2nd Annual Global Forum on Pipeline Maintenance and Integrity Management

18th – 19th of September 2014
Amsterdam, the Netherlands

Discover Implementation of Advanced Inspection Techniques and Develop Effective Maintenance Strategies to Optimize your Pipeline Integrity and Mitigate Operational Challenges

Speaker Panel:

Wolfram Günther & Jens Focke
Manager Operations
Information Systems
Ontras Gastransport GmbH
Germany

Ivana Kaličanin
Lead Expert for E&P Investment Projects
INA
Croatia

Branislav Reťkovský
Head of GIS and ITIS Department
Eustream, a.s.
Slovakia

Turad K. Al-Hujaili
Hot Tap and Stopple Engineer
Saudi Aramco
Saudi Arabia

Prof. Ir. A.M. (Nol) Gresnigt
Assoc. Prof. Steel Structures, Faculty of Civil Engineering & Geosciences
Delft University of Technology
The Netherlands

Hasan Yasir Bora
General Manager
Kayserisigaz A.Ş. (an EWE Grp. Co.)
Turkey

Mihai Zafiu
Projects Office Team Leader, E&P Division
OMV Petrom SA
Romania

Leen Pronk
Senior Advisor Asset Management
Gasunie Transport Services
Chairman of the Working Group Transmission Pipelines
Marcogaz
The Netherlands

Houssam Sabry
Head of Corrosion & Inspection Department
Abu Dhabi Gas Liquefaction Company Ltd. (ADGAS)
United Arab Emirates

Ulrich Schneider
Business Development Manager
Continental Europe
KTN AS
Norway

Ton van Wingerden
Principal Consultant,
Asset Risk Management
DNV GL - Oil & Gas
The Netherlands

Mohamed Daoud
Projects Quality Manager
Abu Dhabi Company for Onshore Oil Operations (ADCO)
United Arab Emirates

Mohamed Hassane
Senior Asset Integrity Engineer
Dolphin Energy Ltd.
Qatar

Topics to be addressed:

- Unpiggable pipelines and methods of their inspection
- In-Line Inspection tools and intelligent pigging
- Pipeline Leak Detection Systems
- Corrosion threats and Cathodic Protection as the main tool
- Stress Cracking Corrosion
- Extending the lifecycle of ageing pipelines
- PIMS and data management within this system
- Challenges for offshore pipelines
- 3rd party interference
- Product and pipe theft

Benefits of attending:

- Meeting selected senior decision-makers from global leading operating companies in Pipeline industry
- Learning from the selected examples of practical approach
- Knowledge and expertise exchange
- Direct networking with industry decision makers in a business-friendly environment

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2nd Annual Global Forum on Pipeline Maintenance and Integrity Management

