Flexible Pipe Technology for Deepwater and Gas Riser Systems

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Imagination at work

Agenda

- GE Oil & Gas Subsea Systems
- FLNG Market and technical requirements
- FLNG Design challenges and solutions
- Taking gas production further:
  - Deepwater Carcass
  - Anti-Flip Carcass

GE Oil & Gas Subsea Systems Product offering

FLNG Market and Technical Requirements

FLNG Market

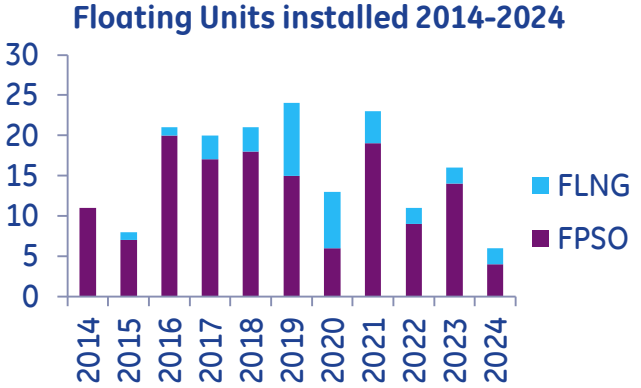
There are 34 current or planned FLNG projects worldwide up to 2024

15 of these projects are in Asia-Pacific, including:

Shell Prelude, Petronas Kanowit, Murphy Block H, INPEX Abadi, Woodside Browse, ExxonMobil Scarborough…

Flexible risers are an existing and proven technology which offer significant benefits for floating production

For FLNG projects flexible risers are for production and export applications rather than transfer of LNG



Energy Maritime Association, May 2014

Shell Prelude FLNG (Source: Shell)

FLNG Risers: Functional Requirements

FLNG production and export risers are typically characterised as follows:

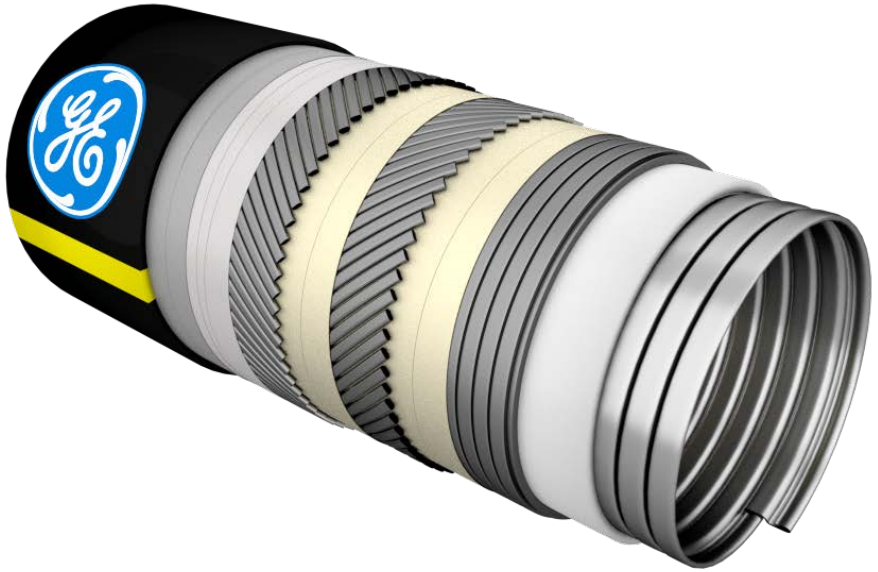
- Internal diameter: 10 to 16 inch
- High fluid velocity: circa 30 m/s
- Internal design pressure: 300 to 450+ bar
- Internal design temperature: -35 to 130˚C
- Water depth: 200m to 1,300m+
- Design life: 25 to 40 years
- Insulation: 0 to 5 W/m2K
- Moderate levels of H2S (circa 50 to 100ppm)
- High levels of CO2
- High levels of sand production

Demands close attention to flexible pipe system design, manufacturing, logistics and Integrity Management

FLNG Design Challenges and Solutions

Design Focus Areas for FLNG Risers

1. **Internal Carcass**:
   Sand erosion at high velocities
2. **Pressure Sheath**:
   Extreme temperature cycling
3. **Pressure and Tensile Armour**:
   High pressure, sour service
4. **Anti-Wear Tapes**:
   Friction resistance
5. **Riser System Design:**
   Extreme loads, interference, fatigue



