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The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

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The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

- **CRA LINED PIPE – DEFINITION & APPLICATION**

- *“Lined pipe (L): Pipe with internal (corrosion resistant) liner where the bond between (linepipe) backing steel and liner material is mechanical” – DNV OS-F101 (2010)*
- CRA Lined Pipe is manufactured to International Standards
 - *API 5LD – Specification for CRA Clad or Lined Steel Pipe*
 - *DNV OS-F101 – Submarine Pipeline Systems*
- Bimetal / CRA Lined Pipe is used for Offshore and Onshore Oil and Gas Flowlines and Pipelines in Pipe Sizes up to NPS 26 for the Transportation of Corrosive Multi-Phase Wellstream Fluids between Well Head and Process Platform or Process Plant, including Subsea Pipeline Systems Operating under High Pressure/High Temperature (HP/HT) Conditions

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

- **CRA LINED PIPE FOR HP/HT SERVICE – WHY?**

- Substantial cost savings – CRA lined pipe is typically 30-60% lower cost than corresponding metallurgically clad pipe
- Wider range of CRA liner alloy selection – typically Stainless Steels such as 316L or 317L and Nickel Alloys such as Incoloy 825, Inconel 625 and including Alloy 904L, where clad pipe from clad plate is not possible
- Faster delivery times can be achieved by CRA lined pipe manufacturers with highly scalable production processes
- Large number of projects in the future that will require CRA flowlines with the result that demand growth for CRA flowlines is likely to outstrip the capacity of the industry to supply metallurgically clad pipes.

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- **CRA LINED PIPE FOR HP/HT SERVICE – DESIGN**

- Pipelines in High Temperature High Pressure (HP/HT) service are susceptible to lateral pipeline buckling on account of high axial compressive forces caused by thermal heating and internal pressure
- Under conditions of high axial compressive strain, the load capacity of lined pipe will be limited by the onset of liner wrinkling or buckling
- DNV design guidance includes a limit state strain criterion for lined pipe for the onset of liner wrinkling - JIP “Lined and Clad Pipeline Materials”
- The DNV limit state strain criterion is derived from bend test data and assumes no or low internal pressure. The strain criterion is found to be dependent on the Diameter to Thickness Ratio (D/t) of the liner.

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- **OUTLINE OF STUDY CONDUCTED BY CLADTEK**

- FOUR POINT BEND TEST PROGRAMME

- Large Diameter (NPS 24) CRA Lined Pipe
 - High Temperature, Low Pressure, High Axial Strain
 - Displacement Controlled Bending

- ADDITIONAL FEATURES

- Gripping Force (Ex-Mill, Post-Coating, Post-Hydrotest)
 - Simulation of Pipeline Coating
 - Offshore S-Lay Barge Installation Conditions
 - Pipeline System Pressure Test (Field Hydrotest)
 - HPHT Operating Conditions (inc. Start-up/Shutdown)

