MCE DEEPWATER DEVELOPMENT 2014
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GE Wellstream

Safety
Quality
Integrity

Development of an Ultra-High Pressure Deep Water Riser/Flowline – Challenges and Progress

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imagination at work

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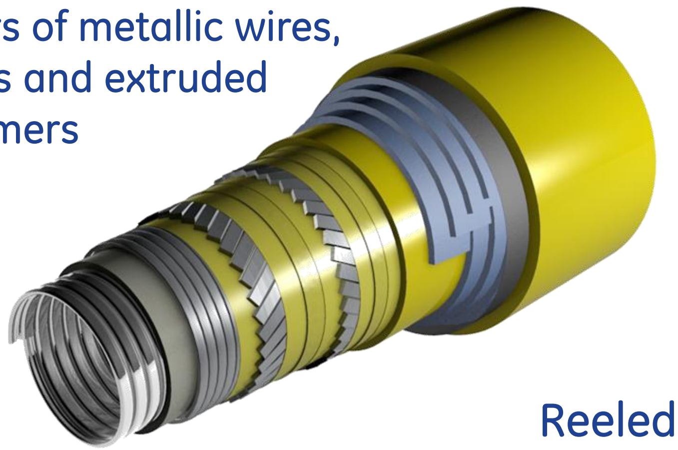
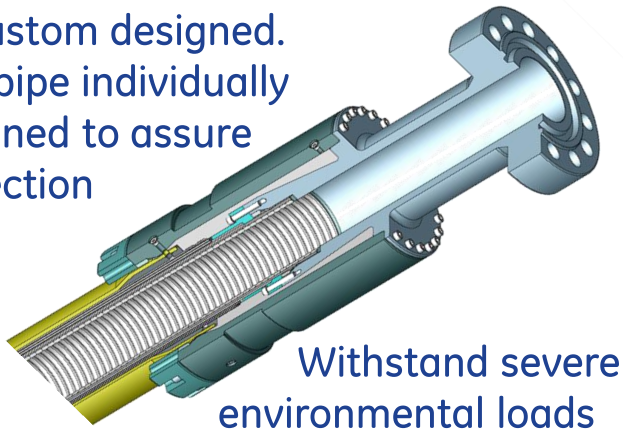
Innovation in Extreme Environment Technologies: High Pressure & Temperature
Thursday, April 10, 2014

Unbonded Flexible Pipe

Pipe consists of concentric layers of metallic wires, tapes and extruded polymers



End fittings are custom designed. Each layer of the pipe individually terminated. Designed to assure a leak tight connection



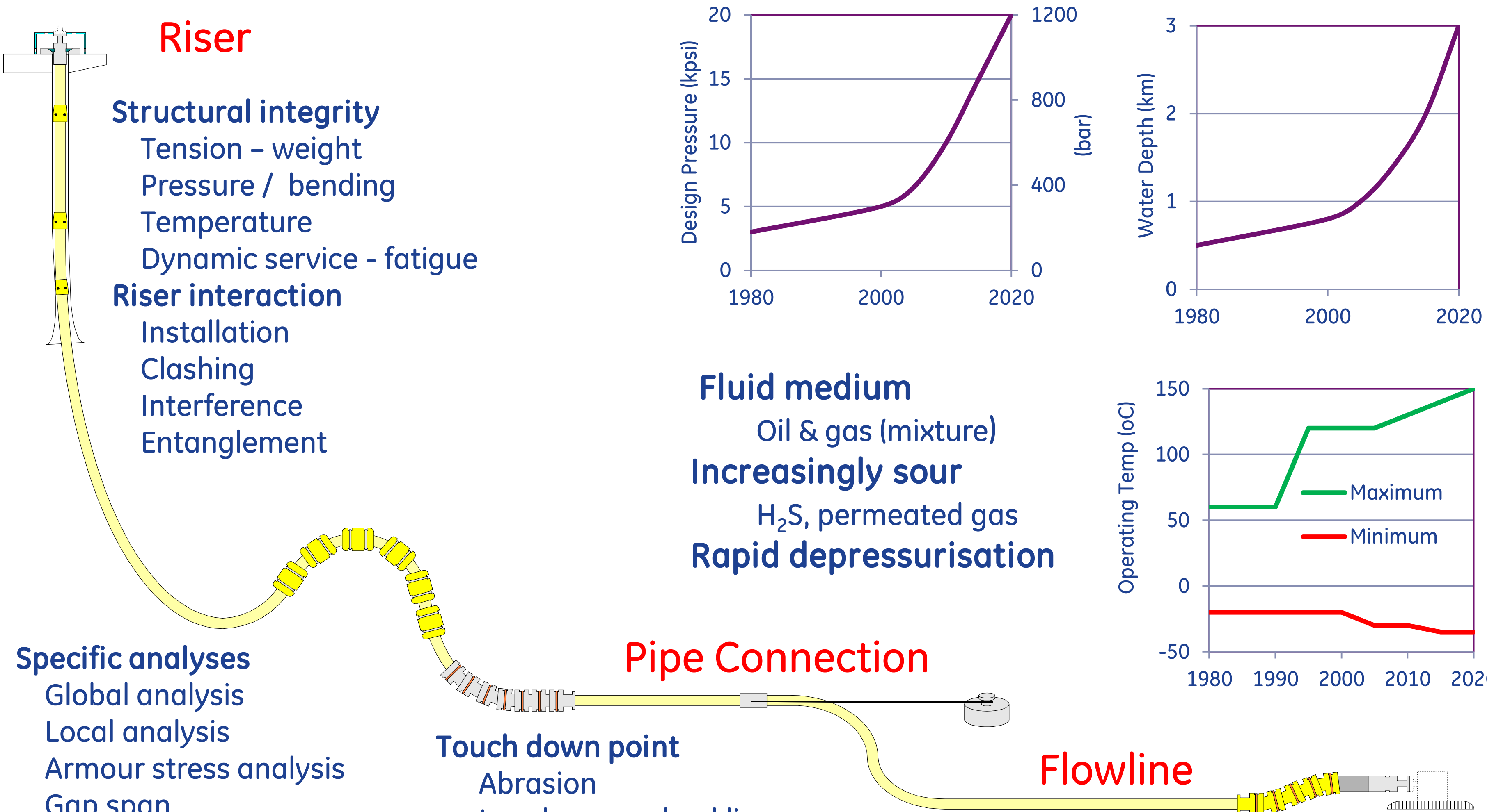
Withstand severe environmental loads and thermal cycling. Stronger than pipe in burst and axial tension. Allow for the venting of permeated gases.