18th of September
Conference Day One

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<tr>
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<td>Registration &amp; Welcome Coffee</td>
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<td>9:00</td>
<td>Opening Address from the Chairman</td>
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<tr>
<td>9:10</td>
<td>PIPELINE INSPECTION AND MONITORING SYSTEMS</td>
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<tr>
<td></td>
<td>Developing Inspection Strategy for Unpiggable Pipelines</td>
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<tr>
<td></td>
<td>• What is an &quot;unpiggable&quot; pipeline / What makes a pipeline &quot;unpiggable&quot;</td>
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<td></td>
<td>• How to change from &quot;unpiggable&quot; to &quot;difficult to inspect&quot;</td>
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<td>• Solutions for inspection of &quot;difficult to inspect&quot; pipelines</td>
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<tr>
<td></td>
<td>• Intelligent BiDi Inspection tools, tethered tools, crawler tools</td>
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<td>• Case studies</td>
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<td></td>
<td>Ulrich Schneider</td>
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<td>Business Development Manager Continental Europe KTN AS, Norway</td>
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<tr>
<td>9:50</td>
<td>Intelligent Pigging</td>
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<tr>
<td></td>
<td>• Types of data that can be collected during pigging and its usage</td>
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<td>• Ways of inspection that can be performed by an intelligent pig</td>
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<td>• ‘Smart’ pigging with ultrasonic applications</td>
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<td>Mohamed Hassane</td>
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<td></td>
<td>Senior Asset Integrity Engineer Dolf Plastic Ltd., Qatar</td>
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<tr>
<td>10:30</td>
<td>Coffee &amp; Networking Break</td>
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<tr>
<td>11:00</td>
<td>Pipeline Commissioning</td>
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<tr>
<td></td>
<td>• What data and equipment does a company need prior to commissioning</td>
</tr>
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<td>• Critical issues in commissioning a pipeline</td>
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<td>• Commissioning of multi-products pipelines</td>
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<td></td>
<td>Mohamed Daoud</td>
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<td>Projects Quality Manager Dolf Plastic Ltd., Qatar</td>
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<td>Abu Dhabi Company for Onshore Oil Operations (ADCO), United Arab Emirates</td>
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<tr>
<td>11:40</td>
<td>CORROSION THREATS: RISKS, CONSEQUENCES, MITIGATION STRATEGIES</td>
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<td></td>
<td>Case Study</td>
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<td>Failure of Crude Oil Main Pipeline due to Sulphate Reducing Bacteria</td>
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<td></td>
<td>• Initial context</td>
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<td>• Description of the first failure</td>
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<td>• Ways to remedy and maintaining in use the pipe</td>
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<td>• Current situation and next step</td>
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<td>• Lesson learned, discussions, opinions</td>
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<td></td>
<td>Mihai Zafiu</td>
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<td></td>
<td>Projects Office Team Leader, E&amp;P Division OMV Petrom SA, Romania</td>
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<tr>
<td>12:20</td>
<td>Lunch Break</td>
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<td>13:20</td>
<td>Coffee and Networking Break</td>
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<tr>
<td>14:00</td>
<td>Stress Cracking Corrosion</td>
</tr>
<tr>
<td></td>
<td>• Causes of Stress Cracking Corrosion (mildly corrosive environments, susceptible materials)</td>
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<td>• Techniques to minimize stress concentrations to avoid SCC</td>
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<td>• Choice of metal as a preventive measure</td>
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<td></td>
<td>Houssam Sabry</td>
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<td>Head of Corrosion &amp; Inspection Department</td>
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<td>Abu Dhabi Gas Liquefaction Company Ltd. (ADGAS), United Arab Emirates</td>
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<td>14:40</td>
<td>Case Study</td>
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<td>Hot Tap and Stopple Successful Story</td>
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<td></td>
<td>• Partial isolation of a 56 in. in-service life crude pipeline using double stopple technique</td>
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<td>• Saudi Aramco capabilities and the magnitude in HT&amp;S operations</td>
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<td></td>
<td>• Engineering analysis, procedure and implantation of life isolation process</td>
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<td>Turad K. Al-Hujaili</td>
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<td></td>
<td>Hot Tap and Stopple Engineer Dolf Plastic Ltd., Qatar</td>
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<td>Saudi Aramco, Saudi Arabia</td>
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<td>15:20</td>
<td>Coffee and Networking Break</td>
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<tr>
<td>16:00</td>
<td>Ageing Pipelines - Extending the Lifecycle</td>
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<tr>
<td></td>
<td>• Pipeline Risk Management: analyse pipelines condition, decide on rehabilitation</td>
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<td>• Reliability problems with ageing pipelines</td>
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<td>• Making a decision on rehabilitation or replacement</td>
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<td></td>
<td>Ivana Kalicañin</td>
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<td></td>
<td>Lead Expert for E&amp;P Investment Projects Dolf Plastic Ltd., Croatia</td>
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<tr>
<td>16:40</td>
<td>Panel Discussion</td>
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<td>Pipeline Leak Detection Systems</td>
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<tr>
<td></td>
<td>• Current pipeline monitoring regulations and governmental control of leak detection standards</td>
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<td></td>
<td>• Mass balance, pressure point, acoustic technology, their advantages and disadvantages</td>
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<tr>
<td></td>
<td>• How to choose the right detection system for your pipeline</td>
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<td>Led by:</td>
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<tr>
<td></td>
<td>Ivana Kalicañin</td>
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<td></td>
<td>Lead Expert for E&amp;P Investment Projects Dolf Plastic Ltd., Croatia</td>
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<td>17:20</td>
<td>Closing Remarks from the Chair &amp; Wrap up of Day One</td>
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<td>18:40</td>
<td>Cocktail Reception</td>
</tr>
</tbody>
</table>
8:30 Registration & Welcome Coffee