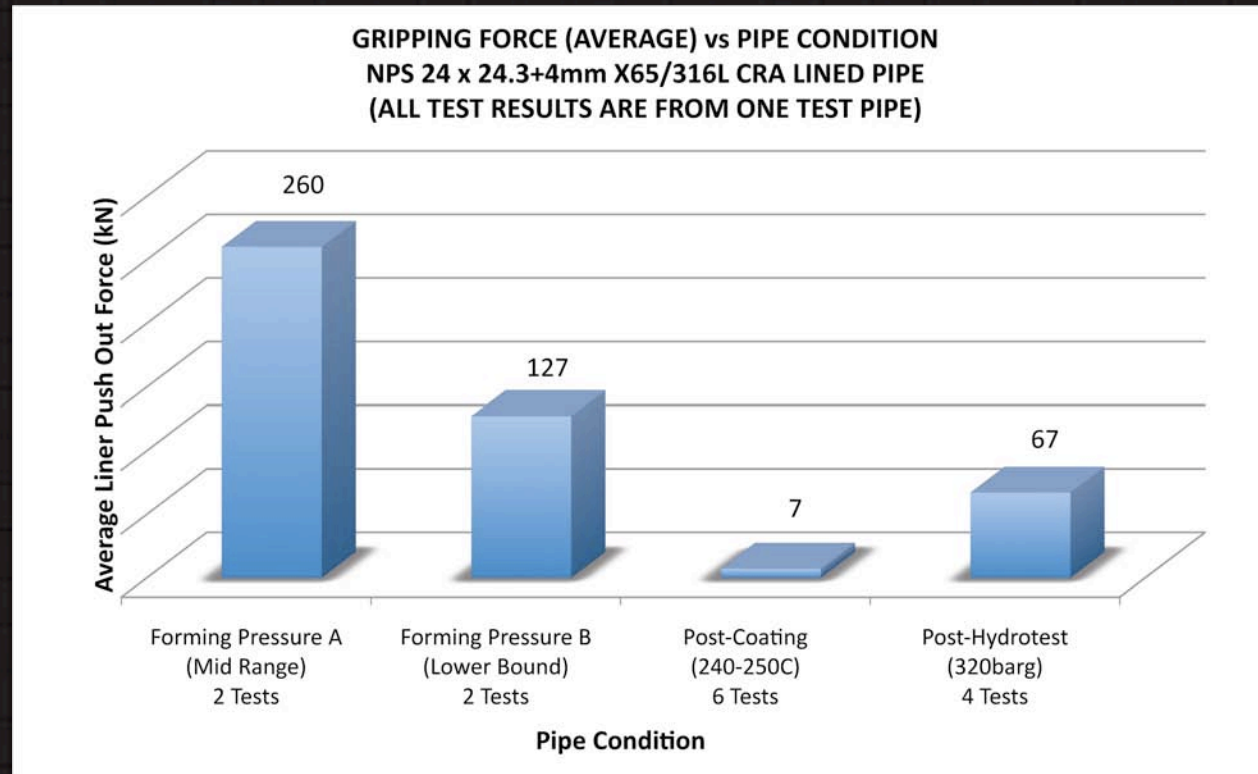
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| Property | Value |
|--------------------------|-----------------------------|
| CS Pipe Outside Diameter | 609.6mm (NPS 24) |
| CS Pipe Wall Thickness | 24.3mm |
| CS Pipe Material Grade | API 5L-X65 (Grade 450) SAWL |
| CRA Liner Thickness | 4mm |
| CRA Liner Material Grade | 316L (UNS S31603) |
| Test Pipe Length | 12m |

TEST PIPE MATERIALS



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Liner Gripping Force for NPS 24 X65/316L Lined Pipe
After Pipeline Coating and Field Hydrotest