Reeled for Transportation

Designed to form a structure that addresses the specific loads, environmental requirements and characteristics of the transported fluids

Important layers – carcass; fluid barrier; pressure armour; tensile armour; anti-wear layers; external sheath (insulation; condition monitoring; annulus control)

Pipe Outlines and Key Design Considerations



Riser

Structural integrity
- Tension – weight
- Pressure / bending
- Temperature
- Dynamic service - fatigue

Riser interaction
- Installation
- Clashing
- Interference
- Entanglement

Market Demand

Fluid medium
- Oil & gas (mixture)

Increasingly sour
- H_2S, permeated gas

Rapid depressurisation

Specific analyses
- Global analysis
- Local analysis
- Armour stress analysis
- Gap span
- Corrosion fatigue
- End fitting analysis

Pipe Connection

Touch down point
- Abrasion
- Local armour buckling (bird-caging)

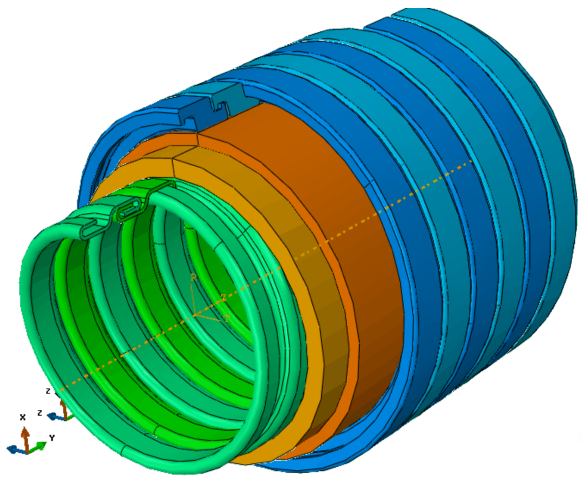
Flowline

Structural integrity
- Pressure/bending -static service
- Temperature

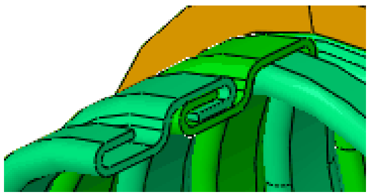
Flexible pipes for high pressure & deep water
Only need a flexible tube (fluid barrier) !!!

Key design features

Strength, durability & integrity
Temperature performance,
Aging behaviour, Fluid compatibility

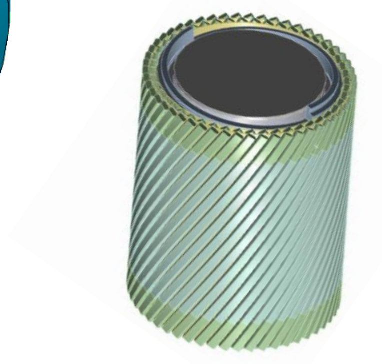


1. Carcass (Flexbody ™)



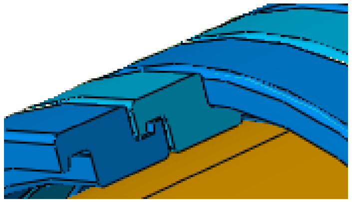
Prevent buckling of polymer tube under external pressure
- Limits water depth
- Limits the diameter

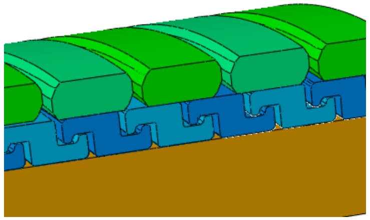
3. Tensile Armour (Flextensile ™)



Prevent extension of polymer tube under weight/axial load.
- Limits water depth
- Several wires
- Multi-layered
- Fatigue resistance (sweet/sour)