9:00 Opening Address from the Chairman

9:10 Strategic Analysis and Planning of Pipeline Assets – Methods and Tools
   - IT Systems methodology systematics behind the system
   - A cost driven approach implemented in pipelines
   - How to find the right asset decisions
   - How to ensure transparency of decisions made
   Wolfram Günther & Jens Focke
   Manager Operations
   Information Systems
   Ontras Gastransport Gmbh, Germany

11:40 How DNV GL bridge asset management and operational excellence using ISO 55000
   - What is Asset Management
   - Introduction to ISO 55000 - the new standard for Asset Management
   - DNV GL approach of implementing the ISO 55000 standard
     - Assessment phase
     - Implementing phase
     - Certification
   - Our success stories
   Ton van Wingerden
   Principal Consultant, Asset Risk Management
   DNV GL - Oil & Gas, The Netherlands

9:50 Case Study

EN 16348 Safety Standard System for Gas Transmission Pipelines
   - Introduction to EN 16348 - functional requirements
   - Safety management system and references to PIMS
   - Practical examples of implementation
   Leen Pronk
   Senior Advisor Asset Management
   Gasunie Transport Services
   and
   Chairman of the Working Group Transmission Pipelines
   Marcogaz, The Netherlands

10:30 Business Card Exchange and Coffee Break

This time slot is an opportunity dedicated specifically to strengthen your business connections by sharing your contact information with the industry peers present.

11:00 Case Study

Pipeline Risk Model in Eustream, a.s. and its Real Behavior (2009-2013)
   - Risk model in Eustream – risk factors
   - Risk model behavior in years 2009-2013
   - Analyses and reasons of risk model behavior
   Branislav Reťkovský
   Head of GIS and ITIS Department
   Eustream, a.s., Slovakia

12:20 Lunch Break

13:20 Coffee and Networking Break

14:00 Panel Discussion

Offshore pipeline management
   - Requirements and standards for offshore pipes
   - Difficulties in offshore pipelines maintenance
   - What challenges offshore pipeline operators are facing and how they overcome them

14:40 Pipelines under ImposeDeformation - Local Buckling
   - Buried pipelines in settlement areas, local buckling limits
   - Post buckling behaviour, safety against leakage and burst, effect of cyclic pressure loading
   - Local buckling limits of lined pipe (carbon steel outer pipe and stainless steel liner pipe) for reeling installation offshore
   Prof. Ir. A.M. (Nol) Gresnigt
   Assoc. Prof. Steel Structures, Faculty of Civil Engineering & Geosciences
   Delft University of Technology, The Netherlands

15:20 Coffee and Networking Break

16:00 Third Party Interferences during the operation of a city natural gas distribution network
   - Brief information about the natural gas network in Kayseri
   - Difficulties of working at highly populated areas
   - Challenges in Maintaining Right of Way
   - Examples to third party damages
   - Preventive measures for pipeline integrity and operation safety
   Hasan Yasir Bora
   General Manager
   Kayserigaz A.S. (an EWE Grp. Co.), Turkey

16:40 Closing Remarks from the Chair & Wrap up of Day Two
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In the oil & gas industry

DNV GL is the leading technical advisor to the global oil and gas industry. We provide consistent, integrated technical and advisory services within risk management and offshore classification, to enable safe, reliable and enhanced performance in projects and operations. We drive the industry forward by developing best practices and standards. Our people combine industry expertise, multi-disciplinary skills and innovation to solve complex challenges for our customers.

