td>Partial collapse of walls and roofs of houses</td>
</tr>
<tr>
<td>2.4</td>
<td>Eardrum rupture</td>
</tr>
<tr>
<td>2.5</td>
<td>Threshold for significant human lethality</td>
</tr>
<tr>
<td>3.0</td>
<td>Steel frame building distorted and pulled away from foundation</td>
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</tbody>
</table>
• Safe Distances – What is Safe?

• Fragmentation Criteria
  • Primary fragments
    • Due to shattering of piping or vessel
    • Small fragments, velocity of thousands of feet per second
    • Compare to 3.5 gram .22 bullet with standard velocity of 1100 fps
  • Secondary fragments
    • Somewhat larger in size than primary fragments
    • Velocity of hundreds of feet per second
• Safe Distances – What is Safe?
  • Consider a project with several test packages
    • TNT equivalents range from < 0.1 lb to 80 lb
    • For largest energy system, small volume but high pressure of approx 1,200 psi or 8,000 kPa [P•V = 324,000 > 50,000]
  • Four energy – safe distance models examined
    • TNT point source
    • Lees equation
    • NASA correlation
    • US Army Corps of Engineers
• Four Safe Distance Models – 80 lbs TNT equivalent

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<tr>
<td>0.15</td>
<td>Glass failure</td>
<td>653</td>
<td>653</td>
<td></td>
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<tr>
<td>0.30</td>
<td>10% windows damaged</td>
<td>381</td>
<td>363</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>Windows shattered, limited minor damage to house structures</td>
<td>239</td>
<td>241</td>
<td>275</td>
<td>1,415</td>
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<tr>
<td>0.70</td>
<td>Upper limit for reversible effects on humans</td>
<td>185</td>
<td>187</td>
<td></td>
<td></td>
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</tbody>
</table>

• Note that NASA methodology aligns with TNT & Lees model for 0.50 limit, for this specific case [may not be case for other situations]

• NASA method is referenced in current jurisdiction guidelines
• Evaluation for Specific Example

  • Pneumatic testing standards problematic
    • Test parameters exceed $P \cdot V \leq 50,000$ criteria $\rightarrow$ no test
    • Calculated safe distances $> 100$ ft exclusion zone standard $\rightarrow$ testing under this rule puts people at risk
    • Some Owner in-house guidelines do not consider stored energy issue – pneumatic testing not limited
    • ABSA require stored energy determination $\rightarrow$ a 275 ft exclusion zone required
    • UACE required distance of 1,415 feet not feasible for many installations
• ABSA guidelines
  • Avoid pneumatic test if possible
  • If required, critical safety precautions to be considered
    • Code requirements for pneumatic test
    • Energy determination
    • Test procedure, site prep, personnel restrictions
    • Distance restrictions accounting for energy content
    • Pressure source, pressure & temp ranges during testing
    • Provision for pressure relief
    • Materials of construction considerations
    • Precautions against gas expansion temperature drop, thermal stresses
    • Job specific test procedure submitted unless prior approved standard in place
• Further definition & recommendations

  • Fracture control plan
    • Review materials of construction & susceptibility for fracture
    • Review welding procedures
    • Review inspection requirements
    • Identify sensitivities [test temperature, fabrication quality]
    • Evaluate critical crack sizes and ensure construction & inspection practices are on par

  • Formal risk assessment
    • Treat pneumatic testing to at least same or preferably, greater rigour than other plant operating & construction activities
• References

1. “NIST Guide to SI Units”, National Institute of Standards & Technology, Gaithersburg, MD
2. “ASME Section VIII Div 1”, ASME, New York, NY 2004
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