2. Pressure Armour (Flexlok ™ / Flexpress ™)

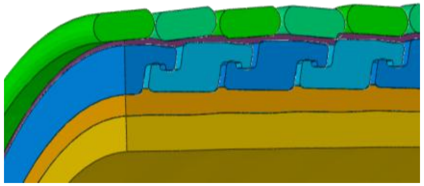




Prevent bulging of polymer tube under internal pressure.
- Limits design pressure
- Limits the diameter
- Can be multi layer
- Need Sacrificial layer for high pressure

4. Anti-wear Layers (Flexwear ™)

Prevent rubbing between metal layers
- Limits pressure
- Fatigue durability
- Annulus Conditions



5. End Fittings - Leak free fluid barrier seal

Termination of carcass, pressure armour and tensile armour wires

6. Installation Requirements

Aim of the Project

Development of a 4 inch (100 mm) diameter riser/flowline for 20kpsi (1200 bar) design pressure and 3 km water depth to operate at 100°C maximum temperature and to transport gas/fluid under mild sour conditions

Key Technical Challenges

- Maintaining the integrity of the polymer barrier
  - Withstand rigorous service temperature and pressure.
  - Compatibility of barrier with service fluids under high pressure
  - Ensuring barrier integrity during service life, thermal cycling, shut-down
- Design of a suitable carcass to resist wet collapse at ultra-deep water
- Selection of metallic hoop armour layers to resist high internal pressure
- Limiting the weight of the pipe and achieving necessary axial stiffness/strength
- Evaluation of layer interaction in two pressure armour layer design
- Development of end fittings with proven seal integrity
- Completion of FAT and offshore field tests without any detrimental effect on pipe
- Achieving necessary bending requirements and packaging
- Ensure damage free dynamic interactions between metal layers
- Safeguard integrity of the pipe under rapid depressurization conditions
- Satisfy Industry design standards (ISO 13628-2)

Design of Fluid Barrier

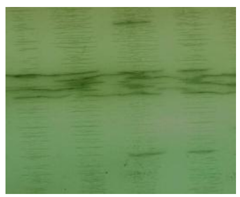
Material - Depends on service temperature : below 60°C – PA or PE and above 60°C PVDF (or PEX/PPS)

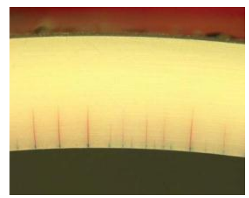
Design Criteria (API 17J) - Static (flowline) require ±7% few cycles + 7% strain for 25 year service
(PVDF) Dynamic (riser) require ±7% few cycles + cyclic ±3.5% strain performance.

Additional Requirements – Manufacture / storage / FAT/ installation
Operation (normal / extreme / abnormal)

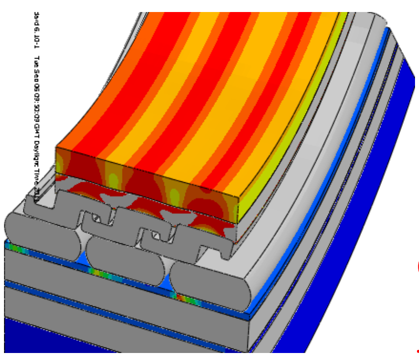
Developing HP & HT Barrier - Challenges

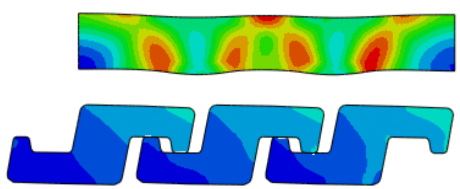
Polymer crazing at high hydrostatic stress





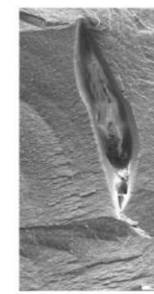
Typical Crazing





Crazing can occur in places of high local Plastic strain if not controlled through design, materials or mitigated through treatment.

Rapid Gas Depression (RGD)

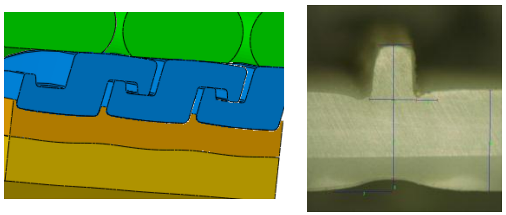


Blistering can occur in some materials if depressurisation rates exceed certain limits.

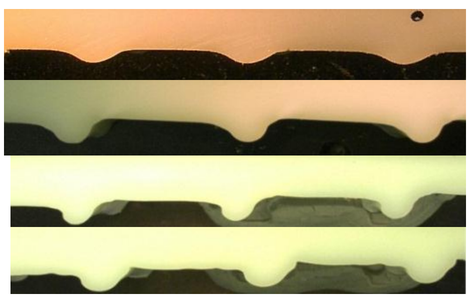
Developing HP & HT Barrier – Barrier Integrity (Fatigue)