DNV GL has specific in-depth asset (integrity) management and safety management experience within the European gas sector, since our heritage partly originates from the Research & Development departments of transmission system operator Gasunie in the Netherlands and the former British utility company British Gas.

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KTN AS is a technology company that specializes in condition assessments and periodic maintenance of oil and gas pipelines. The company performs work on offshore installations and onshore terminals and process plants internationally. KTN is especially well known for their tethered tool inspection technology for challenging pipelines. Different types of measuring technologies are offered: Ultrasonic wall thickness and crack measurement, angular beam pulse echo and TOFD. BIDI UT tools can be pumped or inspect the line self-propelled.

The Technology is under a constant development and every year new types of solutions and applications can be offered to the market.

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Pipelines under Imposed Deformation
Local Buckling

A.M. (Nol) Gresnigt
Delft University of Technology
Faculty of Civil Engineering & Geosciences
Contents

- Introduction, importance of deformation capacity
- Local buckling tests UOE and seamless
- Effect of pressure on local buckling curvature
- Effect of local buckling on burst pressure
- Effect of local buckling on fatigue behaviour
- Current research on spirally welded pipes
- Concluding remarks
- Publications
Deformation capacity of pipelines

- Onshore, pipelines in settlement areas
- Crossings in The Netherlands till 1990
  - Over the dike (no digging allowed in the dike)
  - Soft soils: extra load gives differences in settlements and imposed bending of the pipe
  - In the beginning of the 1970's: elastic theory gave far higher stresses than allowable
  - Requirement: replace crossings or remove settlements
  - Solution: apply plastic theory and limit state design: "strain based design"
  - First Dutch standard on plastic design of pipelines in 1977
- Crossings now: Horizontal drilling
- Offshore: Deformation capacity required: uneven sea bottoms etc.

Dike and Road crossings

Dike and Road crossings
Deformation capacity of pipelines

- Bending moment mostly less important
- Local buckling curvature:
  - D/t ratio
  - Internal pressure - external pressure
  - Soil loads – support loads
  - Imperfections in the geometry
  - Strain hardening properties of steel: Re / Rm ratio
  - Bauschinger effect: UO-UOE
  - Large scatter, especially in thin walled pipes
  - Questionable definition of local buckling: curvature at maximum moment

Pipe 20" - B3

"Thick walled pipe"
Deformation capacity of pipelines

Different buckle shapes

Thin walled pipe

Thick walled pipe
Deformation capacity of pipelines

- **Bending**
  - Low internal pressure
  - High internal pressure

- **Bending + torsion**
  - Low internal pressure
  - High internal pressure
Buckling design equations

AGA research program 1998: many different buckling design equations

**Buckling strain**

BS 8010 (1993):

\[ \varepsilon_c = 15 \left( \frac{t_{\text{nom}}}{D_0} \right)^2 \]

Gresnigt (1986):

for \( \frac{D}{t} < 120 : \quad \varepsilon_c = 0.5 \frac{t}{D} - 0.0025 \)

for \( \frac{D}{t} \geq 120 : \quad \varepsilon_c = 0.2 \frac{t}{D} \)

Murphey and Langner (1985):

\[ \varepsilon_c = 0.5 \frac{t}{D} \]

Igland (1993):

\[ \varepsilon_c = 0.005 + 13 \left( \frac{t}{D_0} \right)^2 \]

\( D_0 = \) outside diameter

\( D = D_0 - t \)

DNV (1996):

\[ \varepsilon_c = \frac{t}{D_0} - 0.01 \]

ABS (2001):

\[ \varepsilon_c = 0.5 \frac{t}{D_0} \]

**Bending moment capacity**

BS 8010 (1993):

\[ M_c = M_p \left( 1 - 0.0024 \frac{D_0}{t_{\text{min}}} \right) \]

with:

\[ M_p = D^2 t_{\text{nom}} \sigma_y \]

DNV (1996):

\[ M_c = (D_0)^2 t_{\text{nom}} \sigma_y \]

ABS (2001):

\[ M_c = M_p \left( 1.05 - 0.0015 \frac{D_0}{t} \right) \]
AGA: Buckling and collapse of UOE pipes (1998)

Table 1. Summary of measured dimensions (averaged values).

