TechnipFMC

Design of Flexible Risers and Flowlines

Richard Daniell
Senior Flexible Pipeline & Package Engineer
richard.daniell@technipfmc.com

Agenda

1. Introduction
2. Layer by Layer: Function & Manufacturing
3. Flexible Pipe Design
4. Static and Dynamic Systems

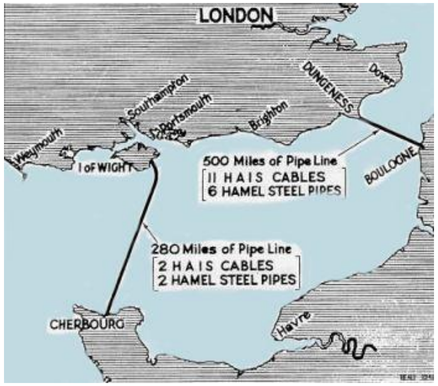
Lunch Break

1. Ancillary Equipment
2. Deep Water Challenges and New Technologies
3. Conclusion

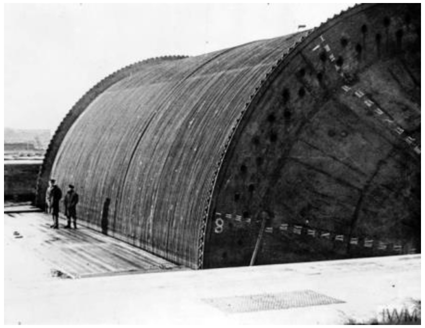
TechnipFMC

Flexible Pipe History:

Pipe Line Under The Ocean (PLUTO) - 1942: HAIS (lead core) & HAMEL (steel) pipes

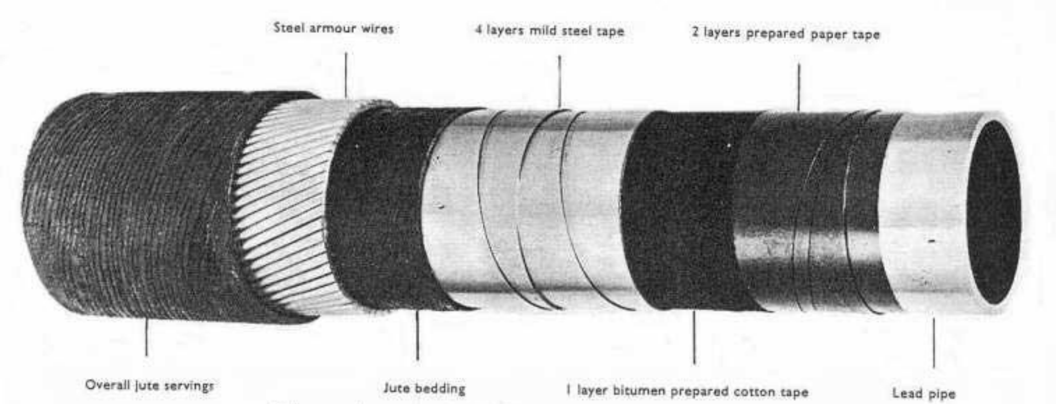


Subsea Pipeline Routes



HAMEL pipe on Conundrum

HAIS pipe (carousel lay)



Telescoped sample of H A I S Cable showing construction

HAIS pipe composition

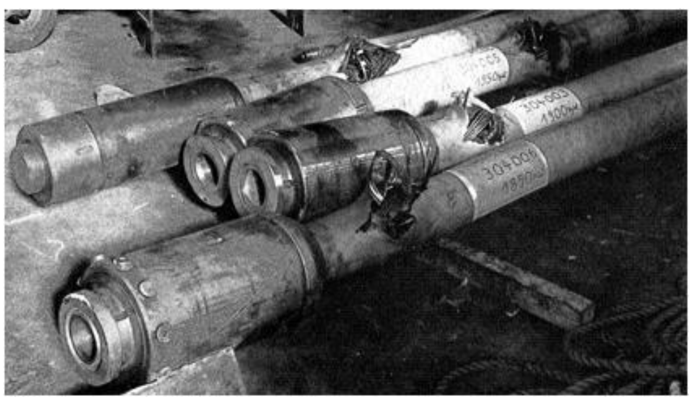
TechnipFMC

Flexible Pipe History: Timeline

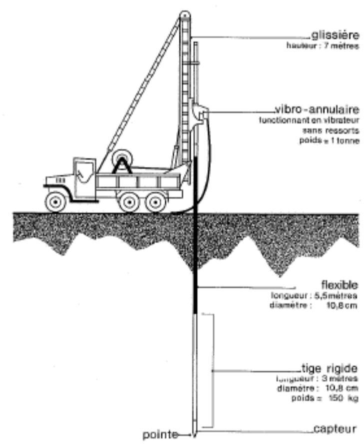
- 1959 Research Work at IFP / Technip (nee Coflexip)
- 1968 Flexible unbonded water pipe – Iceland (mainland to island)
- 1973 Elf Emeraude (Congo) – Flowlines
- 1975 Poleng (Indonesia) – Riser
- 1997 -1000m WD barrier broken
- 2010 - 3000m WD qualification

Currently: Carbon fibre armour, fibre optics, active heating, live monitoring. **Still a developing field with new technologies.**

4” 10,000 psig flowline



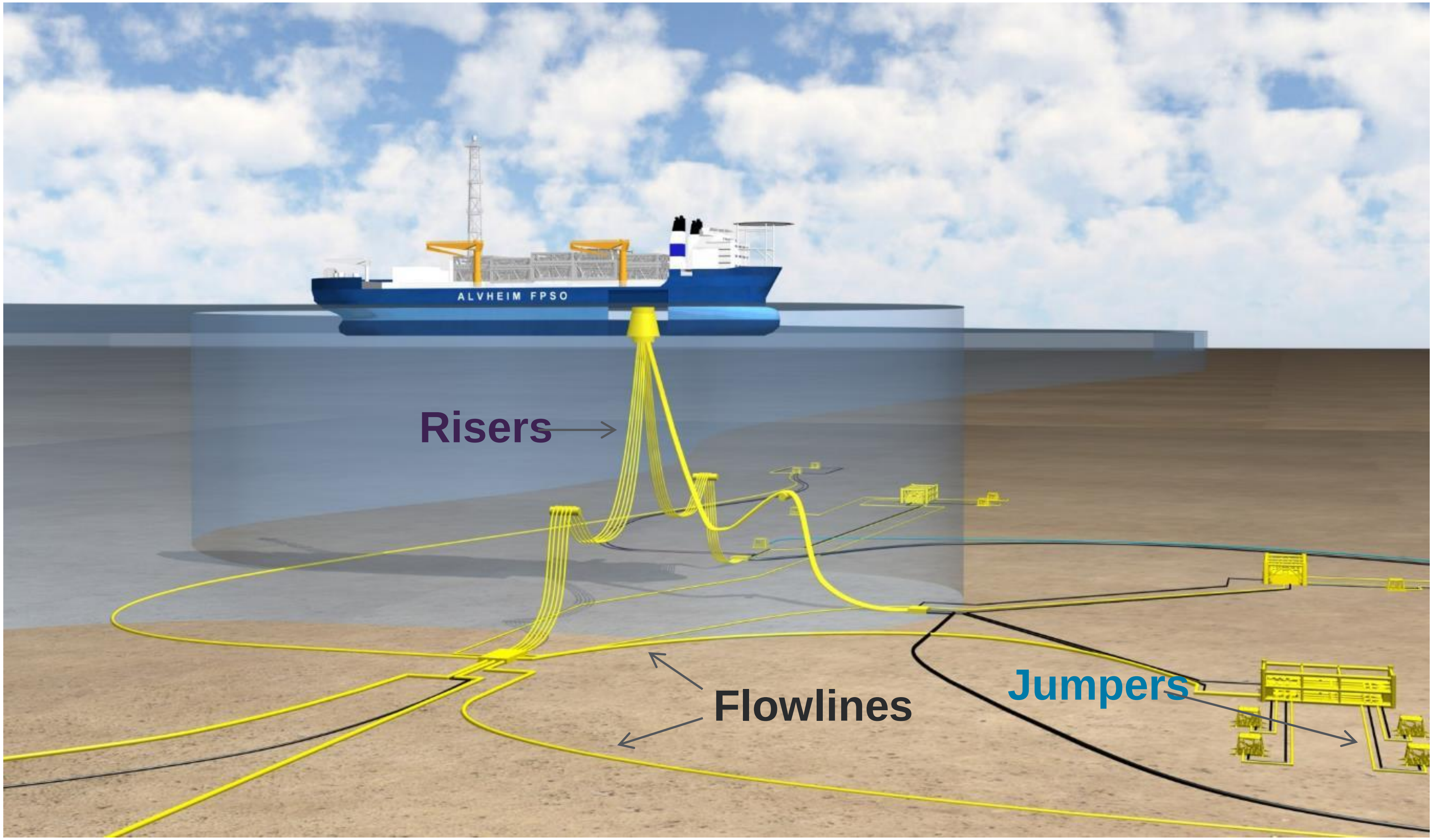
4’’ 10,000 psig Burst Tests February 1976



Flexible pipe concept for drilling

Flexible Pipe - Introduction

FPSO – Floating Production Storage and Offloading



Alvheim field FPSO vessel

Flexible Pipe - Introduction

- **Main applications:**
  - Crude oil production.
  - Gas injection.
  - Water injection.
  - Gas production.
  - Export pipeline (dead oil, gas).
  - Gas lift.
  - Service line (Chemicals, Gas Lift etc…)
- **Static flowlines / dynamic or static risers/ dynamic or static jumpers**
- **Internal Diameter (ID) From 2" to 22"**
- **Service Life 20, 30… 40 Years**

Production fluid: Water + Oil + Gas

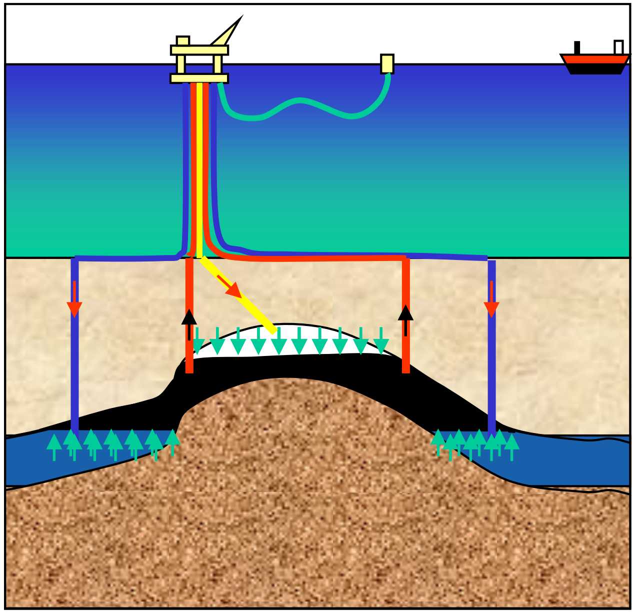


Figure 10: Flexible pipe applications

Flexible pipe design offers a tailor-made solution optimized according to client specific needs (Fluid, Diameter, Pressure, Temperature etc.).