Internal Carcass

Erosion Process:

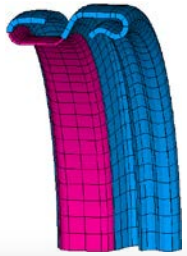
- FLNG projects typically have high levels of produced sand with high fluid velocities and long service life
- Over time carcass material is eroded when impacted by sand particles

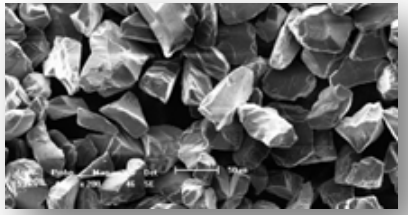
Eroded Carcass (Source: Shell)

Erosion Testing Performed:

- GE has completed an erosion testing campaign dedicated to high velocity gas flows with low liquids content
- Testing performed on a large diameter full scale sample (12.75” ID) at its minimum bend radius
- Sand velocity representative of typical FLNG conditions
- Results used to further calibrate design methodology

FEA Model





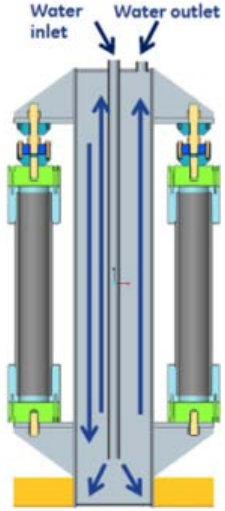
Sand particles

Pressure Sheath

Low to High Temperature Thermal Cycling:

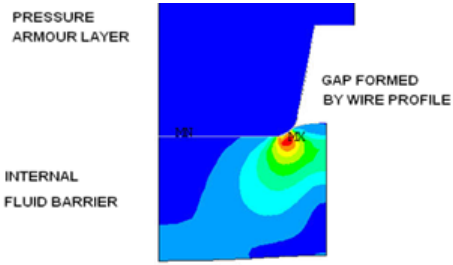
- High temperatures challenge the upper limits of polymer capacity
- Creep into pressure armour layer becomes more pronounced with increased pressure, temperature and service life
- Critical control of barrier nub profile is achieved through manufacturing
- Low temperatures typically occur in start-up and shut-down conditions:
  - Thermal cycling testing performed to confirm pipe and end-fitting sealing integrity
  - PVDF thermal shock testing performed for rapid temperature changes