<table>
<thead>
<tr>
<th>Test</th>
<th>Type</th>
<th>Wall thickness [mm]</th>
<th>Diameter [mm]</th>
<th>Ovalisation [%]</th>
<th>D/t</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>UOE</td>
<td>11.22</td>
<td>509.0</td>
<td>0.285</td>
<td>45.4</td>
</tr>
<tr>
<td>B2</td>
<td>Seamless</td>
<td>17.54</td>
<td>514.7</td>
<td>0.078</td>
<td>29.3</td>
</tr>
<tr>
<td>B3</td>
<td>UOE</td>
<td>18.99</td>
<td>507.9</td>
<td>0.138</td>
<td>26.8</td>
</tr>
<tr>
<td>B4</td>
<td>UOE</td>
<td>23.61</td>
<td>525.6</td>
<td>0.124</td>
<td>22.3</td>
</tr>
</tbody>
</table>

Table 2: Material properties of the pipe sections (tensile tests).

<table>
<thead>
<tr>
<th>Test</th>
<th>Direction</th>
<th>0.2% yield N/mm²</th>
<th>Ultimate N/mm²</th>
<th>Elongation %</th>
<th>Necking %</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Longitudinal</td>
<td>479</td>
<td>568</td>
<td>39</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Circumferential</td>
<td>429</td>
<td>575</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>B2</td>
<td>Longitudinal</td>
<td>459</td>
<td>533</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Circumferential</td>
<td>373</td>
<td>538</td>
<td>36</td>
<td>33</td>
</tr>
<tr>
<td>B3</td>
<td>Longitudinal</td>
<td>474</td>
<td>527</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Circumferential</td>
<td>457</td>
<td>548</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>B4</td>
<td>Longitudinal</td>
<td>450</td>
<td>534</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Circumferential</td>
<td>466</td>
<td>560</td>
<td>31</td>
<td>38</td>
</tr>
</tbody>
</table>

- Bending and collapse tests
- Four 20” pipes
- Big difference longitudinal and circumferential material properties for seamless
- UOE - Bauschinger
AGA: Bauschinger

3 mm compressive tests with strain gauges

Seamless pipe

UOE pipe

Amsterdam, 18-19 September 2014
AGA: Bending tests

Ovalisation and deflection (curvature), (measuring length 1500 mm)
AGA: Bending tests

Pipe 20" - B1

B1: UOE pipe

Pipe 20" - B2

B2: Seamless pipe

TU Delft
AGA: Bending tests

B1: UOE pipe

B2: Seamless pipe

B3: UOE pipe

B4: UOE pipe

Amsterdam, 18-19 September 2014
AGA: Evaluation bending test results

Bending strain of pipes.

<table>
<thead>
<tr>
<th>Prediction model</th>
<th>Mean correction of $\alpha$</th>
<th>CoV of $\alpha$</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 8010</td>
<td>1.123</td>
<td>0.393</td>
<td>0.738</td>
</tr>
<tr>
<td>Igland</td>
<td>0.896</td>
<td>0.311</td>
<td>0.738</td>
</tr>
<tr>
<td>Murphey Langner</td>
<td>1.076</td>
<td>0.260 *)</td>
<td>0.792</td>
</tr>
<tr>
<td>Gresnigt</td>
<td>1.271</td>
<td>0.261</td>
<td>0.791</td>
</tr>
<tr>
<td>DNV</td>
<td>0.854</td>
<td>0.292</td>
<td>0.790</td>
</tr>
</tbody>
</table>

*) Lowest CoV

- Data base of tests
- $15 < D/t < 50$
- Statistical evaluation: Murphey-Langner best for strain
- Gresnigt 2nd best for this D/t range

$$\varepsilon_c = 0.5 \frac{t}{D}$$

$$\varepsilon_c = 0.5 \frac{t}{D} - 0.0025$$
Local buckling equations – big scatter