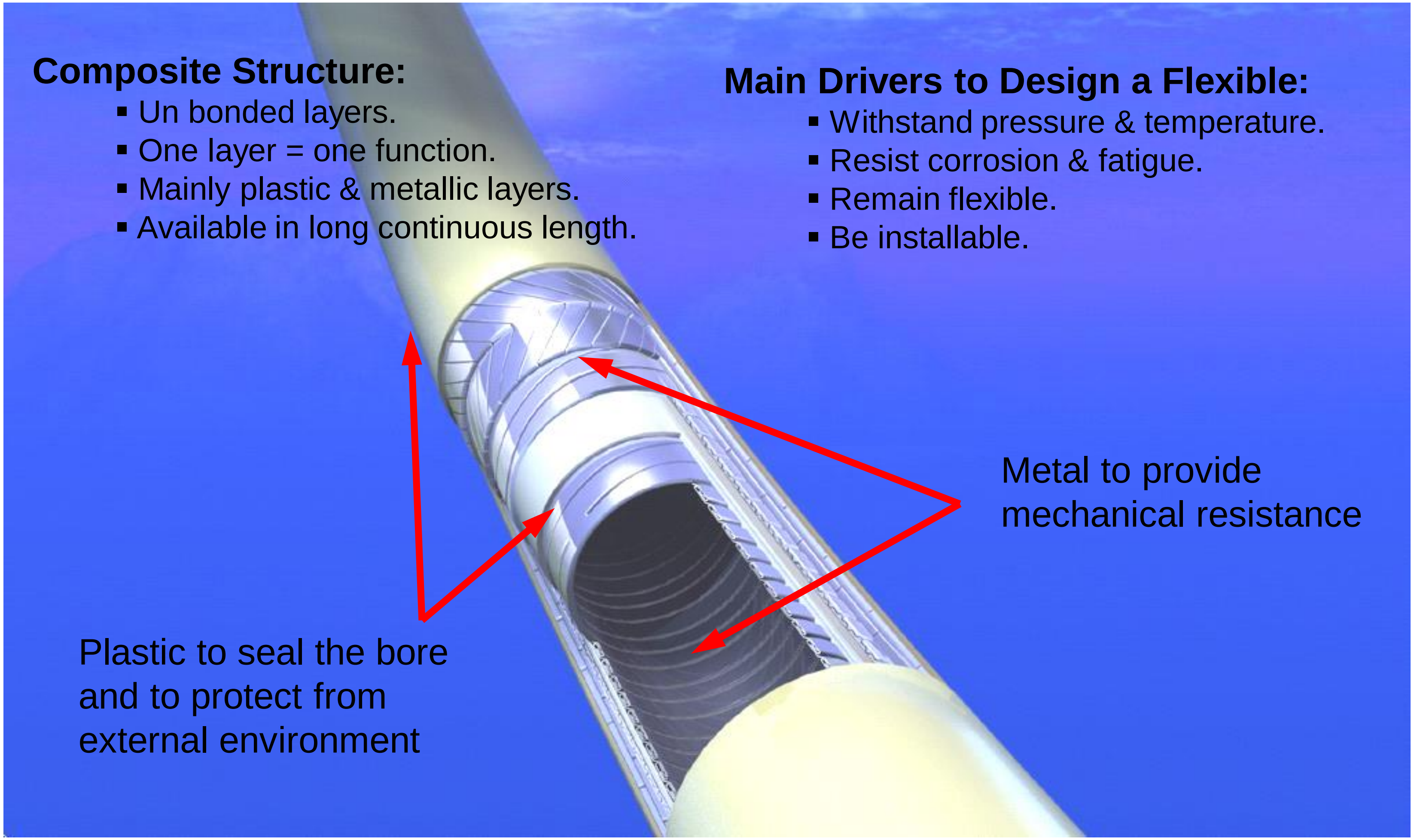
TechnipFMC

Flexible Pipe - Introduction

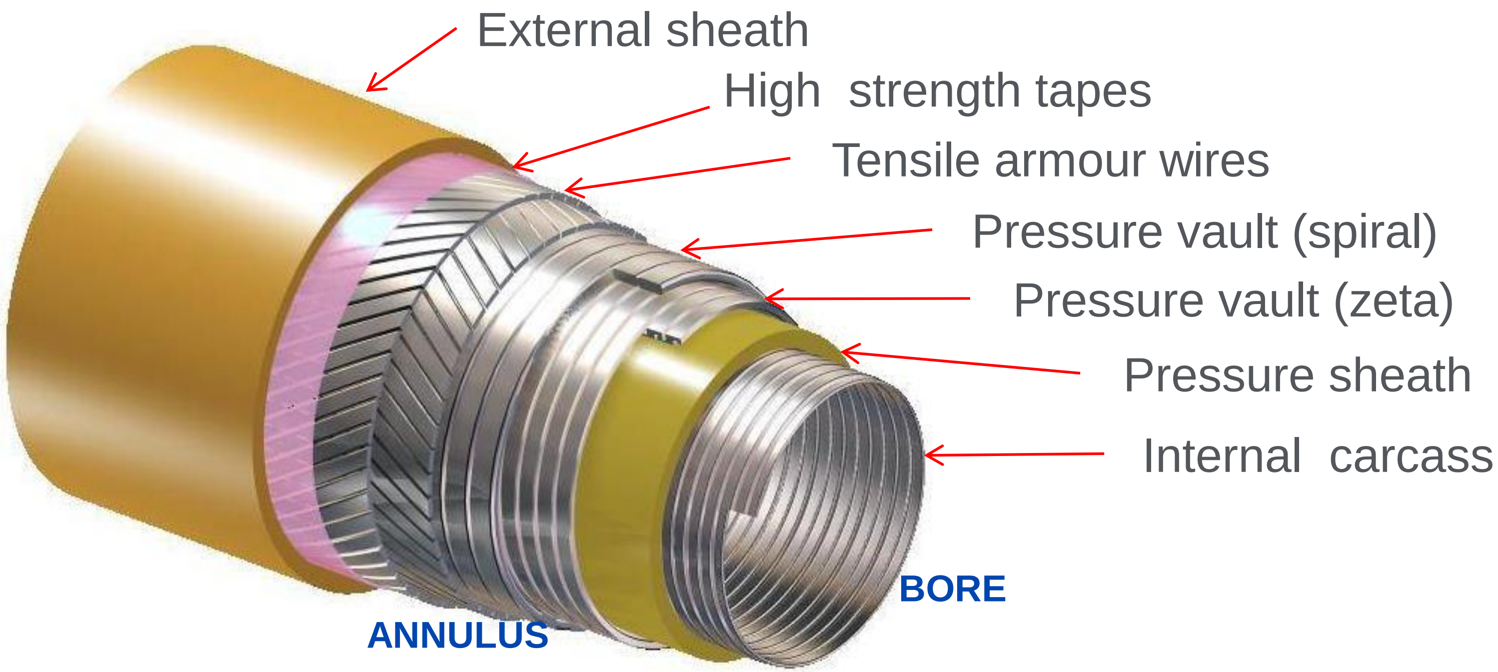
Figure 11: TUI field FPSO vessel

TechnipFMC

So what is a Flexible Pipe?



Flexible Pipe Composition (typ)



- **Manufacturing: inside to outside.**
- **Flexibility: steel layers (wounded wires/ strips) + plastic layers + unbonded layers.**
- **Additional layers (anti-wear tapes/ foams).**
- **Layers independently adjusted – project requirements.**

Unbonded Flexible Pipes: A family of 2 generic members

ROUGH BORE

Figure 12 – Rough Bore Pipe (typ)

STEEL CARCASS INNER LAYER

SMOOTH BORE

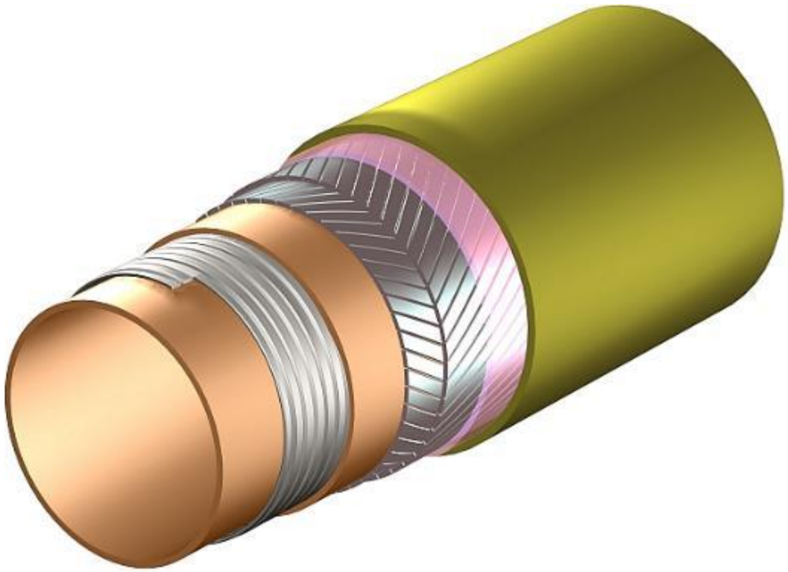


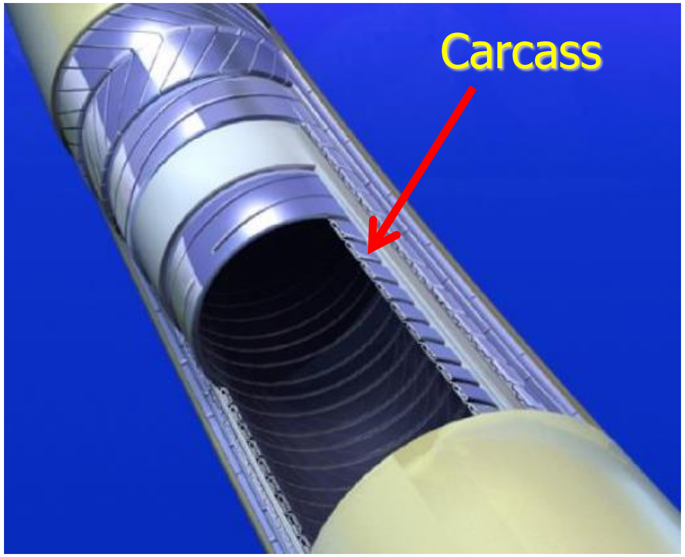
Figure 13 – Smooth Bore Pipe (typ)

PLASTIC TUBE INNER LAYER

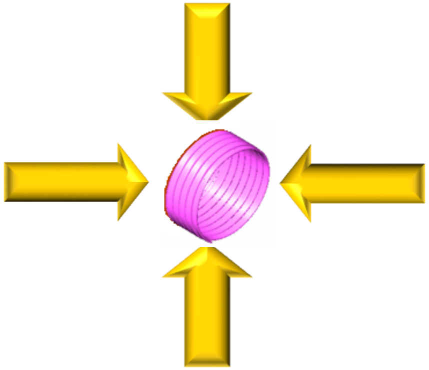
Layer by Layer: Function & Construction

TechnipFMC

Layers by Layer:
Internal Carcass - Function



Internal Carcass



Hydrostatic + Crushing load

Resist Hydrostatic Collapse & Crushing Loads

Sand Erosion Resistance

Profile & Thickness:

- Dependant on water depth and pipe ID (with ID driven by flow assurance.)