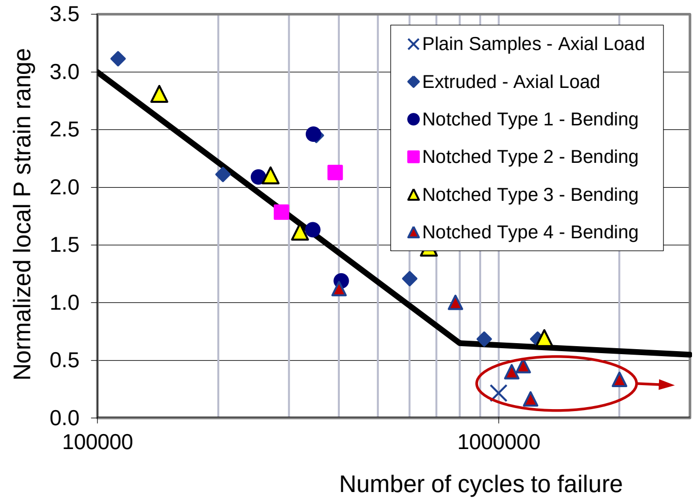
Removing Inner wear layer is considered to be beneficial in high pressure pipes as this facilitates easier additional treatment of the barrier layer to prevent crazing (using GE patent pending technologies). This requires proper design of the polymer barrier for service integrity.

Polymer creep into armour gaps

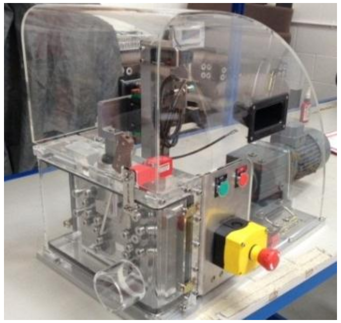


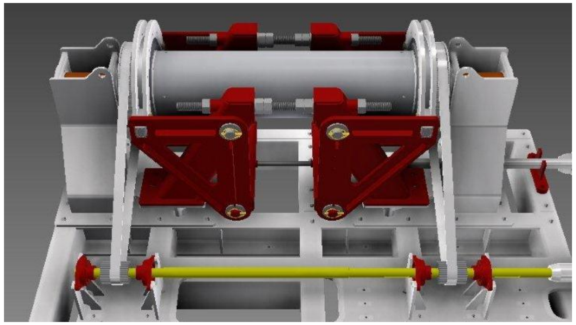
Polymer flow into carcass gaps





Acceptable profile shapes have been identified and the manufacturing procedures and controls have been established and implemented to ensure production of acceptable barrier profiles.





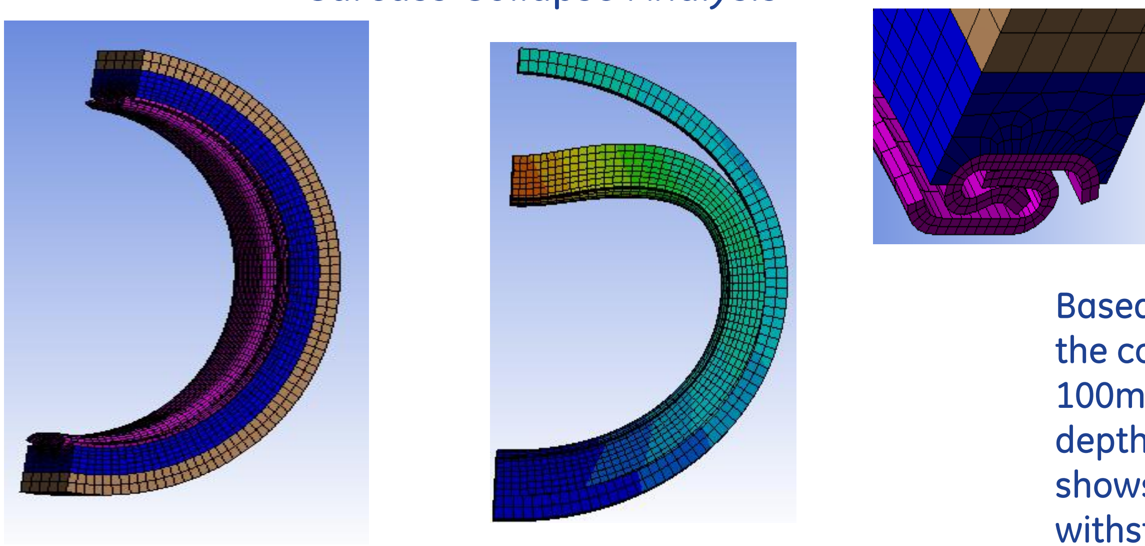
Barrier Pipe Fatigue Testing

Carcass Capability (Limits Inner Diameter of the Pipe)

Carcass prevents inward collapse of the fluid barrier due to external pressure, typically resulting from operating water depth. (API 17J defines utilisation of 0.85 based on yield strength)

2205 Duplex

Carcass Collapse Analysis



Based on the API assessment procedure the collapse capacity predicted for 100mm / 4-inch pipe is 3.5 km sea water depth. Actual qualification test data shows that a 150 mm/6-inch pipe can withstand 4 km water depth (before safety factors are applied for design purposes).

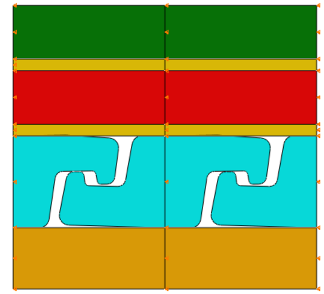
Based on wet collapse test data safe carcass design available for over 3 km water depth.

