EFFECT OF UOE FORMING PROCESS ON THE BUCKLING STRAINS OF STEEL PIPES

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Outline of the Presentation

• Introduction
• Literature
• Element Type
• Model Geometry and Loading Paths
• Results
• Summary and Conclusions
U-O-E Manufacturing Process

Mechanical expansion
Buried Pipes

- Differential Soil Settlement
- Differential Frost Heave
- End Bending Moment
- Internal Pressure
Canadian Oil and Gas Pipeline Standard  
(CAN/CSA Z662-15)

\[ \varepsilon_{cr} = 0.5 \frac{t}{D} - 0.0025 + 3000 \times \left[ \frac{(p_{i\max} - p_{e\min})D}{2tE} \right]^2 \]

for \( \frac{(p_{i\max} - p_{e\min})D}{2tF_y} < 0.4 \)

\[ \varepsilon_{cr} = 0.5 \frac{t}{D} - 0.0025 + 3000 \times \left[ \frac{(p_{i\max} - p_{e\min})D}{2tF_y} \right]^2 \]

for \( \frac{(p_{i\max} - p_{e\min})D}{2tF_y} \geq 0.4 \)

- \( \varepsilon_{cr} \): Buckling strains
- \( t \): Pipe wall thickness
- \( p_{i\max} \): Maximum internal pressure
- \( p_{e\min} \): Minimum external hydrostatic pressure
- \( E \): Modulus of elasticity
- \( F_y \): Yield stress
- \( D \): Pipe outside diameter (OD)

**Notes:**
- The equations are used to determine the critical buckling strain for a pipeline under internal pressure and external hydrostatic pressure.
- The critical buckling strain \( \varepsilon_{cr} \) is calculated using the wall thickness \( t \), outside diameter \( D \), and the pressure difference \((p_{i\max} - p_{e\min})\).
- The equations are separated into two cases based on the ratio of the pressure difference to the yield stress and modulus of elasticity.

**Diagram:**
- A diagram of a pipeline with labels for the critical buckling strain, wall thickness, and pressures.
- The diagram illustrates the calculation of the critical buckling strain using the given formulas.

**Keywords:**
- Buckling strains
- Pipe wall thickness
- Maximum internal pressure
- Minimum external hydrostatic pressure
- Modulus of elasticity
- Yield stress
- Pipe outside diameter (OD)
Objective

Develop a model to improve the prediction of buckling strains by:

1- Predicting the stresses induced in the UOE forming process of the pipe, and then

2- Modeling the deformational behavior of the pipe
Obtain Critical Strains

Previous studies

Experimental

Advantage: Obtain accurate buckling strains
Disadvantage: Expensive

Conducted Coupon Test

Nonlinear

Advantage: Inexpensive
Disadvantage: Overestimate buckling strains

Modeling forming process

Coupon in hoop direction

Modeling combination of bending and internal pressure

Coupon in longitudinal direction

In this study

Obtain better prediction of buckling strains
Closer to experiment

Coupon in hoop direction

Coupon in longitudinal direction
Simplified Model

• FEA modelling in the Past Studies
Detailed Model

- Present Study
### Continuum Element Types

<table>
<thead>
<tr>
<th>Element Type</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3D8</td>
<td>- In incompressible materials, provides a constant volumetric strain to prevent mesh locking. - Ideal for modeling curved geometry with fewer elements.</td>
<td>- Suffers from shear locking for problems involved bending. - Suffers from volumetric locking for nearly incompressible materials - Hourglassing (can be controlled by distributing load points and boundary conditions)</td>
</tr>
<tr>
<td>C3D8R</td>
<td>- Use for simple problems/modeling.</td>
<td>- Reduced integration points used to form stiffness matrix thus reducing running time</td>
</tr>
<tr>
<td>C3D20</td>
<td>- Use for complex problems/modeling.</td>
<td>-</td>
</tr>
<tr>
<td>C3D20R</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Longitudinal Tension Test

UOE Forming Process

Longitudinal Tension
(Pipe elongates by 15% of its initial length)
Hoop Tension Test

UOE Forming Process

Hoop Tension
(Pipe expanded radially by 15% of the inner radius)
FEA Simulation of Longitudinal and Hoop Tension Tests
Longitudinal and Hoop Stress-Strain Curves (C3D20R)

- Experimentally measured-for flat plate
- FEA predicted longitudinal-for formed pipe (C3D20R)
- FEA Predicted hoop-for formed pipe (C3D20R)
Model Geometry

- Simplified Model
- Detailed Model
Model Geometry

• Detailed Model
Loading Path for the Simplified Models

- Un-pressurized
Loading Path for the Detailed Models

- Un-pressurized

UOE Forming Process

- Pressurized

End Bending
Internal Pressure and End Bending
### Buckled Configuration – Simplified Versus Detailed Model

<table>
<thead>
<tr>
<th>Hoop Stress (Mpa)</th>
<th>Simplified</th>
<th>Detailed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>0.4 Fy</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>0.8 Fy</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>
Local Moment-Curvature Comparison

![Graph showing local moment and buckling strain comparison for different conditions.](image)

Legend:
- P00S-T10
- P00D-T03
- P40S-T10
- P40D-T10
- P80S-T10
- P80D-T03
### Local Buckling Strain

<table>
<thead>
<tr>
<th>Buckling strains</th>
<th>P= 0.0</th>
<th>P=40% $F_y$</th>
<th>P=80% $F_y$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Z662 Design Standard</strong></td>
<td>0.5 %</td>
<td>0.8 %</td>
<td>0.8 %</td>
</tr>
<tr>
<td><strong>Peak moment criteria</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simplified</td>
<td>0.8 %</td>
<td>1.1 %</td>
<td>2.3 %</td>
</tr>
<tr>
<td>Detailed</td>
<td>0.5 %</td>
<td>1.0 %</td>
<td>1.8 %</td>
</tr>
<tr>
<td><strong>0.95 % of peak moment value</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simplified</td>
<td>1.8 %</td>
<td>2.0 %</td>
<td>4.2 %</td>
</tr>
<tr>
<td>Detailed</td>
<td>0.8 %</td>
<td>1.4 %</td>
<td>2.8 %</td>
</tr>
</tbody>
</table>
Summary and Conclusion

1. A technique for modeling forming process and predicting buckling strains was developed.

2. Apparent stress-strain curves for the pipe are found to differ from the stress-strain pipes for the flat steel plate.

3. For curved pipe, FEA-predicted hoop stress-strain curve is found to be different from longitudinal stress-strain relationship.

4. Buckling strain predictions based on the present model are more realistic than FEA predictions in previous studies.

5. Modelling residual stresses induced in UOE are found important to accurately predict buckling strains.
Thank You!