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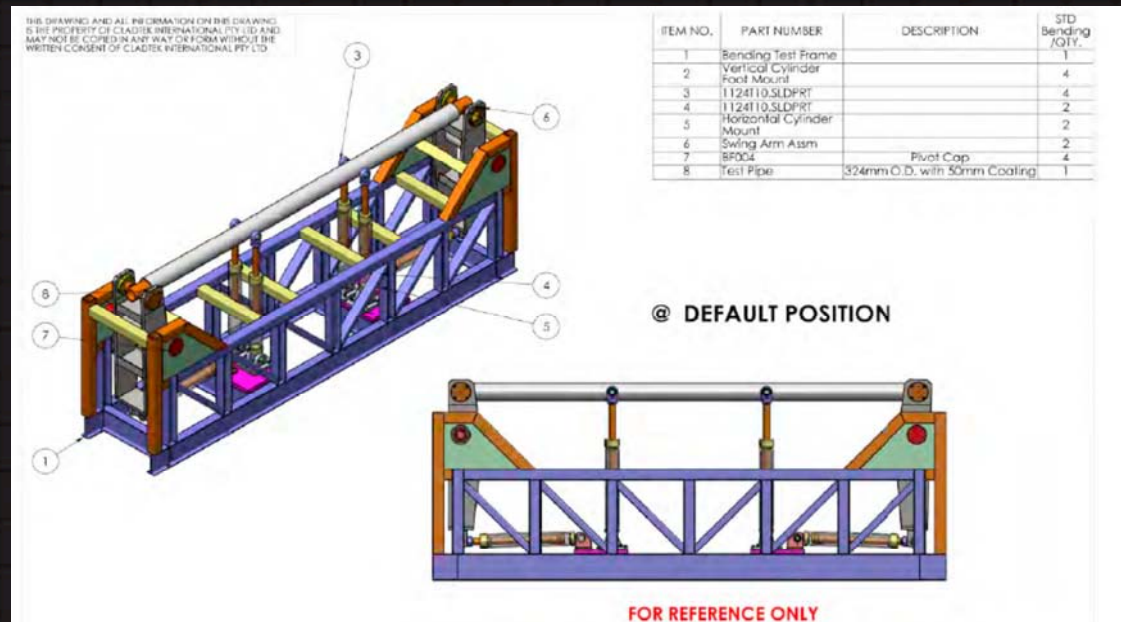
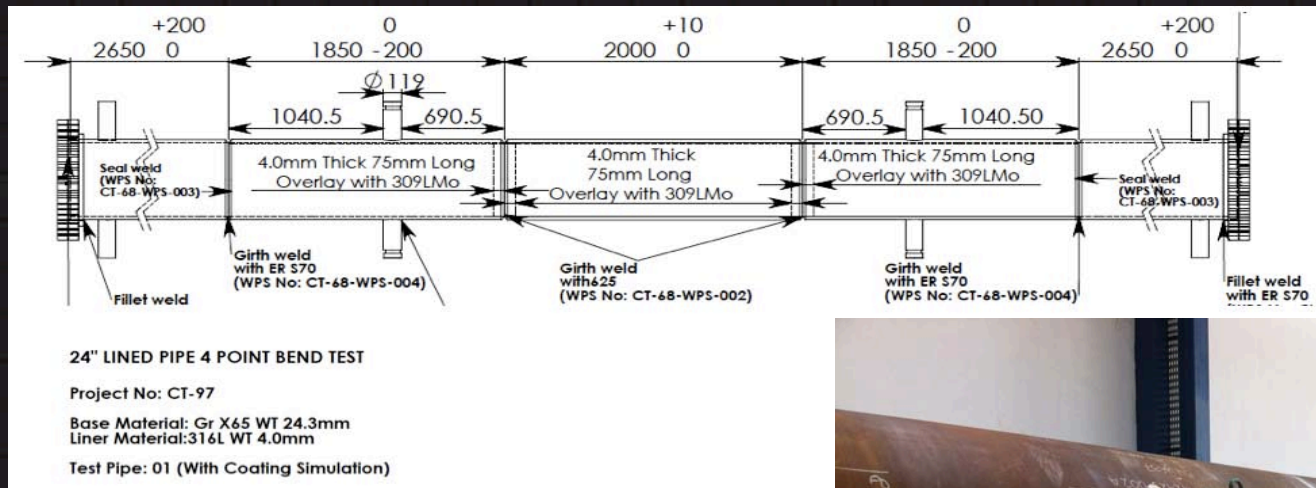


Diagram of Test Loading Equipment showing 4 Point Bend Test Configuration

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling



Details of Test Pipe Assembly

Photograph of Test Pipe Mounted in Rig for INSTALLATION TESTS



The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling



Internal HD 1080p Colour
Video Camera (top) in
Air Cooled, Pressure Tight
Enclosure with Halogen
Lighting (bottom)

Two (2) Video Cameras used
inside each Test Pipe to
Continuously Monitor CRA
Liner Condition