Thermal Shock Chamber



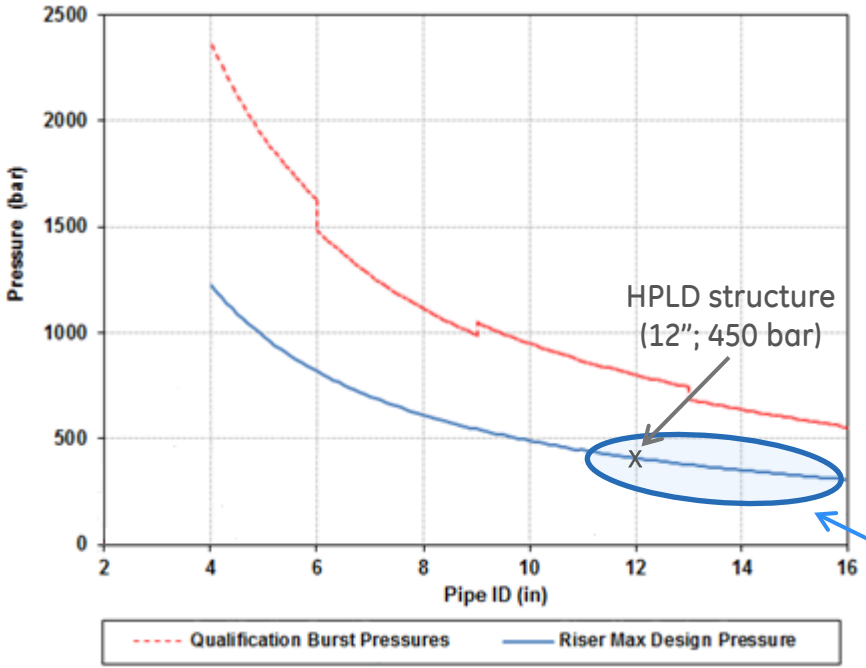
Thermal Cycling Rig

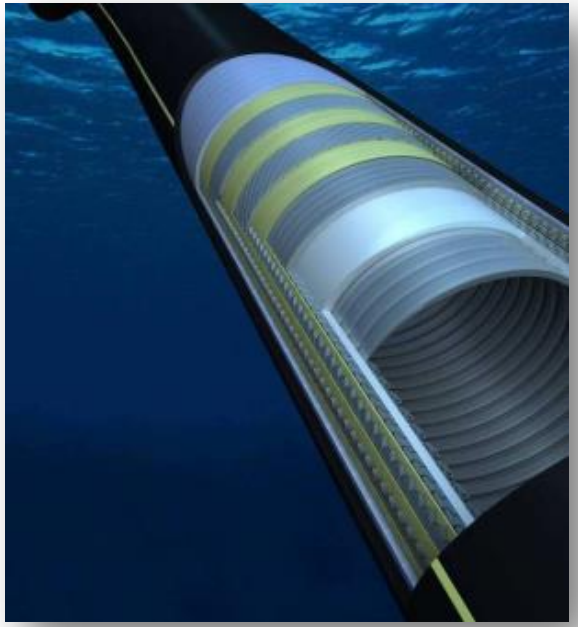
Barrier nub ingress testing



Barrier ingress FEA

Pressure and Tensile Armour





Requirement for large diameter pipes at high pressures

Pressure and Tensile Armour

FLNG demands combination of high pressure and large inner diameter:

- Most challenging known requirement is 12” ID / 450 bar which is within the qualified range of GE flexible risers
- Achieved through high capacity pressure and tensile armour layer(s)

H_2S in annulus requires use of reduced strength wires:

- Realistic approach to permeation and H_2S effects
- Qualification of high yield strength materials for sour service

Extended service life raises challenges with respect to wire:

- Fatigue resistance
- Corrosion resistance

Application of Pressure Armour

Application of Tensile Armour

Anti-Wear Tapes

Key challenges:

- High interlayer pressures require high strength materials
- Longer design life (up to 40 years)
- High temperatures accelerate degradation
- Materials need to be compact and cost-effective

Extensive material qualification of:

- PVDF/PTFE tape (high contact pressures/temperatures)
- PEEK/Crystalline Polymer Wrap (Extreme temperature and contact pressures)
- Aramide Fibre Tapes (high temperature/strength)

Application of Flextape™

Tape Testing Rig

Riser System Design

Manage Extreme Loads:

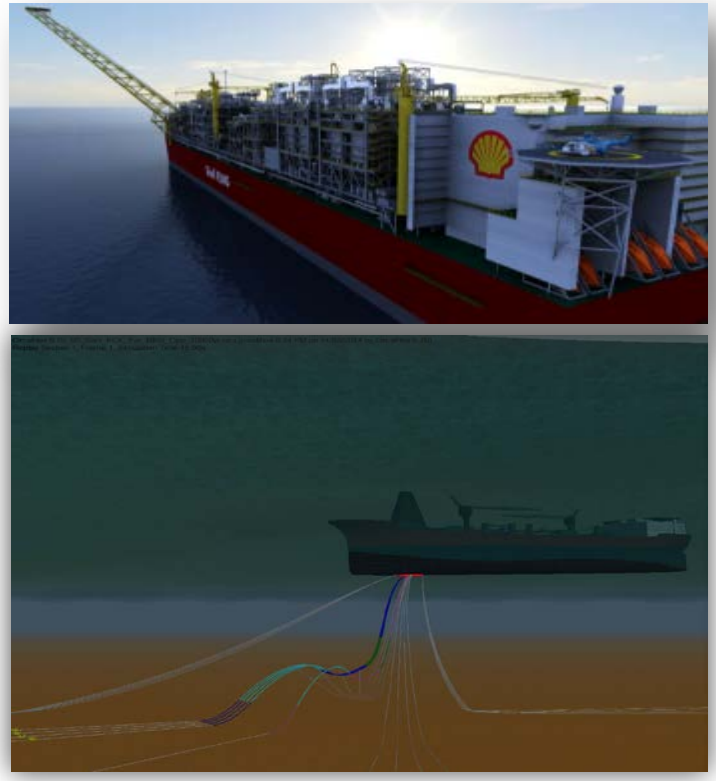
- 10,000 year wave and current conditions
- Survivability in cyclonic conditions
- Variance in risers contents density, marine growth
- High pressures and temperatures variations effect on pipe stiffness

