External Loads on Pipelines

Understanding What’s Important
Do external loads matter?

• Won’t cause failure (loss of containment)
  • Except in truly extreme circumstances
  • Worst case might be ovalling (pigging problems)
  • May cause fatigue if repeated very often
• Don’t solve a problem that might not exist
  • May create unnecessary difficulty for both pipeline operator and third parties
  • Installing unnecessary protection may increase risk
They matter (a little)

- Unwise to ignore any load on a pipe
- Ovaling or fatigue do need to be managed
- AS 2885 and API 1102 provide rules
  - Working right up to the limit is completely safe
  - Inadvertently going a little over the limit is unlikely to have serious consequences
History - early

- Marston-Spangler ("Iowa") method
- Developed in 1930s for drain pipes, still the basis for drain and culvert design
- Known to be not good for pressurised pipes
  - Over-estimated stresses at low internal pressure
  - OK at higher pressure, but for dubious reasons
- But no alternatives available before 1993
Research - 1988-91

- Research by Cornell University and Gas Research Institute
- Comprehensive theoretical study well-validated by field measurements
  - Analytical and numerical modelling of pipe/soil interaction
  - Strain-gauged DN 300 and DN 900 pipes under real railway to verify numerical results
- Generated dimensionless curves for design use

Reference: Reports GRI-91/0284 & 0285
API 1102

- Origins in 1934, but 1993 edition included new GRI/Cornell method
- Referenced by AS 2885 for the calculation method (but not stress limits)
- Design factor not nominated by API 1102
  - Refers to US regulations instead
Failure criteria

- GRI criterion: avoid any yielding, consider increasing safety factor with location class
  - Very reasonable for repeated loads
  - Cyclic yielding → rapid fatigue
- GRI did not mandate safety factors but API 1102 does (for US users)
- But what are we trying to avoid? What is the **FAILURE** condition?
Hoop Stress

Uniform hoop stress

Internal Pressure
External Load

External load from backfill and vehicles

Bending: internal compression, external tension

Bending: internal tension, external compression

Trench reaction

Bending stress usually highest at invert, because trench reaction is more concentrated than loads above or beside pipe.
Combined Stress

External load from backfill and vehicles

Bending reduces tensile stress at inner wall

Bending increases tensile stress at inner wall

Internal Pressure

Trench reaction

Plastic corrugated pipe with buckled invert

Max combined stress usually at inside invert
How would it fail?

<table>
<thead>
<tr>
<th>Limit State</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serviceability</td>
<td>Oval pipe ➔ pigs unable to pass</td>
</tr>
<tr>
<td>Ultimate</td>
<td>Cracking due to fatigue ➔ rupture</td>
</tr>
<tr>
<td>Ultimate</td>
<td>Collapsed pipe</td>
</tr>
</tbody>
</table>

All of these would require loads much higher than allowable.
Allowable stress - road & rail

• Allowable combined stress is 72% SMYS

• Pipe must have pressure design factor < 0.72 to allow “headroom” for stresses due to external loads

• Typically use max wheel loads from AS 5100.2 (bridge design loads)
  • Exceeds current legal wheel loads
## Road crossing examples

Allowable combined stress: **72% SMYS**

<table>
<thead>
<tr>
<th>Diameter</th>
<th>DN 150</th>
<th>DN 150 (min WT)</th>
<th>DN 350</th>
<th>DN 1050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WT &amp; Grade</strong></td>
<td>6.35, Gr B</td>
<td>4.94, Gr B</td>
<td>6.7, X65</td>
<td>18.0, X70</td>
</tr>
<tr>
<td><strong>Hoop stress, %SMYS</strong></td>
<td>54.4%</td>
<td>70.0%</td>
<td>60.4%</td>
<td>62.6%</td>
</tr>
<tr>
<td><strong>Comb. stress, % SMYS</strong></td>
<td>56%</td>
<td>72%</td>
<td>62%</td>
<td>64%</td>
</tr>
</tbody>
</table>

Various conservative assumptions - soft soil, large bore diameter, no pavement, max wheel loads, etc. All for 10.2 MPa MAOP.
Allowable stress - field crossings

• AS 2885 allows up to 90% SMYS for combined stress at informal crossings

• eg. heavy truck crossing paddock, not at designated road crossing

• Almost any road-legal vehicle will be OK, even with pipe designed for 80% SMYS hoop stress

• Hence stringent restrictions unnecessary (provided ground is firm)
### Field crossing examples

Allowable combined stress: 90% SMYS

<table>
<thead>
<tr>
<th>Diameter</th>
<th>DN 150</th>
<th>DN 350</th>
<th>DN 1050</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT &amp; Grade</td>
<td>4.8, Gr B</td>
<td>5.62, X65</td>
<td>14.1, X70</td>
</tr>
<tr>
<td>Hoop stress, %SMYS</td>
<td>72%</td>
<td>72%</td>
<td>80%</td>
</tr>
<tr>
<td>Comb. stress, % SMYS</td>
<td>74.2%</td>
<td>72.7%</td>
<td>80.8%</td>
</tr>
</tbody>
</table>

Various conservative assumptions - soft soil, no pavement, max wheel loads, etc. All for 10.2 MPa MAOP.
Extra protection needed?

• Do the calcs, compare with 72% or 90% SMYS criterion
  • If stresses OK, don’t solve a non-existent problem

• Most likely situation needing more protection:
  • New road crossing with **FREQUENT** traffic over high DF pipe
  • Not critical for very limited traffic (one or a few transits over pipe)
Providing protection
(if really needed)

• Extra cover

• Steel plates
  • Dubious - won’t spread load, might help prevent bogging

• Concrete slab, at or below road surface
  • Engineered to distribute the load to undisturbed ground beside trench
  • Possible soft fill beneath slab, above pipe
Other issues

- Coating damage due to increased external load?
  - Seems unlikely unless fill around pipe is known to be very poor (i.e. gravel or rocks)
- No known incidents
Consider TOTAL risk

• Protect against external loads in a way appropriate to the risk

• Will installing additional protection against external loads INCREASE the risk during the installation process?
Thank you