Material Selection Based on Duty:

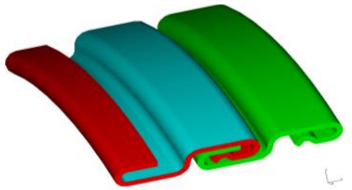
- Temperature
- H_2S, CO_2 & pH
- Chloride Content (Cl^-)

Material Grades Available:

- Ferritic Stainless Steel
- Austenitic Stainless Steel
- Duplex / Super Duplex Stainless Steel
- Alloy 31

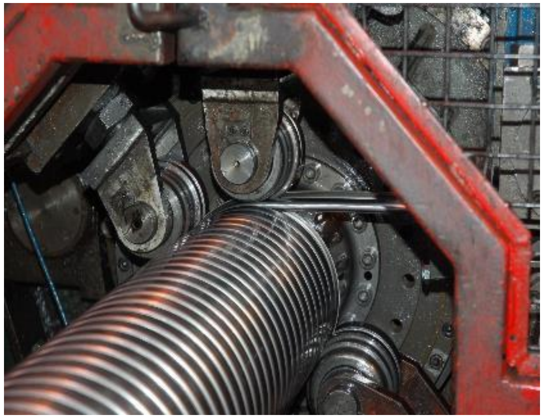
Layers by Layer:
Internal Carcass - Construction

- Single work hardened, interlocked, steel strip.
- Strip passes through set of shaped rollers.
- Manufacturing criteria include ID, OD, carcass profile.
- Sections of carcass can be joined by “screw lock”.



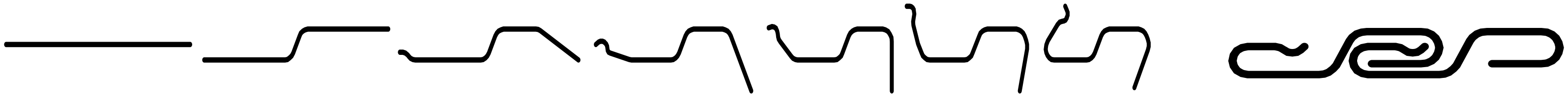
Carcass cross section

Steel Strip



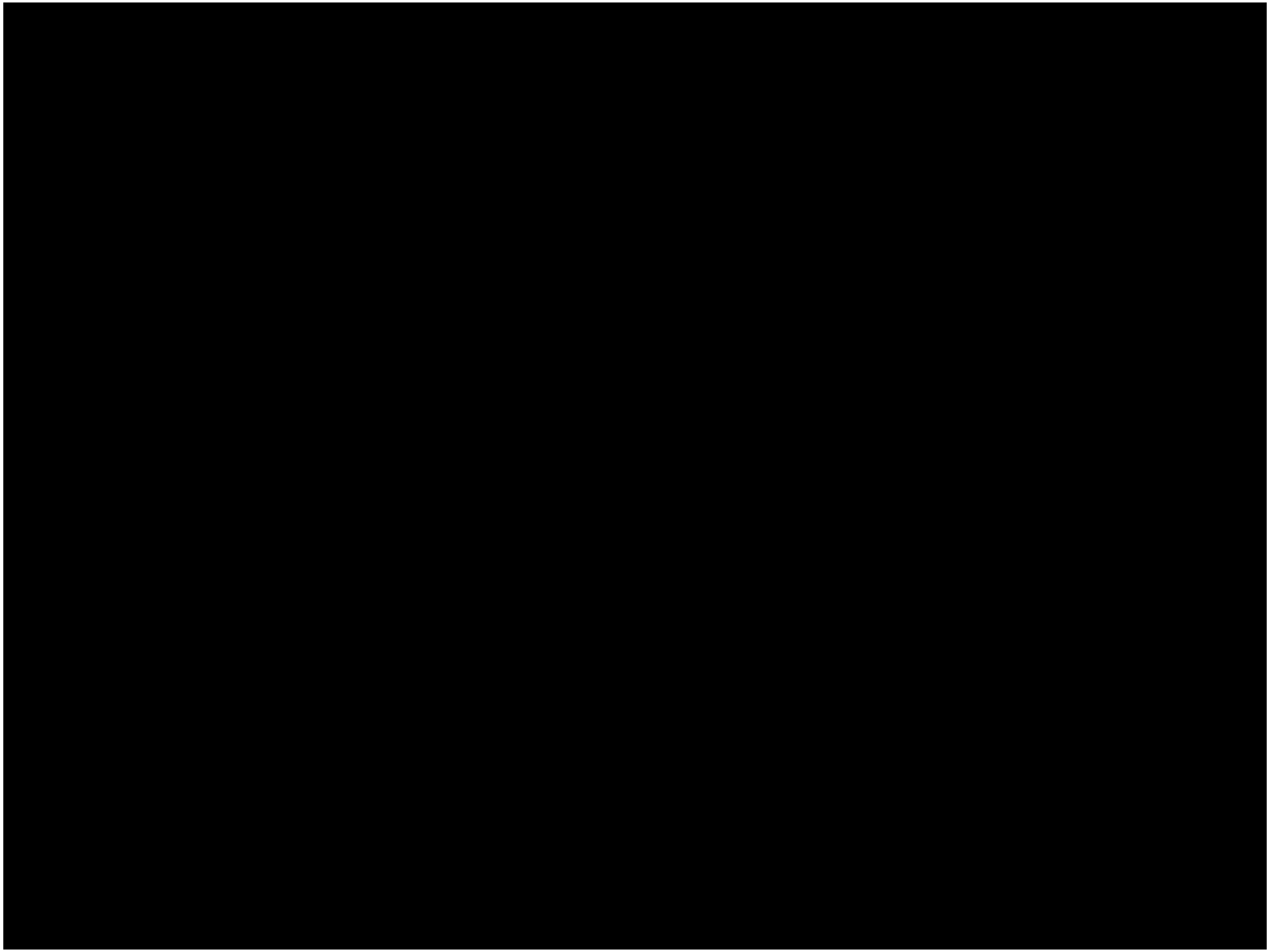
Rollers and carcass formation

Completed carcass



Carcass profile change during manufacturing

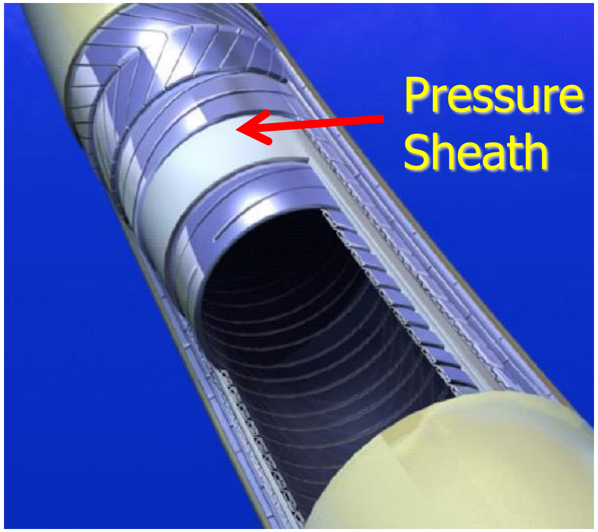
Internal Carcass – Construction video



TechnipFMC

Layer by Layer: Pressure Sheath - Function

- Primary function: Contain internal fluid.
- Subject to gas diffusion
- Material selected based on:
  - Transported fluids.
  - Temperature.
  - Required service life.
- Thickness: Design conditions, ID and subsequent layers.
- Extruded from thermoplastic material:
  - Polyethylene.
  - High Density PE.
  - Polyamide (i.e. PA11).
  - PVDF.