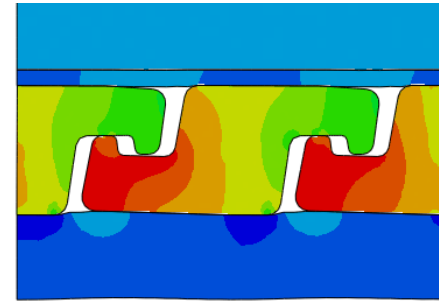
New material options and design improvements

- New materials (higher yield strength)
- Increased Collapse Resistance (modification to section)
- Improve prediction capability- modelling work hardening
- Corrosion resistance
- Additional barrier support
- Elimination of flow induced vibration

Pressure Armour Capacity

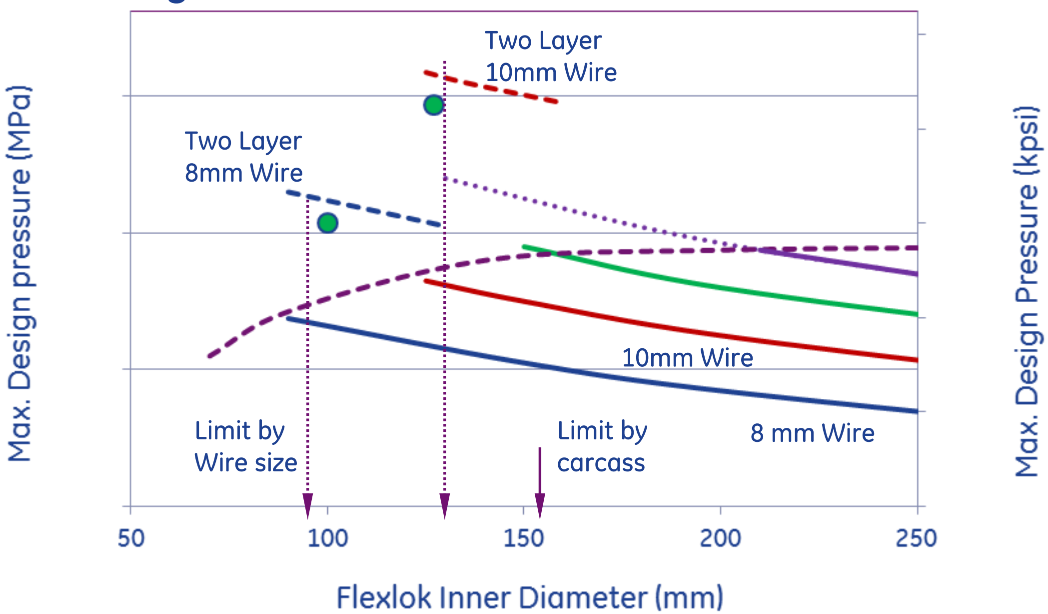
Function of the pressure armour is to resist internal & external pressure and give strength in the hoop direction during manufacture, installation and operation. Provide a guard against creep extrusion of the polymer.



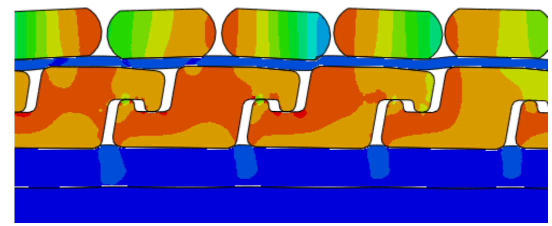


Utilisation depends on load case

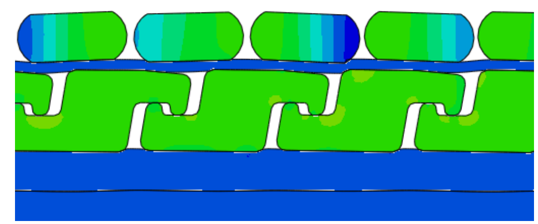
HP Design Criteria



Dual pressure armour design



Hoop stress at FAT



Hoop stress at P DESIGN

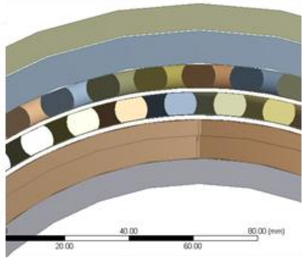
Based on available carcass design for 3 km water depth maximum pipe internal diameter is limited to 150 mm. Due to manufacturing limitations the pressure armour wire thickness needs to be below 12 mm. Single pressure armour (8 mm and 10 mm) insufficient to achieve design pressure of 15kpsi

Dual pressure armour required - 8 (+ 8) mm wire scan give 15 kpsi
10 (+10) mm wires can give 20 kpsi

Tensile Armour Capacity

Multiple helically formed wires - Support axial load (mainly due to weight.
Pairs of contra-wound layers to give torsional stability.
Lay angle optimised during pipe design to balance axial capacity and hoop strength, giving additional support to the pressure armour layer.

The high strength requirements coupled with the suspended riser length result in a very heavy structure and corresponding high topside loads.