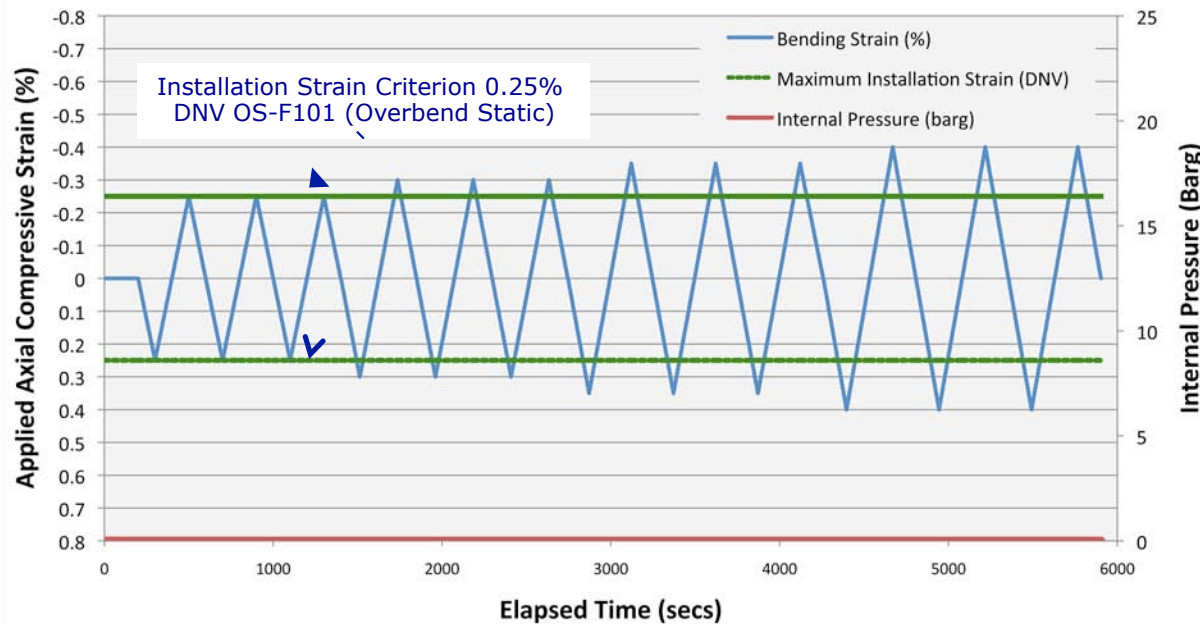
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| Activity | Parameter | Value |
|---------------------------|---------------------|-----------|
| Pipeline External Coating | Coating Temperature | 240-250°C |
| | Pipe Temperature | Ambient |
| Installation Simulation | Internal Pressure | Ambient |
| | | ±0.25% |
| | Axial Strain | ±0.30% |
| | (3 Cycles per Test) | ±0.35% |
| | | ±0.40% |

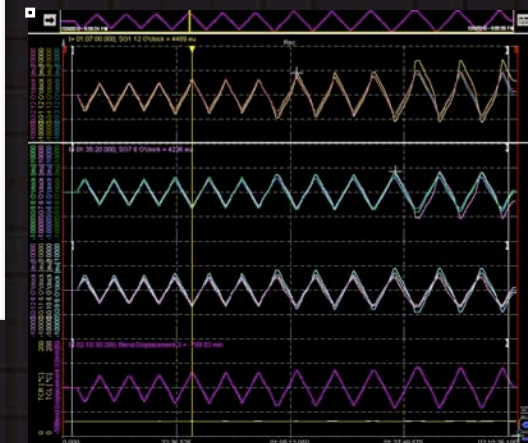
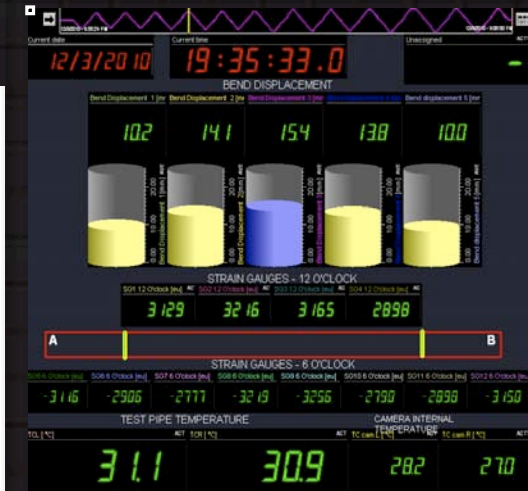
INSTALLATION CONDITIONS: Test Parameters