Compressive strains

Murphy: \[ \varepsilon_{cr} = 0,50 \frac{D}{t} \]
Gresnigt: \[ \varepsilon_{cr} = 0,50 \frac{D}{t} - 0,0025 \]
DNV: \[ \varepsilon_{cr} = 1,00 \frac{D}{t} - 0,0100 \]
DeGeer: \[ \varepsilon_{cr} = 0,75 \frac{D}{t} - 0,0075 \]

Need for improvement!
AGA: Concluding remarks thick walled pipes

- Cold expansion is beneficial for the buckling strain in bending.
- The Bauschinger effect due to cold expansion reduces the collapse resistance up to 20% (collapse tests on the same pipes). Confirmed in FEA.
- Whether Bauschinger is beneficial for the combination bending and external water pressure, will depend on the water depth.
- The definition for the buckling strain is taken as the strain at maximum moment. In deformation controlled situations this is not a real failure mode.
- The difference in post buckling behaviour between thin walled and thick walled pipe allows a lower safety level for thick walled pipe.
- A lower safety level for deformation controlled situations to be adopted than for load-controlled situations, especially for thick walled pipelines. DNV gives guidance on that.
Thinner walled pipes

- Much scatter
- Influence of internal pressure
- Influence of ovalisation e.g. due to earth loading

For $t/r' < 60$: 
$$ \varepsilon_{cr} = 0.25 \frac{t}{r'} - 0.0025 + 3000 \left( \frac{Pr}{Et} \right)^2 \cdot \frac{|P|}{P} $$

For $t/r' \geq 60$: 
$$ \varepsilon_{cr} = 0.10 \frac{t}{r'} + 3000 \left( \frac{Pr}{Et} \right)^2 \cdot \frac{|P|}{P} $$

$$ r' = \frac{r}{1 - \frac{3a}{r}} $$
Effect of local buckling on burst pressure

- Deformation controlled: bending moment capacity is not important
- Plastic design: redistribution of stresses to give optimal resistance to avoid failure
- Requirement: ductile material behaviour
- Many tests to validate theoretical findings and to convince authorities
- Mostly the “non loaded” pipe did burst first

E.g. Out of plane bending
Effect of local buckling on burst pressure

- Bending – burst test on 24” - 6.4 mm X52 pipe
- Buckling away from girth weld
- Burst away from local buckle
- Burst pressures equal
Remaining Life of Buckled Pipelines – Fatigue

Installation of pipeline crossings

- Now: Horizontal drilling
- Till about 1990: “Zinkers”
  - Often in a bundle
  - Underwater dredging not always accurate
  - Lowering the “zinker” not always well controlled
  - Soft soils: settlements and bending occur
- Severe bending has caused local buckles in a “zinker” near Rotterdam

“Zinker”
Local buckles in a pipeline crossing near Rotterdam

- Pipeline crossing
  - Installed in 1969
  - 24″ - 70 mm
  - Steel ST 37.2, specified minimum yield stress 240 MPa
  - Water transport, Max Operating Pressure 7 bar

- Local Buckles and dents
  - Inspection with video camera through pipe revealed local buckles and dents
  - Shape and depth could be estimated
What to do with the local buckles?

- Replacement or strengthening of buckled part?
  - In under water section not well possible
  - Only solution: replacement of complete crossing

- Fitness for purpose
  - What is required safety level?
  - What is present safety level?
  - If acceptable: What is remaining safe operating time?

- Loading conditions
  - Variations in internal pressure give:
    - Variations in ovalisation and buckle configuration
    - Variations in bending moment due to stretching of buckles and nearby bends
Low cycle fatigue

- What strain variations occur?
- Low cycle fatigue tests on similar pipe
  - Four point bending to introduce local buckles
  - Variations in internal pressure / bending moment
  - Measurement of strains and strain variations
- Finite element calculations:
  - To simulate the tests and validate the FEA model to calculate strain variations
  - To carry out parameter studies
- Analytical modelling:
  - Load - deformation behaviour near and in buckles
  - Estimate of fatigue life
Low cycle fatigue tests