Tensile armour wires are qualified to ISO 13628-2:2008
Utilisation depends on load case

Deep Water 3 km

High Pressure 20 kpsi

Tensile + Hoop Strength

Established Materials

New Materials

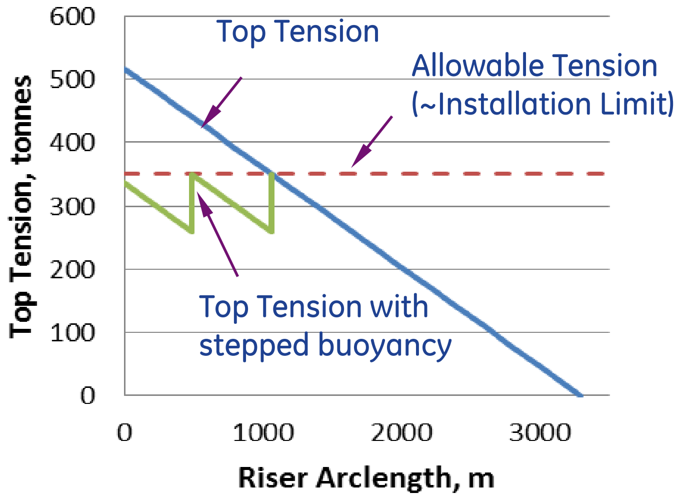
2 Armour	4 Armour	2 Armour	4 Armour
Hoop - OK	Hoop - OK	Hoop - OK	Hoop - OK
Tensile – Not Acceptable	Tensile – OK	Tensile – OK	Tensile – OK
	Not ideal, significant buoyancy required	buoyancy or split riser design	

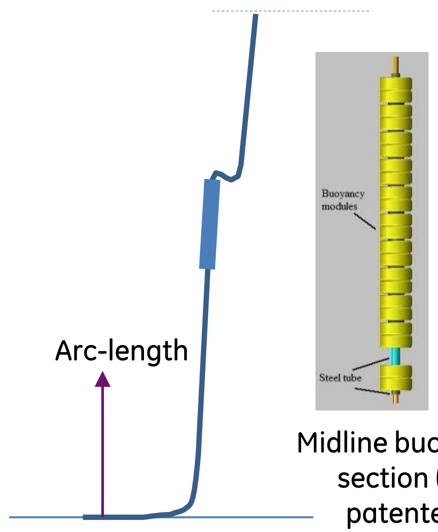
Touchdown zone

Tensile wire buckling resistance is also a consideration. The minimum bend radius of the pipe depends on water depth.

Buoyancy Requirements of HP Deep Water Pipes

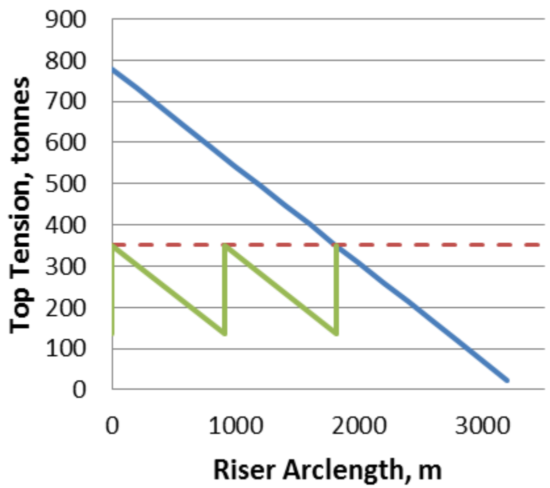
2 Tensile Armour Design – New Materials
(2 x 90 tonnes buoyancy)





Midline buoyancy section (GE patented)

4 Tensile Armour Design
Current Materials
(2 x 214 tonnes buoyancy)



New Armour Materials

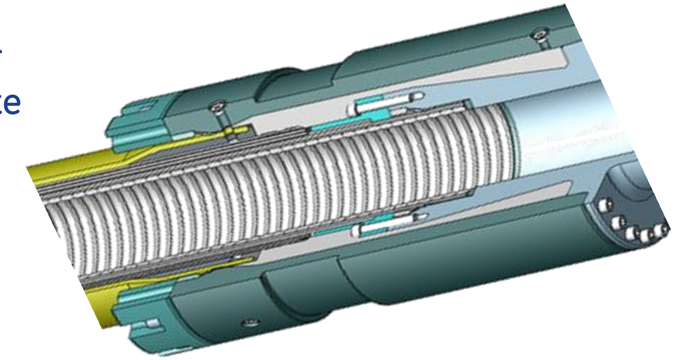
Alternatives to the current carbon-manganese steels:

Required Properties,

- Mechanical strength, weld and corrosion properties
- Confirm potential 'improvement' in capability using design software
- Ability to form and deliver suitable wires to the required profile
- Ability to wrap and weld using available manufacturing machines
- Technical and economic feasibility.

High Pressure End Fitting

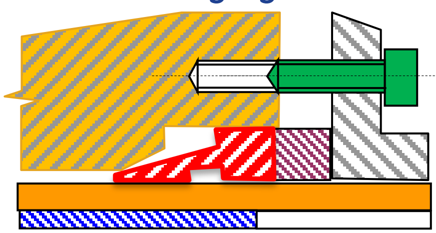
End fitting is an essential component of flexible pipes enabling their connection between moving structures and pipes to make complete pipe infrastructure.