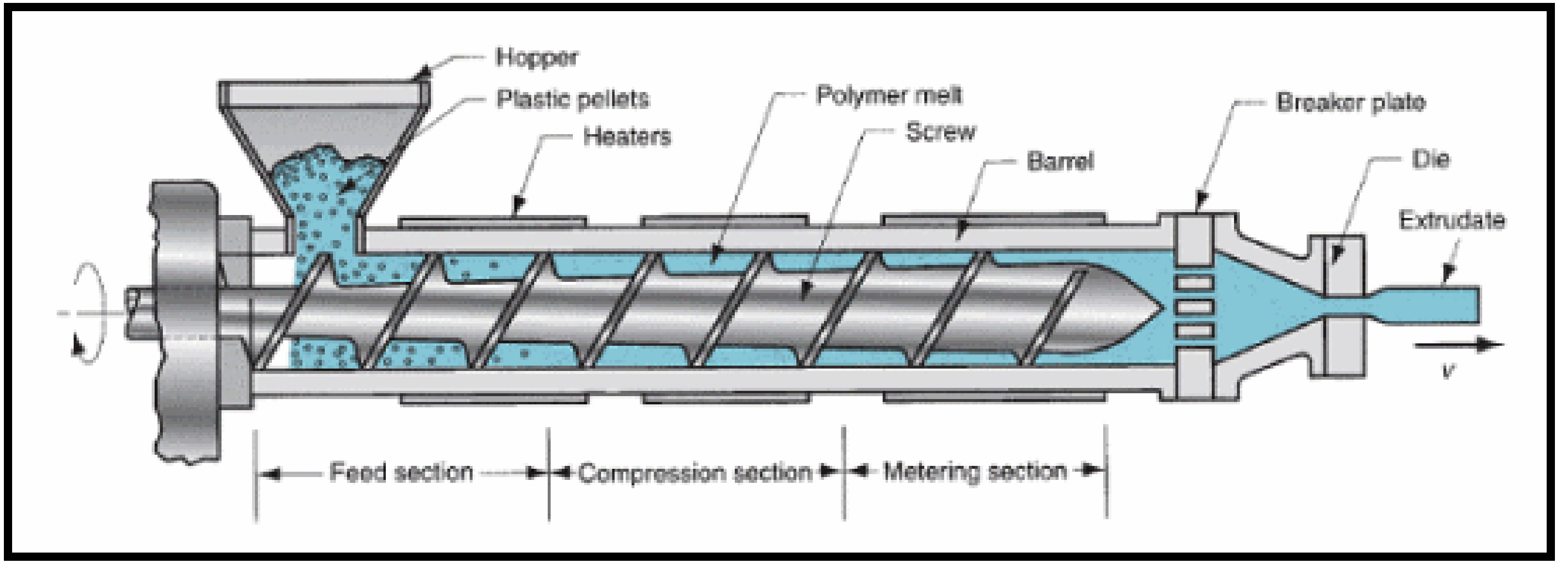


Layer by Layer:
Pressure Sheath - Construction

Raw material +
Masterbatch

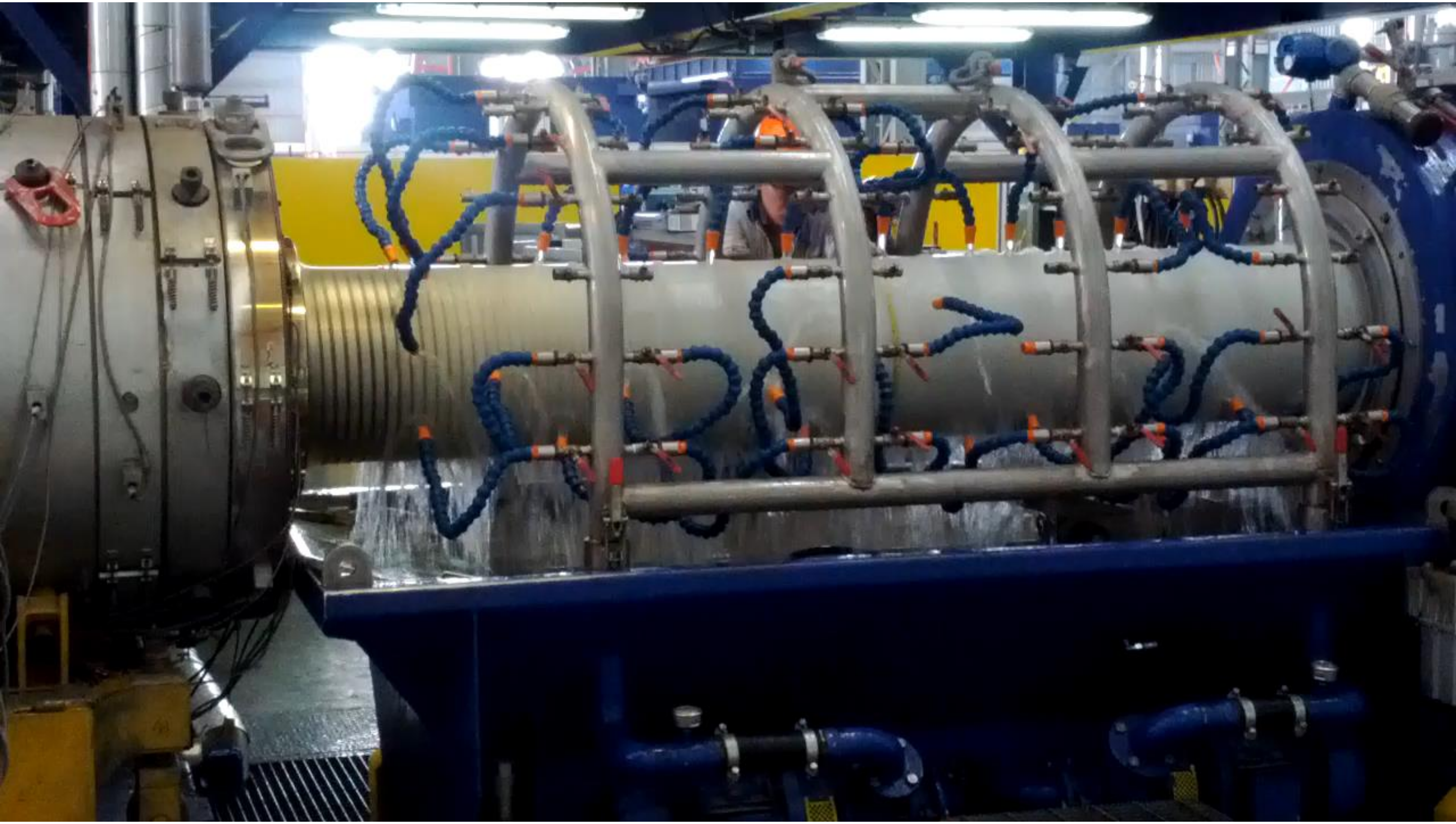
Extrusion head preparation

Extrusion

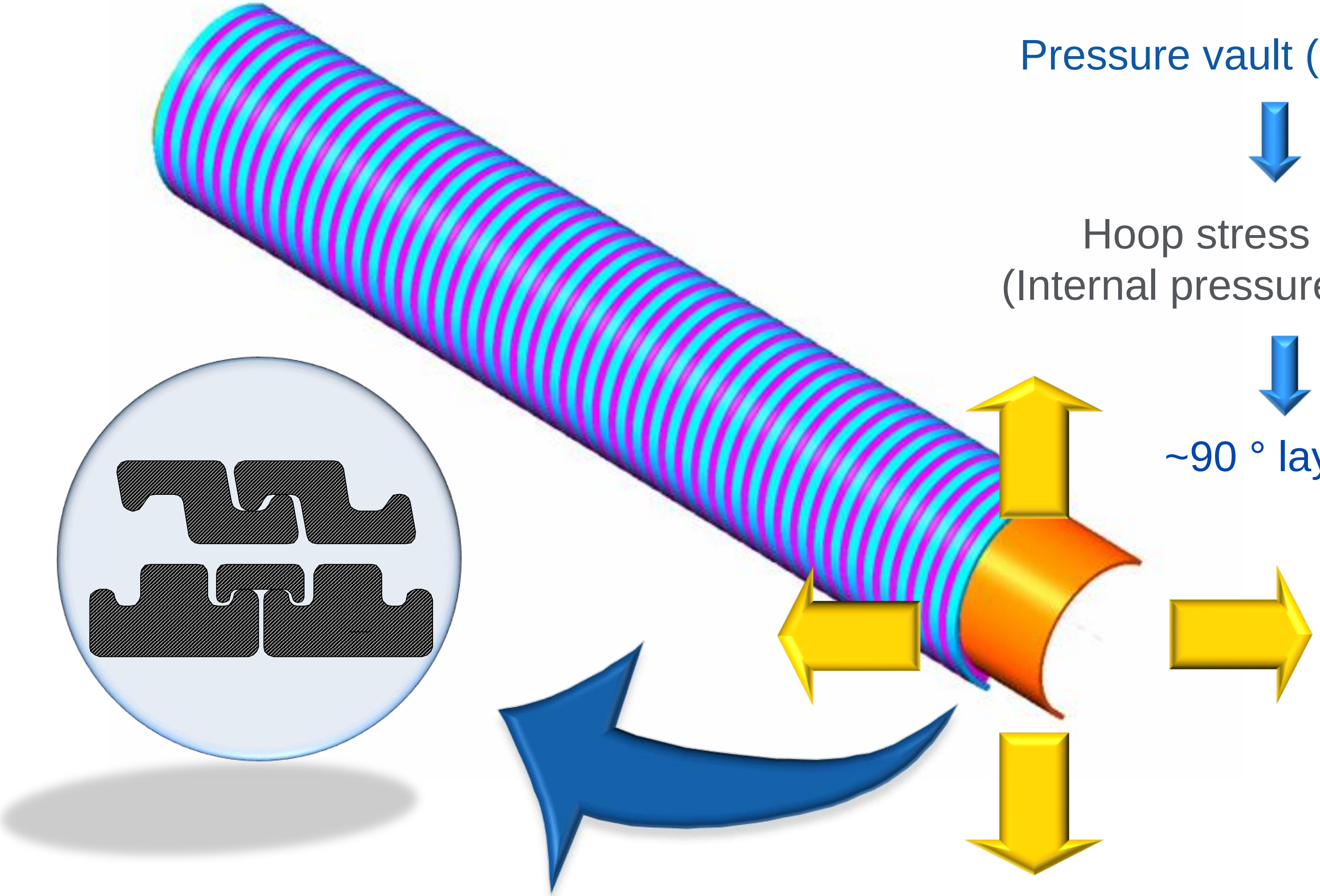


Plastic Extrusion Screw (Typ)

Layer by Layer:
Pressure Sheath - Construction



Layers by Layer:
Pressure Vault - Function



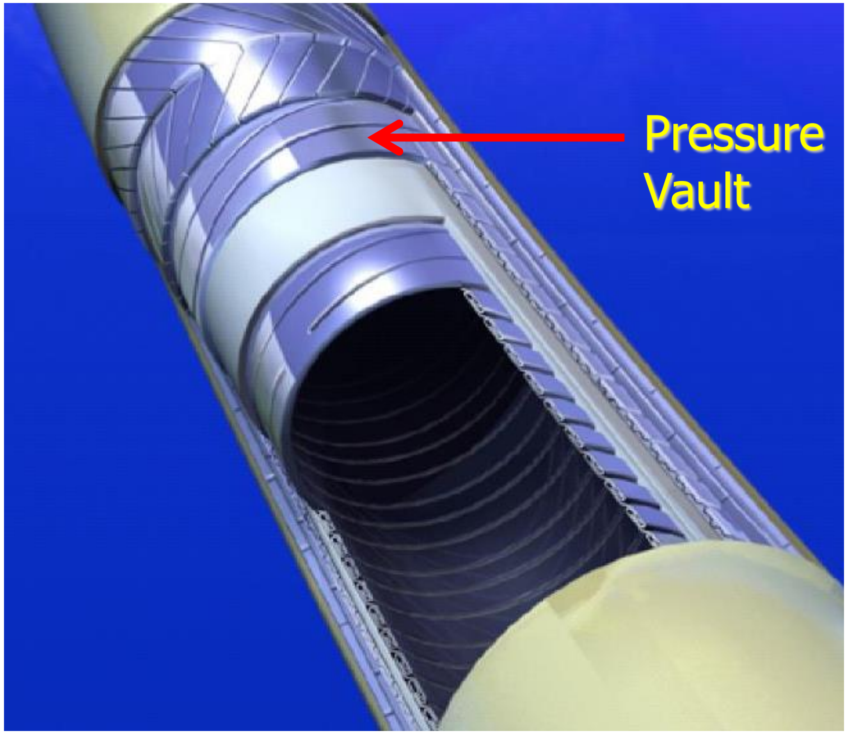
Pressure vault (metallic layer)

Hoop stress resistance
(Internal pressure on PS/ Tube)

~90 ° laying angle

Figure 21 – Pressure Vault

Layers by Layer:
Pressure Vault - Function



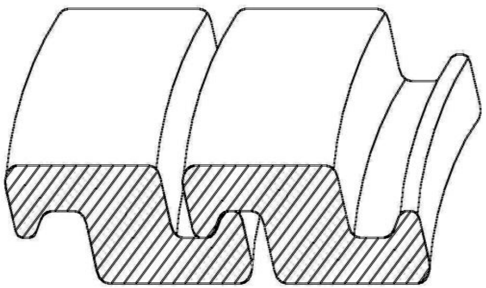
Pressure Vault

- Withstands hoop stress due to internal pressure.
- Contributes to collapse & crushing resistance of structure.
- Different wire sizes & shapes.
- Provide controlled gap to support pressure sheath.
- Designed for fatigue in dynamic riser applications.
- Material grades available from sweet service, mild sour, sour through to extreme sour service.

