Achieving Resilient Water Networks: Experimental Performance Evaluation

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ACHIEVING RESILIENT WATER NETWORKS: EXPERIMENTAL PERFORMANCE EVALUATION

Outline

- System vulnerability to ground movement
- Seismic Design of Pipelines
- Hazard Resilient Systems
  - Axial response
  - Lateral response
- Fundamentals of Performance Evaluation
Horizontal Ground Strain: LIDAR Measurements
## Pipeline Performance Classification

<table>
<thead>
<tr>
<th>Parameter (+ and -)</th>
<th>Class</th>
<th>Performance Level*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Strain</td>
<td>Continuous Pipe</td>
<td>Segmented Pipe</td>
</tr>
<tr>
<td>$\varepsilon_1$</td>
<td>0.01% up to 0.1%</td>
<td>0.01% up to 0.1% of L</td>
</tr>
<tr>
<td>$\varepsilon_2$</td>
<td>0.1% up to 0.5%</td>
<td>0.1% up to 0.5% of L</td>
</tr>
<tr>
<td>$\varepsilon_3$</td>
<td>0.5% up to 1%</td>
<td>0.5% up to 1% of L</td>
</tr>
<tr>
<td>$\varepsilon_4$</td>
<td>1% or greater</td>
<td>1% or greater of L</td>
</tr>
</tbody>
</table>

**Curvature / Joint Deflection**

<table>
<thead>
<tr>
<th>Parameter (+ and -)</th>
<th>Class</th>
<th>Performance Level**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curvature</td>
<td>Continuous Pipe (Radius of Curvature $R$)</td>
<td>Segmented Pipe (Joint Deflection Angle $\delta$)</td>
</tr>
<tr>
<td>$\rho_1$</td>
<td>$R &gt; 382'$</td>
<td>$\delta &lt; 3$ degrees</td>
</tr>
<tr>
<td>$\rho_2$</td>
<td>$229' &lt; R &lt; 382'$</td>
<td>$3 \leq \delta &lt; 5$ degrees</td>
</tr>
<tr>
<td>$\rho_3$</td>
<td>$143' &lt; R &lt; 229'$</td>
<td>$5 \leq \delta &lt; 8$ degrees</td>
</tr>
<tr>
<td>$\rho_4$</td>
<td>$\leq 143'$</td>
<td>$\delta \geq 8$ degrees</td>
</tr>
</tbody>
</table>

**Joint Resistance Force***

<table>
<thead>
<tr>
<th>Parameter (+ and -)</th>
<th>Class</th>
<th>Performance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint Resistance</td>
<td>Continuous Pipe</td>
<td>Segmented Pipe</td>
</tr>
<tr>
<td>$\Phi_2$</td>
<td>0.5$\sigma_A$ up to 0.75$\sigma_A$</td>
<td>0.15$\sigma_A$ up to 0.35$\sigma_A$</td>
</tr>
<tr>
<td>$\Phi_3$</td>
<td>0.75$\sigma_A$ up to $\sigma_A$</td>
<td>0.35$\sigma_A$ up to 0.5$\sigma_A$</td>
</tr>
<tr>
<td>$\Phi_4$</td>
<td>$\sigma_A$</td>
<td>0.5$\sigma_A$ up to $\sigma_A$</td>
</tr>
</tbody>
</table>

$L$ is the typical joint spacing in feet (commonly the length of a standard pipe segment)

$\sigma_A$ is the pipe material yield strength in psi

$A$ is the cross-sectional area of the pipe in square inches

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**Davis & Wham, 2018**

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**Resilient Water Network Performance Evaluation | Brad P. Wham**
Continuous pipelines [HDPE, steel, insitu liners]
axial elongation of pipe barrel

(Wham, et al., 2017)
Hazard Resistant Pipeline Systems: Axial Response

Continuous pipelines [HDPE, steel, in situ liners]
Axial elongation of pipe barrel

Segmented Pipelines [ERDIP, restrained ductile iron,]
Axial movement at the joint- compressive/tension displacement
Hazard Resistant Pipeline Systems: Axial Response

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Hybrid Pipeline Systems

JFE Wave Feature

(Wham, et al., 2016)
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Continuous Pipe

Segmented Pipe

Resilient Water Network Performance Evaluation | Brad P. Wham
Hazard Resistant Pipeline Systems: Lateral Response

Continuous Pipe

Segmented Pipe

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Fundamentals of Performance Evaluation

• General Evaluation Considerations

  - Material Characterization
  - Design of Loading System
    - Stiffness
    - Specimen Size
    - Boundary Conditions
  - Internal Pressure
  - Limit States
  - Instrumentation (redundancy)
  - Number of Tests
Performance Evaluation: Full-scale Four-point Bending Test
Conclusions

• Need for seismic design guidelines for underground distribution systems
• Design predicated on realistic ground movement and system characteristics
• Requires meaningful product evaluation—providing consistent testing across materials/components
• Encourage new technologies
• Read the paper!

Thank You!