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

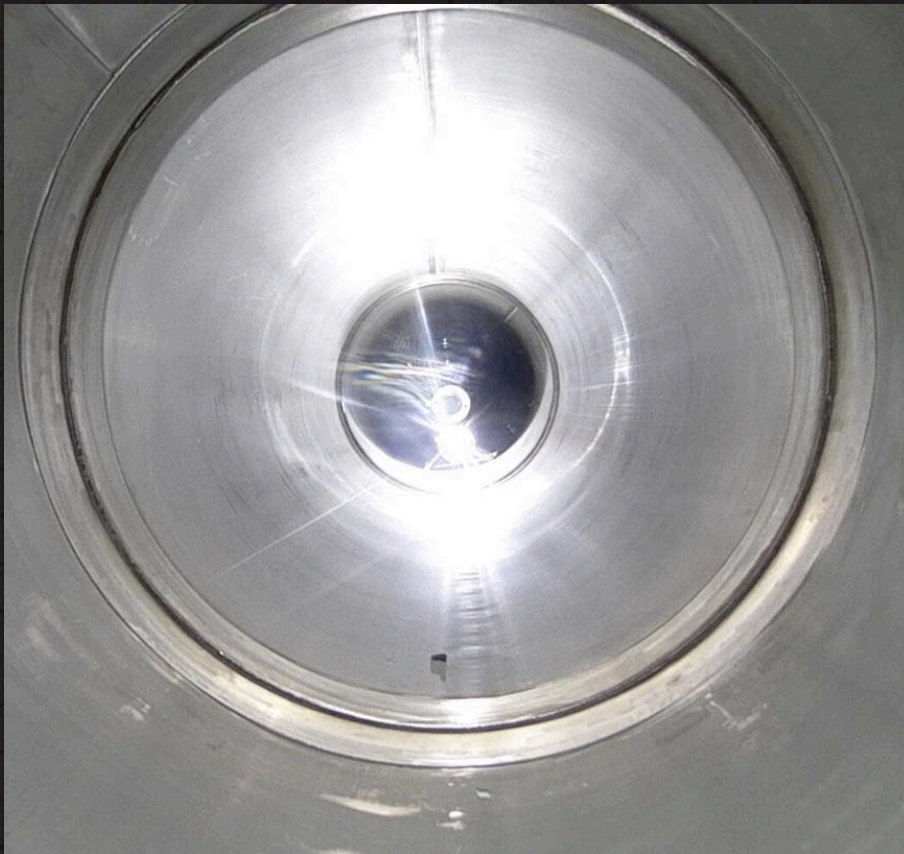
Diagram Showing Applied Cycles of Compressive Axial Strain vs Pressure
Laybarge Installation Condition Bend Testing
NPS 24 x 24.3+4mm X65/316L Lined Pipe