Mitigate Interference:

- Riser to Riser; Riser to Mooring; Riser to Vessel

Evaluate Fatigue:

- Long design life in challenging environment
- Vortex Induced Vibration (VIV) effects



Prelude FLNG (Sources: GE & Shell)

Taking Offshore Gas Production Further…

Ultra-Deepwater Carcass

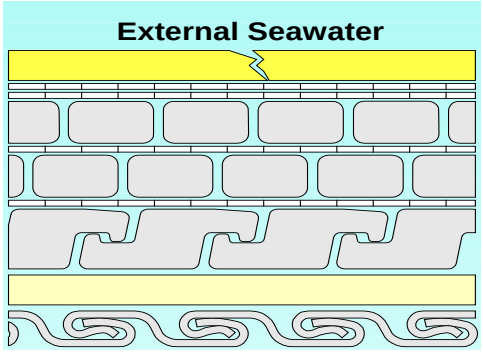
The carcass is the critical layer for collapse prevention:

- Accidental flooding of annulus (damaged outer sheath)
- Hydrostatic pressure applied to the barrier
- Low internal Pressure (e.g. empty pipe)

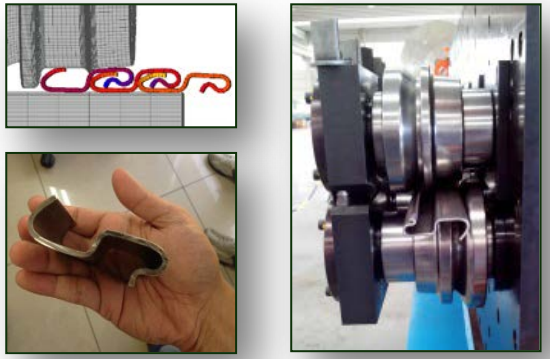
⇒ High differential pressure and risk of barrier collapse

Qualification of a new large size profile:

- Up to 22mm formed thickness
- Key for future pre-salt & deep water FLNG
- Product portfolio expansion (Gas/Oil Export)
- Develop LD/UDW products