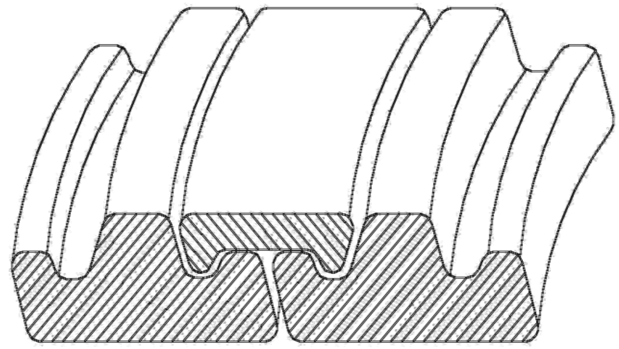
TechnipFMC Definition → Sweet Service: Nil H_2S
Sour Service: Presence of H_2S

Layers by Layer
Pressure Vault: Function

Different Pressure Vault Wire Shapes / Names

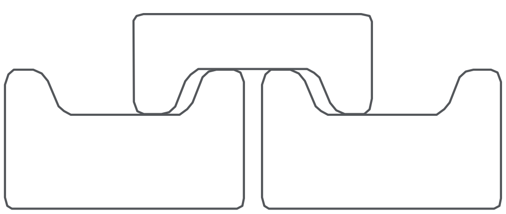


Zeta (TechnipFMC)
Flexlock (GE)

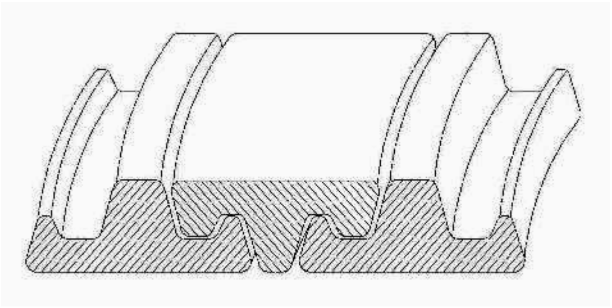


Teta (TechnipFMC)

C-LiNKT (NOV)



Te (TechnipFMC)



Steel tape (NOV)
Static flowlines only

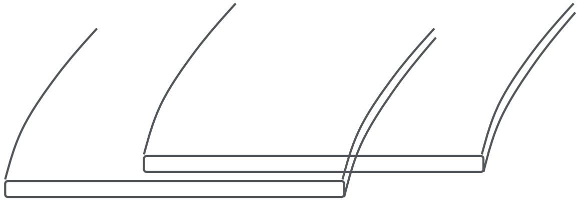


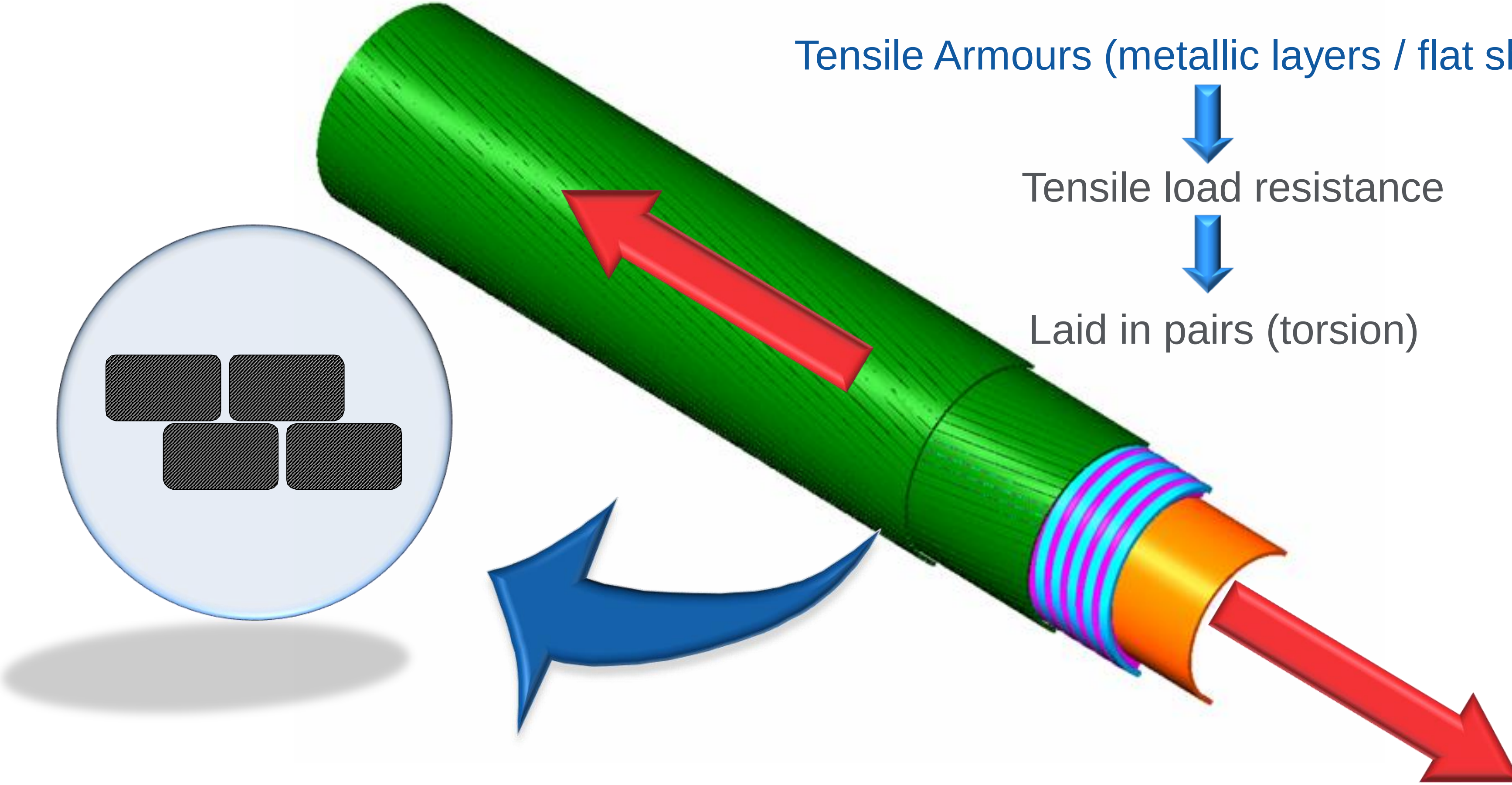
Figure 22 – Pressure Vault Shapes

Layers and Functions
Pressure Vault - Manufacturing

Figure 23 – Pressure Vault Spiralling Process

Layer by Layer
Pressure Vault: Manufacturing

Layers by Layer
Tensile Armours: Function



Tensile Armours (metallic layers / flat shape)

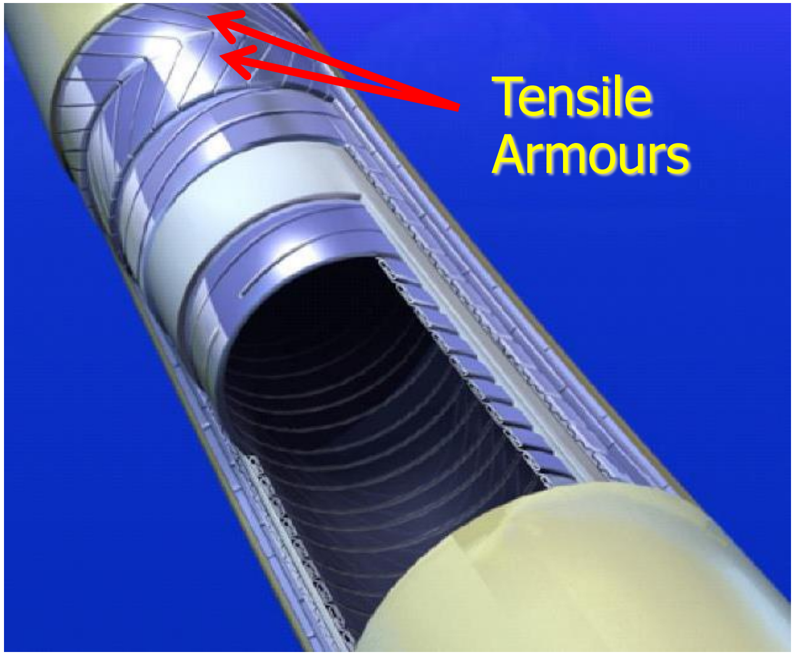
Tensile load resistance

Laid in pairs (torsion)

- If required: 2^{nd} set of armour wires
- Laying angle can be adjusted

TechnipFMC

Layers and functions
Tensile Armours



Tensile Armours

- **Withstand tensile loads**
  - Tension
  - End Cap Effect
- **Contribute to withstand radial loads.**
- **Cross-wound for torsional stability.**
- **Designed for fatigue in dynamic riser applications**
- **Material grades available (static and dynamic applications): Sweet service, Mild Sour, Sour and Extreme Sour Service**

Layers and functions
Tensile Armours

Figure 26 – Armouring Process

TechnipFMC

Layers and functions
Tensile Armours

Layers by Layer:
Pipe with 55° Tensile Armour

Typical structure with Pressure Vault and Tensile Armours

Structure with Tensile Armours laid in 55° and no Pressure Vault

- **55° Armour laying angle: Balance to withstand Tension *plus Pressure.***
- **Depends on project P/T requirements, design conditions.**
- **Economical (less material and one less manufacturing step).**