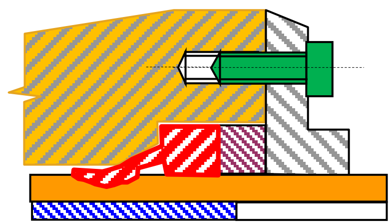
Key Functions - Effective barrier seal
Termination of all layers
Anchoring tensile amour
Transfer of external loads

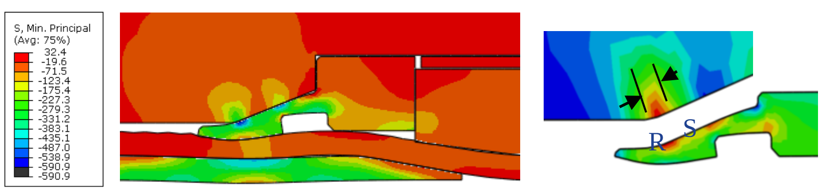
Barrier Seal

Before swaging



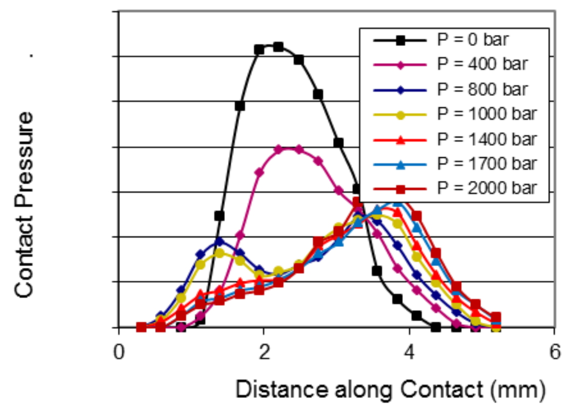
After swaging





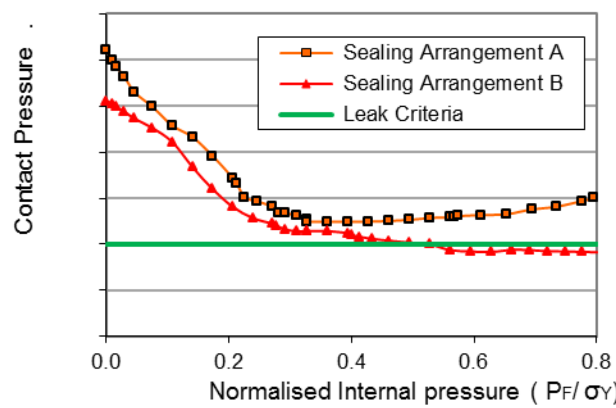
Outer taper of seal ring engages with the inner taper of the end fitting body.

Seal ring is plastically deformed creating highly localized contact pressure at the contact edge.



Maximum contact pressure at the interface changes with applied internal pressure

Maximum contact pressure must be greater than leak criteria to maintain a seal



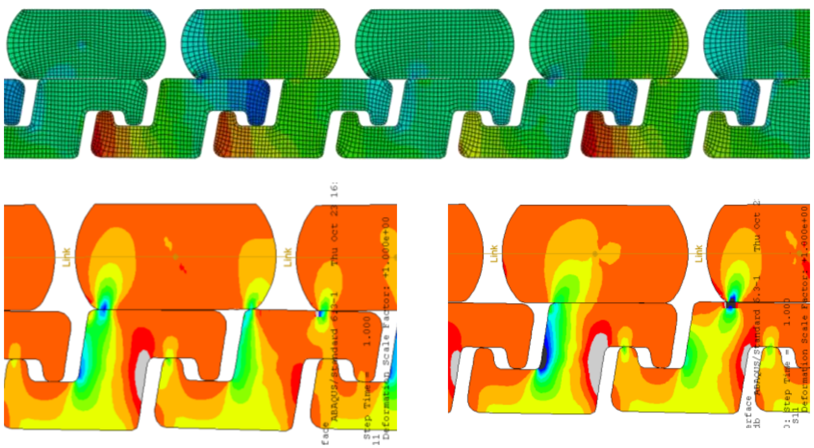
New end fitting designs proven to work above 30 kpsi

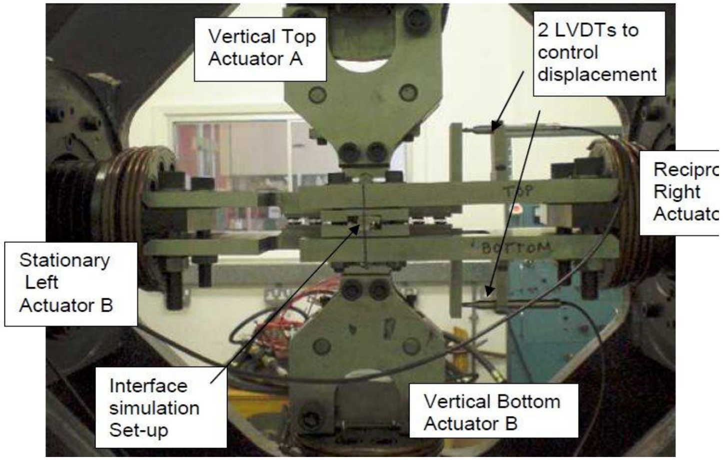
Anti-Wear Tapes

Anti-wear tape layers are used to prevent direct contact between the reinforcement layers. The contact stresses in HP pipes are significantly high, leading to an increased risk of fretting or contact fatigue of the metallic wires.