Flooded Annulus Scenario

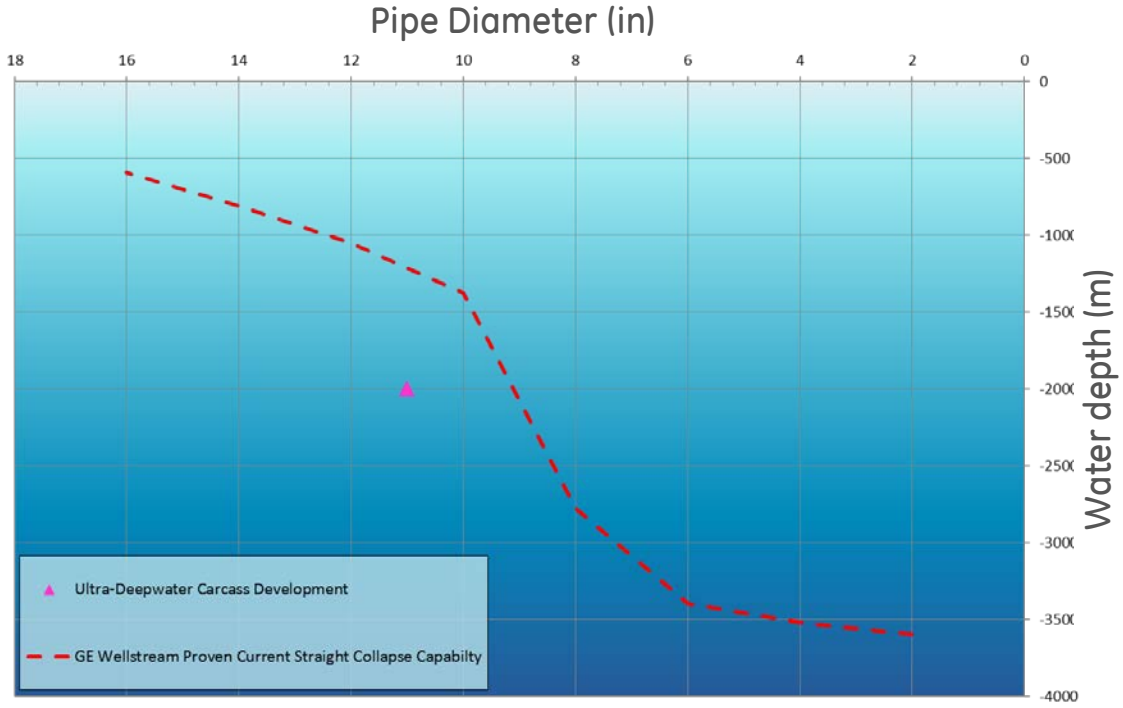


Carcass manufacturing

Ultra-Deepwater Carcass

Performance target:

11 inch @ ~2000m WD



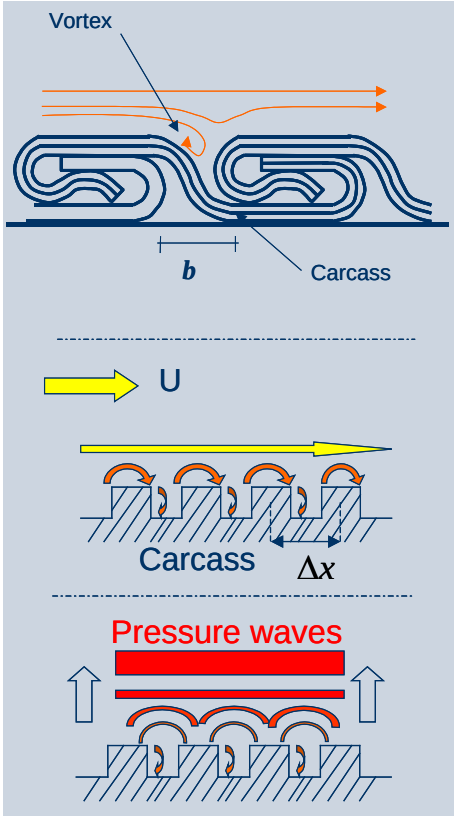
Anti-FLIP Carcass

The FLIP phenomenon:

- High-Frequency sound and vibrations are induced in gas export risers at certain flowrates.
- These vibrations affect secondary structures both topside and subsea, producing potential fatigue failures.

Impact of FLIP on operations:

- Restrict production capacity to a lower export rate
- Boosting gas export pressure beyond critical conditions



FLIP Phenomenon

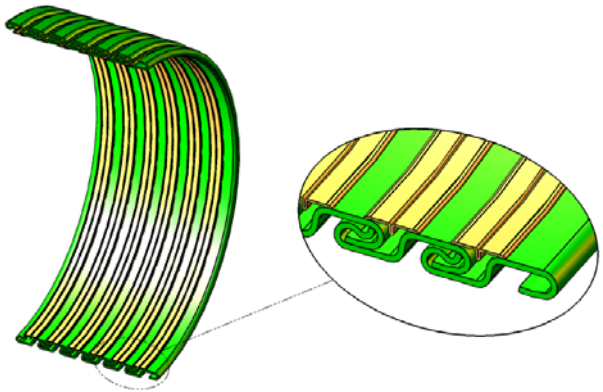
Anti-FLIP Carcass

Development in partnership with a major oil company:

- T-Strip inserted in the carcass eliminates the gaps
- Profile based on extensive CFD to minimise drag
- Extensive trials performed to confirm piggability and stability of the insert

Robust and cost effective solution:

- Minimal deviation from standard flexible pipe structure
- Strip inserted in parallel with carcass wrapping using standard manufacturing methods
- Minimal use of CRA
- Reduced pipe roughness / pressure drop



T-Strip in Carcass (Source: GE Oil&Gas)

Conclusions

A Robust, Proven Solution for Challenging Environments

- Flexible risers have a proven track record spanning many decades
- Significant further testing and development in recent years has addressed some of the key design challenges of FLNG projects
- The introduction of new solutions allows to address industry concerns and allow the use of larger bore risers
- R&D work continues to help operators extend the operating envelope of flexibles and unlock new assets