INSTALLATION SIMULATION: Load Schedule and Instrumentation Monitoring



The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling



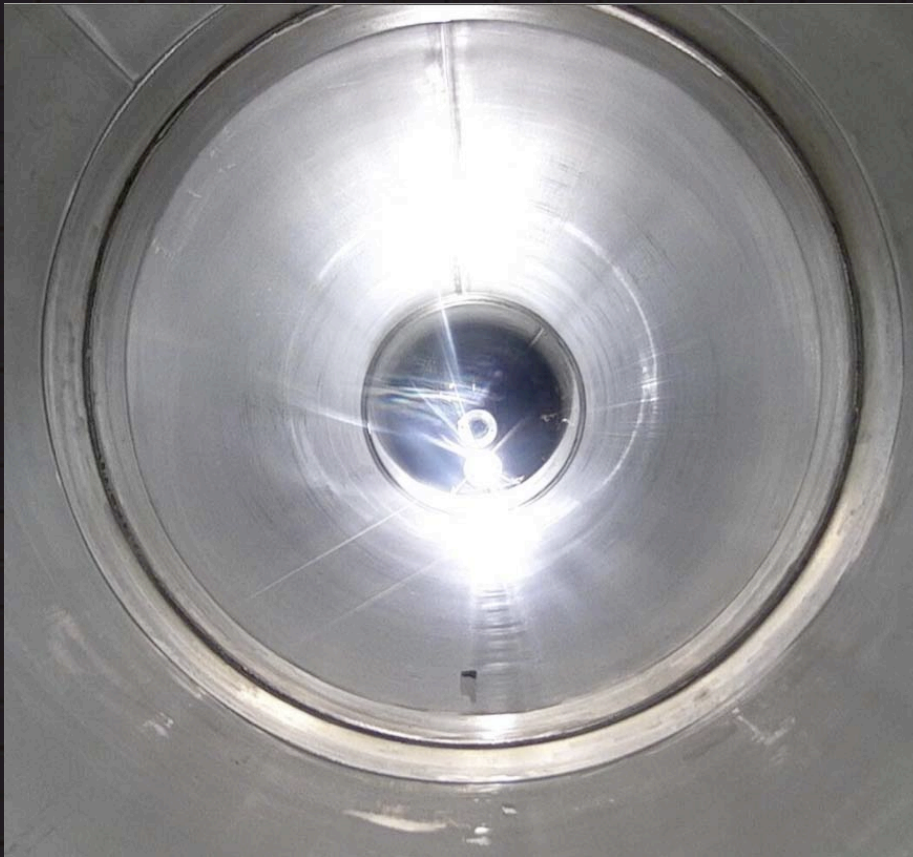
INSTALLATION TESTS

View of Internal CRA
Liner at -0.35% Axial
Compressive Strain –
Exceeds DNV Limits

(Pipe Lined at Lower
Bound Pressure)

NO WRINKLES

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling



INSTALLATION TESTS

View of Internal CRA
Liner After
Completion of All
Installation Tests
($\pm 0.40\%$ Strain)

(Pipe Lined at Lower
Bound Pressure)

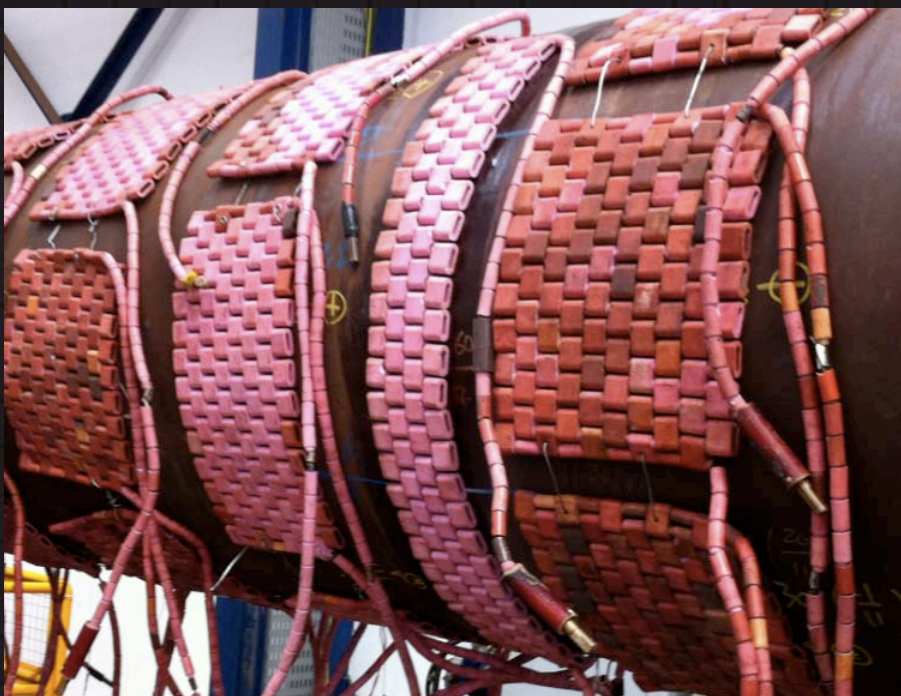
NO WRINKLES

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

| Activity | Parameter | Value |
|------------------------------------|--|-----------------------|
| Pipeline System Pressure Test | Hydrotest Pressure | 320 barg |
| HPHT Operating Conditions | Pipe Temperature | 110°C |
| | Internal Pressure | 20, 15, 10, 5, 0 barg |
| | Axial Strain (1 Cycle per Test) | -0.40% |
| | | -0.50% |
| | | -0.60% |
| HPHT Startup / Shutdown Conditions | Axial Strain 500 Cycles at Temperature 110°C and Pressure 10 barg | -0.2% to -0.5% |