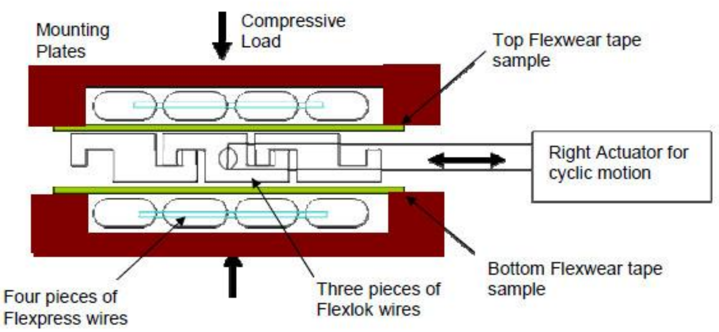
In flowlines these tapes are subjected to static non-uniform compression whist in risers these may be subjected to compression loading with dynamic slip.

Typical deformation in wear tapes





Tape testing facility

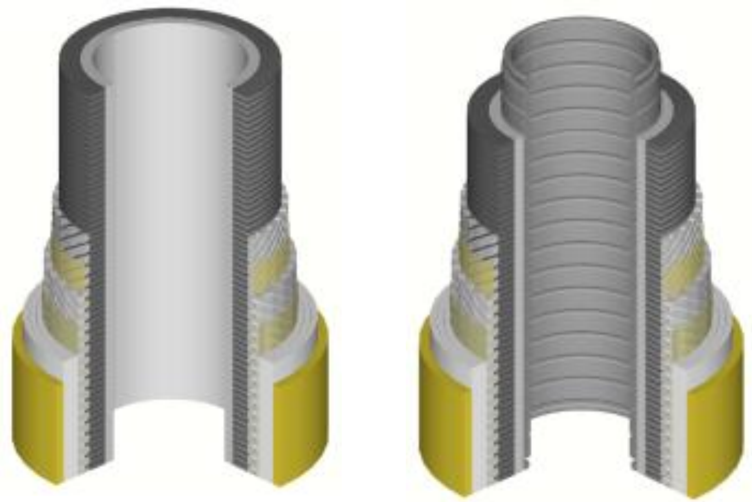


New Tape Material

- High performance materials
- Interlayer interaction – friction, wear, damage mechanisms
- Wear models – prediction of service life
- Environmental effects – temperature, annulus conditions
- New experimental facilities

Composite Pipe Design

Composite Smoothbore	Composite with metal Carcass



200 mm/ 8 inch ID Pipe. 15% OD reduction

	A	B
Reduction of Mass/Top Tension	60%	55%

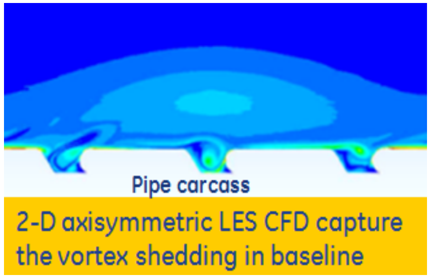
Composite Armour - Optimized fiber angles and thicknesses to meet design requirements

Bonded Liner/Barrier - PVDF - with high chemical resistance; reduced permeated gas risks

Thermoplastic Matrix - PVDF - qualified material

Carbon Fiber - Not susceptible to environmental stress corrosion; chemically resistant

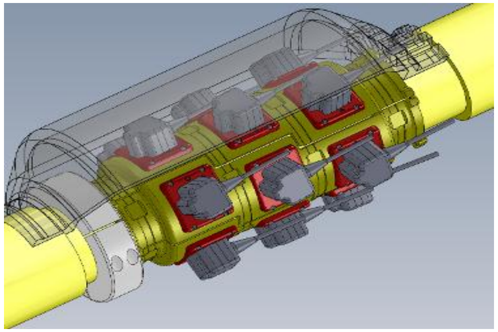
Flow Induced Pulsation



Flow induced pulsation can effects the dynamic performance of the pipe. This is pronounced when transporting gas in deep water pipes.

New design technology has been used to develop pulsation free carcass profiles (GE patents pending)

Condition Monitoring



the MAPS® wire stress and wire break monitoring and inspection systems, integrated fibre optic sensors embedded within the pipe structure, and topsides equipment for the monitoring of polymer and pipe annulus condition.

Summary - Key Challenges & Progress

High pressure ultra-deep water flexible pipe

Validate dynamic performance

High pressure design strategy

Managing weight and strength

Integrity of polymer barrier

Passing FAT and offshore field tests

Future Developments

Packaging and bending limits

Manage interaction between layers

Rapid depressurisation (multilayer barrier)

Achieve seal performance

Integrity of end fittings

New Technology Developments

Manage tensile capability

Prevent collapse (carcass)

Resist internal pressure (Flexlok)

Comply with design standards

Burst/design pressure ratio

Existing Technology

END - Any Questions ?

Acknowledgements
- GE Oil & Gas
- Deepstar Programme
- Sheffield University, UK
- RPSEA Programme