TechnipFMC

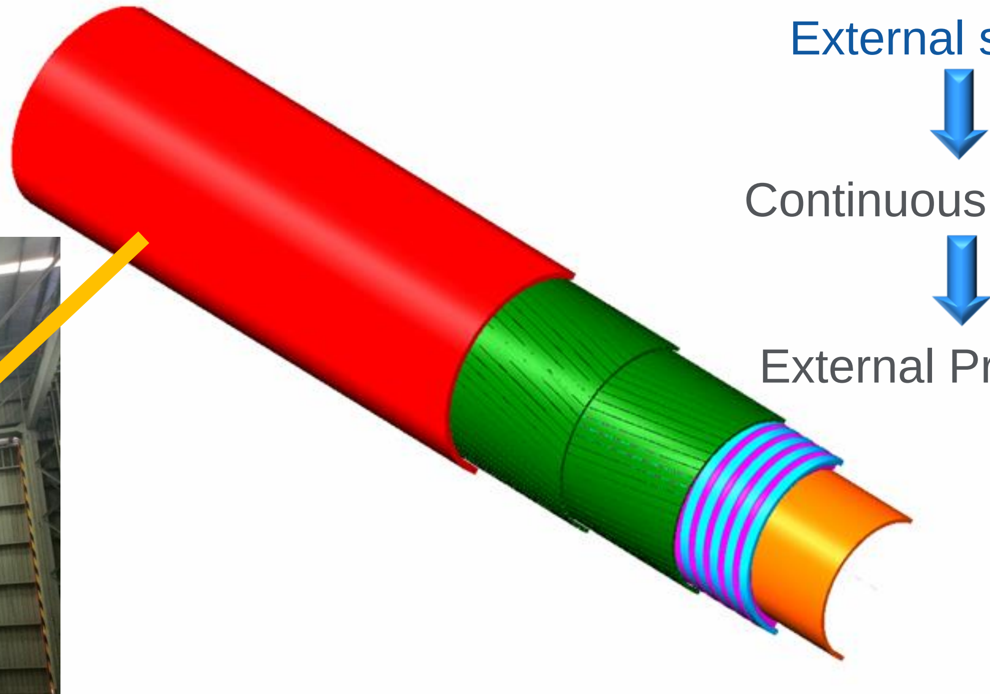
Layer by Layer:
High Strength, Anti-Wear & Construction Tapes

- Anti-Wear tape (AWT) layers (between metallic or layers or plastic sheaths).
- High Strength Tapes (HSTs) resist bird cage effect and lateral buckling of armour wires (from compression).
- Typically multiple HST layers laid above each set of armour wires.
- Construction tapes: to maintain HST tapes and provide a good surface for plastic extrusion.
- HST tapes are aramid, typically Kevlar® or Technora®.

Roll of high strength tape

High strength tape laid on pipe

Layers by Layer
External Sheath: Function



External sheath

↓

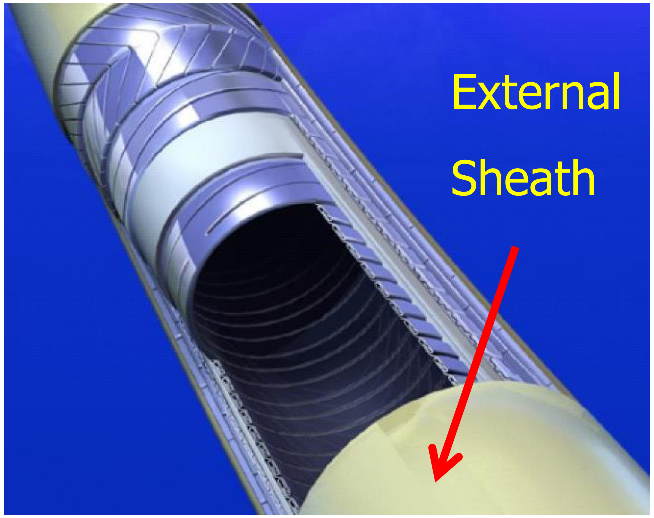
Continuous layer

↓

External Protection

External Sheath at end of extrusion process

Layers by Layer
External Sheath: Function & Manufacturing



External Sheath Extrusion Process

- Protects metallic layers from seawater ingress (corrosion)
- Provides abrasion resistance to wear & tear (i.e. from installation, seabed or j-tubes).
- Provides thermal insulation.
- Extruded from thermoplastic material.
- Additional protective layers possible.
- Similar to Pressure sheath extrusion – same machine
- Materials:
  - Polyethylene.
  - Polyamide.
  - Polypropylene.

Layer by Layer:
Other layers and functions

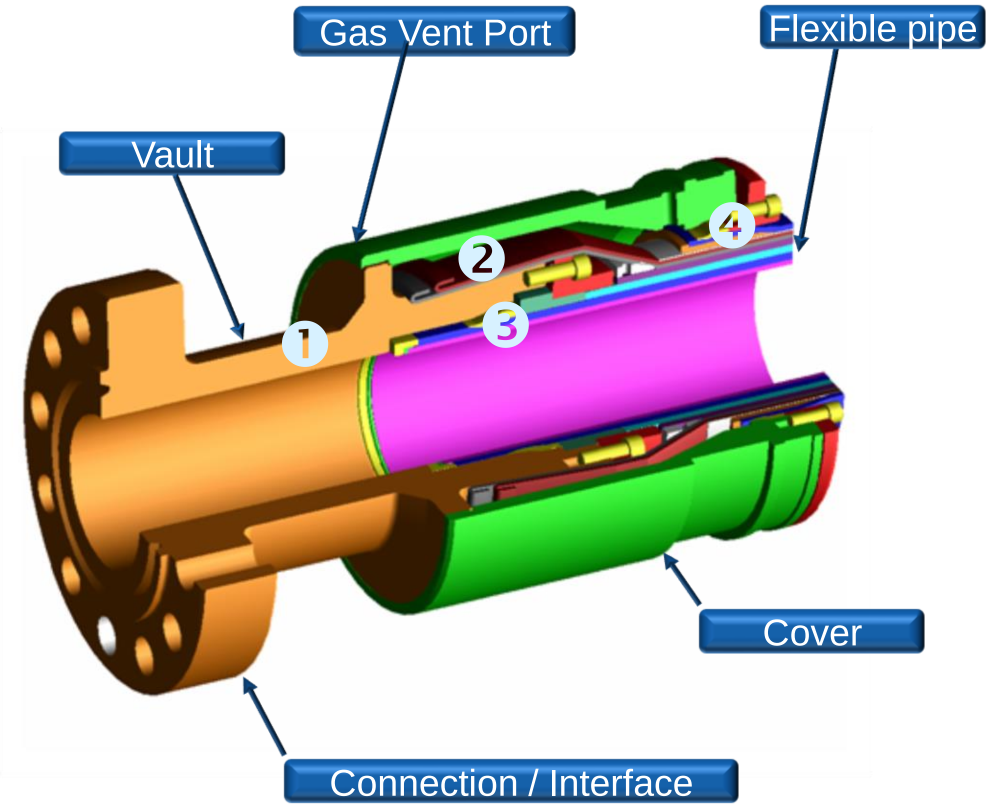
- Insulation (syntactic)
- Protective (plastic) sheath: additional layer on top of insulation or external sheath.
- External carcass: For abrasion or protection of fire resistant coating.
- Fireproof coatings; chloroprene rubber with carcass
- Also (to be covered in new technology section):
  - Anti H_2S sheath
  - S-Carcass

Flexible pipe with insulation

Layer by Layer
End Fitting: Function

Primary functions :

- Provide a connection to adjacent equipment (1)
- Withstand & transfer loads from flexible pipe (P, T, BM, Shear).
- Armour anchoring (2): Tensile loads.
- Front crimping (3): Internal sealing integrity.
- Rear crimping (4): External sealing integrity.
- Mounting/installation point for ancillary equipment.



Flexible Pipe End Fitting (cross section)

TechnipFMC

Layer by Layer
End Fitting: Function & Manufacture

- **Equipment that can be connected to or mounted on End Fittings:**
  - Gas Relief Valves (GRV)
  - Anode cables
  - Bending restrictor (reaction collar)
  - Hang off collar
  - Any other customisation where required.

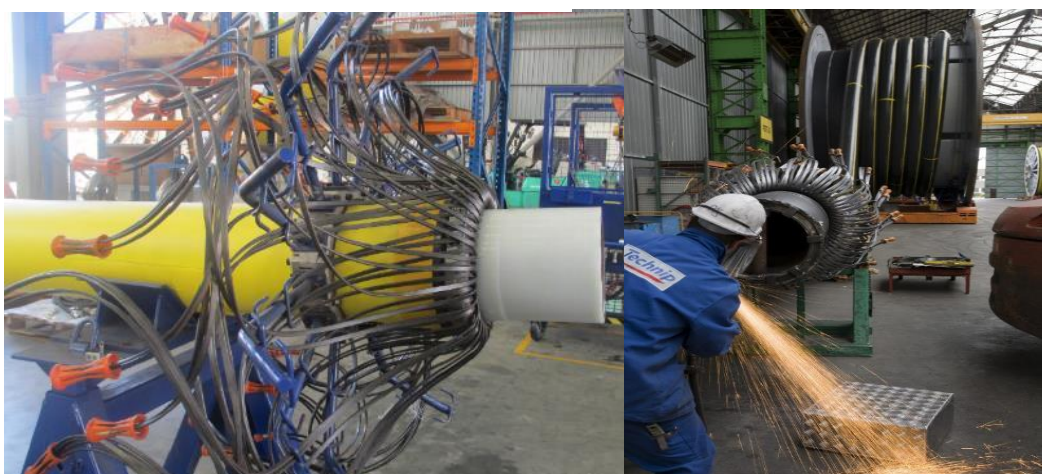
- **Raw Materials:**
  - From Standard API6A 60K Steel (4130) up to Duplex.
  - Grade adapted to fluid composition, pressure & temperature.
  - Corrosion Protection with Painting, Nikaflex® or Inconel Cladding.
  - Comply with NACE MR 0175 (materials exposed to H_2S).