HPHT OPERATING CONDITIONS: Test Parameters

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HPHT OPERATING CONDITION TESTING

Picture showing
method of heating
test pipe using
ceramic pad electric
resistance heaters

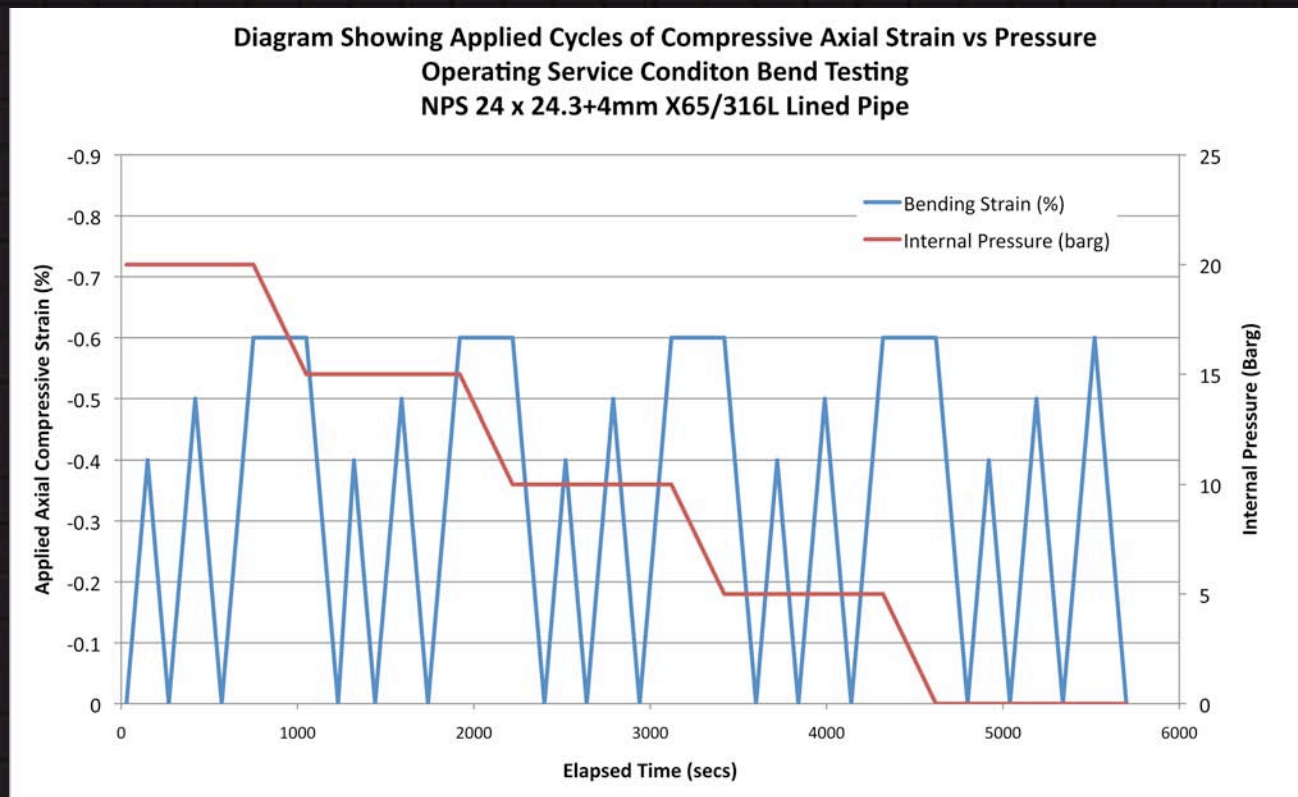
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HPHT OPERATING CONDITION TESTS



NPS 24 Lined Test Pipe Mounted on 4-Point Bend Test Rig

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HPHT OPERATING CONDITION SIMULATION: Schedule of Loading

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HPHT OPERATING CONDITION TESTS