- Four point bending in two directions
- Large deformations
Low cycle fatigue tests, 1, 2, 3

Tests:
1. Bending
2. Pressure
3. Bending, pressure, burst

Start of bending 24" - 7,9 mm pipe
Low cycle fatigue test 1: bending

- Constant pressure 1 bar
- Variations in bending
- FEA indicated correct crack location
- Measured and FEA strains OK
Low cycle fatigue test 3: Bending, pressure variation, burst

- After 50% fatigue loading: burst test
- Burst outside buckle and fatigue damage area
- Buckle "disappeared"
- Advise: Replacement of pipeline crossing: not necessary
Concluding remarks fatigue

- **Replacement** of pipeline crossing near Rotterdam not necessary
- **Tools are available to evaluate fatigue life** of buckled pipe
- Pipelines get older, inspection techniques get better: **more buckled pipes will be found**
- More work to be done to come up with **"design rules"**
Local buckling of spirally welded pipes

- RFCS project, focusing on application in combined walls: quay walls in harbours and building pits
- Bending moment capacity $M = \frac{D^2 f_y}{t}$
- Economic design: thin walled $D/t = 80 - 120$
- Spirally welded pipes:
  - Much lower purchase costs than longitudinal welded pipe
  - Available in large diameters
  - Can be fabricated at any length

Tubular pile Connector

New Quay Wall Rotterdam
European research – Eurocode 3

- Motivation RFCS:
  - Present rules Eurocode 3: too conservative and uneconomic for local buckling.
  - Present rules are stress based instead of strain based: influences that affect the bending moment behaviour directly reduce the bending moment capacity instead of rotation capacity.

Other influences can be:
- Soil load
- External pressure
- Internal pressure
- Support loads
- Ovality
- Geometrical imperfections
- Attachments
- ....

- $\Delta M$ is often small and easy to calculate.
- Working along the strain (curvature) axis offers better insight in the effect of “other influences” on local buckling and thereby on the bending moment capacity.
Bending test #1

- Pour point bending, with thin straps for load introduction to avoid influences of load introduction on ovalisation and local buckling
- Measurement of Diameter, wall thickness, imperfections, residual stresses, material data, moment-curvature, ovalisation, strains
- Laser cart to follow growth of wrinkles from initial imperfections

Pipe 1067mm x 16mm, X70

Amsterdam, 18-19 September 2014
Bending test #1

Spirally welded pipe, 1067x16.0 - X70

Local buckling

Imperfections with laser show:
- Spiral welds
- Smaller imperfections between spiral welds

\[ \varepsilon_{cr} = 0.5 \frac{t}{D} - 0.0025 = 0.5 \frac{16}{1067} - 0.0025 = 0.004998 \]

\[ C_{cr} = \varepsilon_{cr} \cdot \frac{D}{2} = 0.004998 \cdot \frac{1067}{2} = 9.37 \cdot 10^{-6} \text{ mm}^{-1} = 0.00937 \text{ m}^{-1} \]

Design rule for local buckling in e.g. EN1594 pipeline standard gives safe prediction.
Bending test #2

- 14 tests in Delft
- Also test program in Karlsruhe University (KIT): bending plus normal force
- Variation in D/t, steel grade, effect of girth weld, coil weld
- Tests used for calibration FEM models (Abaqus) in U-Volos and U-Edinburgh
- Parameter studies where all relevant geometrical and material properties are taken into account:
  - To develop design guidance that cover test results better: less scatter
  - Design guidance will also be important for pipelines

Pipe 1067mm x 9mm, X70
Concluding remarks Local Buckling

- There is large scatter in tests results and design rules
- Sources for scatter are identified
- An extensive research program is set up to quantify the influence of these scatter sources to develop more accurate design rules:
  - Further analysis of own test data and test data reported elsewhere (databases)
  - Test programme with extensive measurements of relevant influences
  - Validation of FEM models at two different places
  - Parameter studies
  - Special attention of remaining life after local buckling

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Thank you for your attention!!

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Volos
Publications (1)

Publications (2)


Publications (3)