TechnipFMC

Layer by Layer
End Fitting: Manufacture

End fitting forging

End fitting cover and vault after machining



End Fitting mounting process – preparation of flexible pipe layers

End fitting components pre-assembly

Annulus Venting - End Fitting

- **Gas diffusion: Pressure build-up (annulus) –> Gas released through Gas Vent Ports (GVP)**

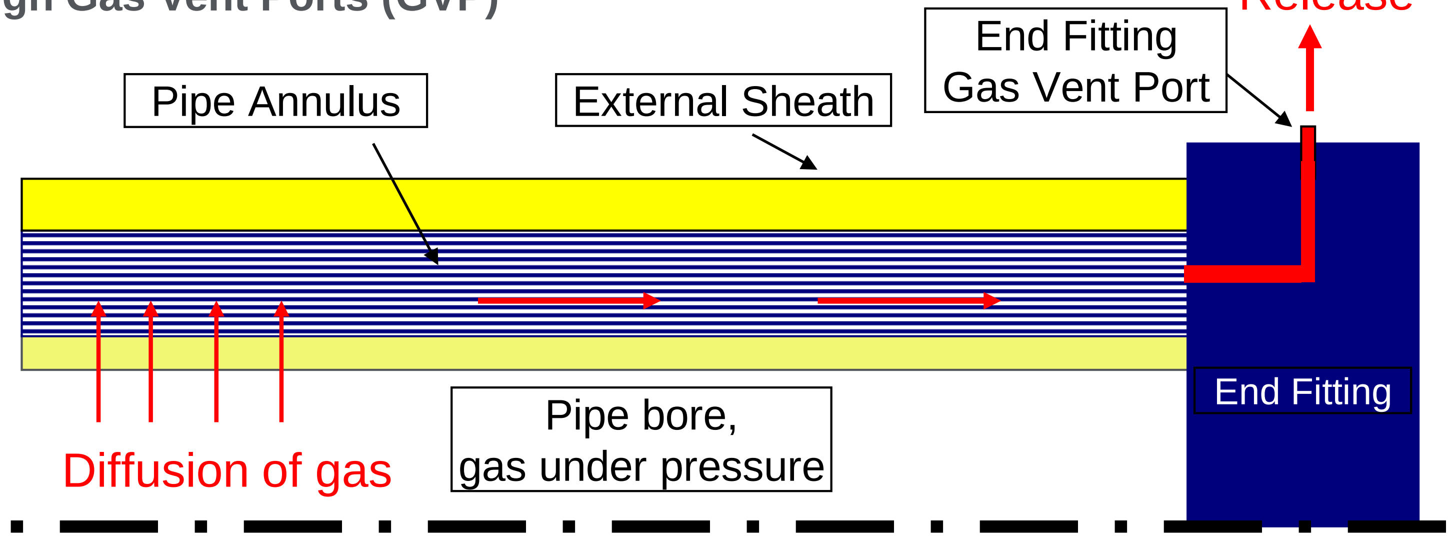


Figure 51 – Annulus gas release through EF

- **Gas Vent Ports (GVP):**
- Standard EF designed with 3 GVPs (2 guaranteed to work).
  - GVP Connected to topside gas disposal system (Topside).
  - Gas Release Valves (GRV), typically Inconel material.
  - Standard: 2 barg +/-0.5 barg (qualified up to 3000m WD).

Figure 52 – GRV

Flexible Pipe Manufacturing Unit

Figure 33 – AsiaFlex Manufacturing Unit

Packing and Transport

Carousel

- Longer lines
- Large diameters

Reel:

- Standard Packing

Basket/ Pallet:

- Jumpers

Carousel

Pallet

Reel lift and move by Reel Carrier

Packing and Transport

Transport typically via Heavy Lift Vessel (i.e. multiple reels) or Installation vessel (Carousel)

Dependant on operation/installation strategy, location of field, availability of assets etc.

Reel on HLV next to installation vessel

Reel transport via HLV

Fast Track Transport: Delivery

Pipe Fast Track Transport (Macondo)

Flexible Pipe Design

Design Codes and Standards

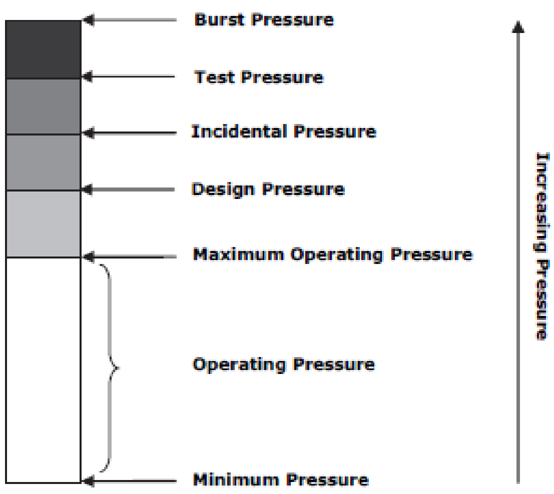
- **20-25 years ago, no design codes/ standards specifically developed for flexible pipe.**
    - Each operator had their own specifications with different requirements.
- **Joint Industry Project (JIP) launched in early 90s to define an industry standard specification for flexible pipe.**
    - Contribution from a wide range of operators, manufacturers, contractors and regulatory authorities (HSE etc.) which resulted in API standards for flexible pipe.
- **API 17J – Specification for Unbonded Flexible Pipe -** Current version: 4th Edition, May 2014
- **API 17B – Recommended Practice for Flexible Pipe -** Current version: 5th Edition – May 2014
- **API 17L1 – Specification for Flexible Pipe Ancillary Equipment -** Current version: 1st Edition – March 2013
- **API 17L2 – Recommended Practice for Flexible Pipe Ancillary Equipment –** Current version: 1st Edition – March 2013
- **Most clients / operators have additional requirements to API Standards.**

Flexible Pipe Design

- **Design is an iterative process. Accuracy in design inputs (and good design tools) speeds up this process.**
- **Main requirements (inputs) for flexible pipe design:**
  - Internal Diameter (ID)
  - Design Pressure & Temperature.
  - Operating Pressure & Temperature (permanent normal operation).
  - Application – Static / Dynamic.
  - Fluid Composition.
  - Water Depth.
  - External Environment Temperatures.
  - Design Life.
  - Pipe Length.
  - Insulation or U-value Requirement.
  - Metocean Data (current/ waves), Vessel Motions (RAO).
  - Connection Type Requirement (hub/ flange size) and location.

Figure 34 – Flexible Pipe Design

Figure 35 – Pressure Definition (API 17J)



Flexible Pipe Design: Failure modes

- **Internal progression**
  - Carcass fatigue
  - Carcass collapse
  - Erosion
  - Temperature cycling fatigue
  - Ageing
  - Chemicals
  - Temperature
  - Water
  - H_2S / CO_2 diffusion
  - Armour fatigue
  - Vent system malfunction (external sheath breach)

- **External progression**
  - Wear from external interface. I.e. j-tube, arch, stiffener.
  - Wear of fabric tape
  - Entanglement/interference with other structures or flexibles
  - Dropped objects (impact damage)
  - Aging
  - Corrosion
  - Hydrogen Inducted Stress Cracking (HISC)