View of Internal CRA
Liner at -0.60% Axial
Compressive Strain,
at Temperature 110°C
& Ambient Pressure
(ZERO barg):

NO WRINKLES

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

- **ADDITIONAL HIGH STRAIN TESTS (HPHT CONDITIONS)**
 - Tested at strains exceeding maximum design strain
 - *Previous bend testing of NPS 20 X65/316L lined pipe under HPHT conditions (130°C and 6 barg) demonstrated that with internal pressure, lined pipe could withstand -1.9% axial strain without any liner wrinkling or buckling.*
 - TEST (A): One NPS 24 lined pipe (at 110°C and 20 barg) was bent to more than the maximum design strain. With no sign of any wrinkle initiation, testing was stopped at -0.8% strain to preserve the pipe for test (B) below.
 - TEST (B): The same NPS 24 lined pipe at 110°C was bent up to -1.0% axial strain with ZERO internal overpressure.

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HPHT OPERATING
CONDITION TESTS
TEST (A) = 20 BARG

View of Internal CRA
Liner at -0.80% Axial
Compressive Strain,
at 20 barg Pressure and
110°C Temperature:

NO WRINKLES

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling



HPHT OPERATING
CONDITION TESTS
TEST (B) = 0 BARG

View of Internal CRA
Liner at -1.0% Axial
Compressive Strain,
at ZERO barg Pressure
and 110°C
Temperature:
Some Wrinkle Initiation

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

| Simulation Test | Temp. | Internal Pressure | Applied Axial Compressive Strain | Liner Condition After Testing |
|---------------------------|---------|-------------------|----------------------------------|--|
| Installation | Ambient | 0 barg | $\pm 0.40\%$ | No wrinkling |
| HPHT Operating Conditions | 110°C | 0 barg | -0.60% | No wrinkling |
| HPHT Start-Up/Shutdown | 110°C | 10 barg | -0.2% to -0.5% (500 cycles) | No wrinkling |
| Test A (20 barg) | 110°C | 20 barg | -0.80% | No wrinkling – <u>limit state strain not reached</u> |
| Test B (ZERO barg) | 110°C | 0 barg | -1.0% | Liner wrinkles first observed at -0.83% |

Summary of All Bend Test Results for NPS 24 Lined Pipe

The Suitability of CRA Lined Pipe for Flowlines Susceptible to Lateral Buckling

| ONSET OF LINER WRINKLING NPS 24 x 24.3+4mm X65/316L LINED PIPE Operating Service Conditions Temperature 110°C and Internal Pressure 0-20 barg | | |
|--|--|--|
| Strain Limit (DNV Design Guidelines) | Wrinkling Strain (ZERO barg Pressure) | Wrinkling Strain (20 barg Pressure) |
| - 0.61% | - 0.83% | Not determined (No wrinkling) |

DNV Limit State Strain Criterion
For Onset of Liner Wrinkling

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- **CONCLUSIONS (1)**

- Liner gripping force is substantially reduced after pipeline coating on account of the preheating for FBE application.
- Hydrostatic pressure testing (including pipeline system pressure test) can restore some liner gripping force.
- No wrinkles or buckles after testing to $\pm 0.40\%$ strain. This level of strain exceeds DNV OS-F101 guidelines limiting the maximum static installation strain to 0.25% for X65 pipe.
- NPS 24 x 24.3+4mm lined pipe can be installed offshore by pipelay barge without liner wrinkling or buckling occurring.

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- **CONCLUSIONS (2)**

- No liner wrinkling or buckling at the maximum design strain (-0.6% at 110°C) with or without internal pressure
- No liner wrinkling or buckling after 500 startup/shutdown cycles of -0.2% to -0.5% at 110°C with 10 barg pressure
- Relatively low internal pressure (20 barg) was able to suppress wrinkle initiation – this is consistent with results from other test programmes (e.g. 20" pipe, 6 bar, 1.9%)
- DNV strain criterion looks conservative for HPHT conditions
- NPS 24 x 24.3+4mm X65/316L lined pipe performance meets, or exceeds, the specified pipeline design criteria and as such is suitable for use in HPHT flowline applications.

THANK YOU!

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