Flexible Pipe Design: Mechanical loads

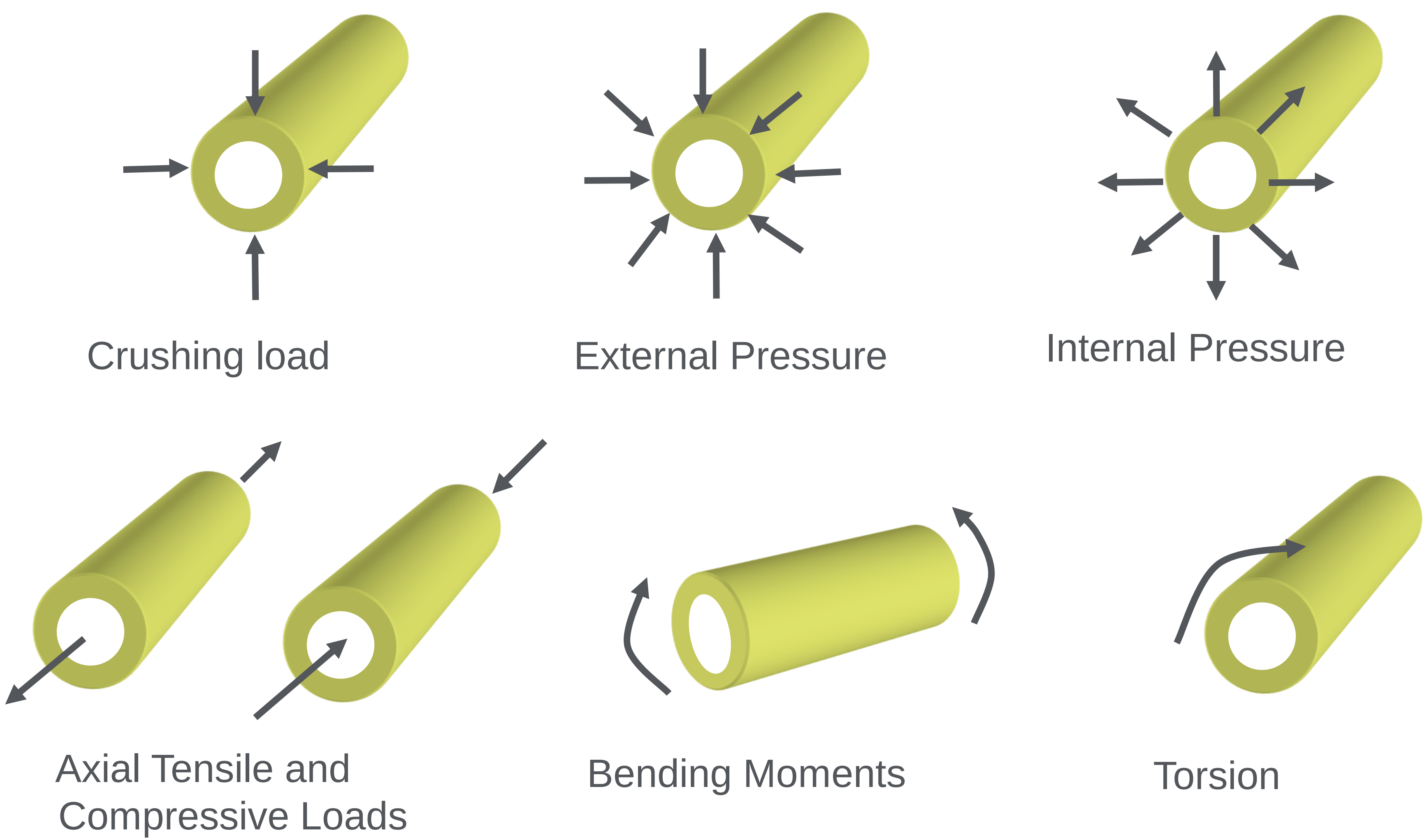


Figure 36 – Loads on Flexible Pipe

Flexible Pipe Design: Allowable Utilisation

Layer	Primary Pipe Failure Mode	Design Criteria	Operating Conditions			Nonoperating Conditions			Survival
			Permanent		Abnormal	Temporary			
			Normal	Extreme		Normal		Extreme	
						Installation	Test		
Internal carcass	Collapse (1) (2)	Load	0.85						
Inner liner smooth bore	Collapse (1)	Load	For each polymer material for both static and dynamic applications, the allowable utilization for collapse shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that load.						
Internal pressure sheath	Rupture	Thinning (3)	The maximum allowable reduction in wall thickness over the service life below the minimum design value, due to deformation into gaps in the supporting structural layer, shall be 30 % under all load combinations.						
		Strain	For each polymer material for both static and dynamic applications, the allowable bending strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain. The maximum allowable bending strain at nominal dimensions shall be 7.7 % for polyethylene (PE) and polyamide (PA), 7.0 % for polyvinylidene fluoride (PVDF) in static applications and for storage in dynamic applications, and 3.5 % for PVDF for operation in dynamic applications (4).						
Pressure armors	Loss of interlock breakage	Stress	0.67	0.85	0.85	0.67	0.91 (9)	0.85	0.97 (5)
	Collapse (1) (2)	Load	0.85						
Tensile armors	Breakage	Stress	0.67	0.85	0.85	0.67	0.91 (9)	0.85	0.97 (5)
	Buckling	Load	0.85						
	Wire disorganization	Displacement	The cumulative radial gap between each tensile armor and its adjacent layers shall not exceed half the wire thickness						
Anticollapse sheath (6)	Rupture	Strain	For each polymer material for both static and dynamic applications, the allowable bending strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain.						
Antibuckling tape	Birdcaging (7)	Stress or strain (8)	0.67	0.67	0.85	0.85	0.85	0.85	0.91
Outer sheath	Rupture	Strain	For each polymer material for both static and dynamic applications, the allowable bending strain shall be as specified by the manufacturer, who shall document that the material meets the design requirements at that strain. The maximum allowable bending strain shall be 7.7 % for PE and PA.						

Figure 37 – Flexible Pipe Layer Design Criteria (API 17J)

Flexible Pipe Design: Locking & Minimum Bending Radius

Locking Radius (LR): Radius to cause locking of interlocked layer. Measured from the pipe centreline

- **Minimum Bending Radius (MBR)**

- MBR: maximum value between (at least):
  - 1.1 x LR
  - Radius generating the maximum allowable bending strain on the polymer layers
    - PE/ PA – 7.7% allowable strain
    - PVDF – 7% (static) and 3.5% (dynamic) allowable strain
- MBR relation with pipe diameter:
  - 6” ID pipe typical MBR ranging from 1.3 to 1.5m
  - 10” ID pipe typical MBR ranging from 2 to 2.5m
  - 16” ID pipe typical MBR ranging from 3 to 3.6m

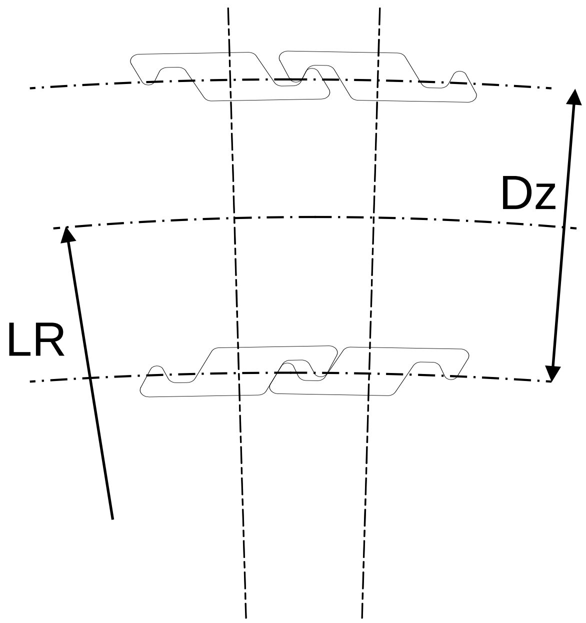


Figure 38 – Pipe sectional view (pipe bent): LR: Locking Radius Dz: Zeta diameter

TechnipFMC

Flexible Pipe Design:
Factory Acceptance Tests (API 17J)

- Hydrostatic strength test – 24 hours hold period
  - TP = 1.3 x DP for subsea flexible flowlines and static jumpers
  - TP = 1.5 x DP for dynamic risers and topside jumpers
- Electrical continuity and isolation test
- Gas venting test
- Sealing test
- Gauge test

Table 20—Factory Acceptance Test

		Gauge Test	Hydrostatic Pressure Test	Electrical Isolation Test	Electrical Continuity Test	Gas-venting System Test	Sealing Test
Without cathodic protection	Rough bore	X (1)	X	n/a (1)	n/a	X	X (2)
	Smooth bore	n/a	X	n/a	n/a	X	X (2)
With cathodic protection	Rough bore	X	X	X	X	X	X (2)
	Smooth bore	n/a	X	n/a	X	X	X (2)
NOTE 1 X—required; n/a—not applicable.							
NOTE 2 The sealing test is required for risers and optional for other applications.							

Figure 39 – Factory Tests (API17J)

TechnipFMC

Flexible Pipe Design: Materials Selection & Corrosion Considerations

Pressure Sheath Material Selection

Polymer Selection

- Pressure/ Temperature conditions
- Creep (max allowable thickness reduction: 30%)
- Blistering (not enough time for gas absorbed to diffuse out of polymer during rapid depressurisation)
- Swelling (fluid absorption – volume increase – mechanical properties affected)
- Stress cracking (sensitive to a product and under strain)
- Chemical ageing
  - PA: hydrolysis
  - Amines: Chemical attack on PVDF

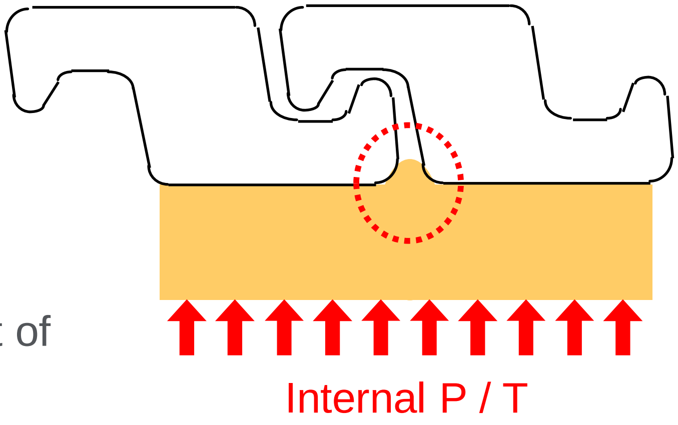


Figure 40 – Creeping

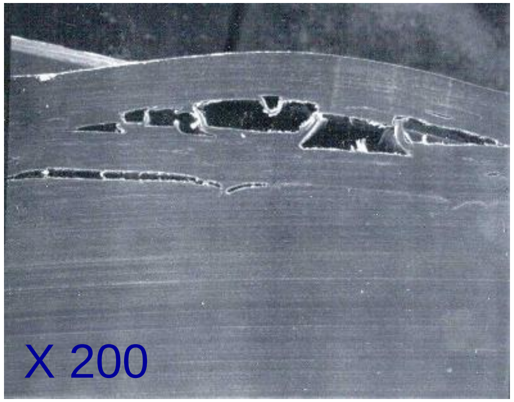


Figure 41 – Blistering

Figure 42 – Stress Cracking

Pressure Sheath - Materials

- PA: Rilsan® P40 TL, Pipelon® 401, Polyamide TP30
- PVDF: Gammaflex®, Coflon® XD, Coflon®
- PE: Finathene, Crossflex®
- HDPE: TP35

Temperature range: -50°C to 150°C
Up to 170°C - Thermal screen (PTFE)

TechnipFMC

Plastic Sheath Material Selection

	Advantages	Drawbacks
PE	Good chemical resistance Low cost	Blistering resistance
HDPE	Same as standard PE but with excellent blistering behavior Low cost	Less track record compared to other polymers (Woodside Greater Enfield)
PA	No affinity with hydrocarbons Good behavior in blistering	Susceptible to hydrolysis
PVDF	Chemically inert High temperature resistance	High cost
TP-Flex/ HD-Flex	Low cost Thermal insulation	Poor creep resistance (external sheath only)

Figure 44 – Sheath materials comparison

Polymer suitability: field's requirements

TechnipFMC

Metallic Material Selection

- **Corrosion Considerations in Flexible Pipe Design**
  - Inner carcass in contact with transported fluid but not under any tensile stress in operating conditions
  - Annulus steel layers (load bearing metallic layers) not in direct contact with transported fluid (shielded by pressure sheath) - exposed to diffused transported gases (CO_2 / H_2S) but in much lower quantity than in the bore

Steel grades used must be suitable for the application to prevent excessive corrosion and HIC/SSC

Metallic Material Selection - Carcass

- **Inner carcass**
  - Grade must be suitable for transported fluid / design conditions
  - Stainless steel
  - Grade selection driven by
    - Design temperature and pressure
    - Fluid CO_2, H_2S, Chloride content
    - Water composition - bore pH
  - Material allowable range use -> Corrosion testing on manufactured carcass samples (conditions)

Figure 45 – Carcass strip

Metallic Material Selection - Carcass

- **Inner Carcass – Flexible Pipe Storage**
  - Flexible stored full of sea water or fresh water case
  - Risk of pitting corrosion due to stagnant water with chloride or presence of oxygen
  - Account for:
    - Storage duration
    - Temperature
    - Use of Corrosion Inhibitors

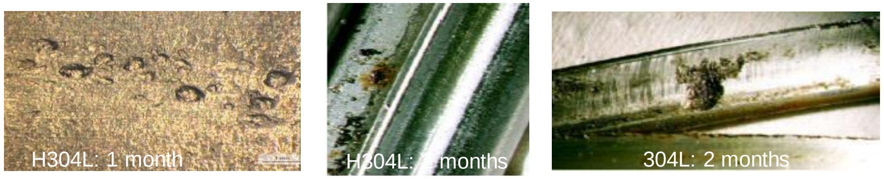


Figure 47 – Pitting Corrosion

  - Pipe can be stored filled with sea water for limited duration depending on temperature conditions with no corrosion inhibitors.
  - For extended duration use of corrosion inhibitors compulsory.

Metallic Material Selection – Annulus Wires

INPUT DATA

INNER BORE
- Pressure
- Temperature
- Fluid composition

ANNULUS
- Structure
- Pressure
- Seawater(damage)

EXTERNAL ENVIRONMENT
- Temperature
- Depth

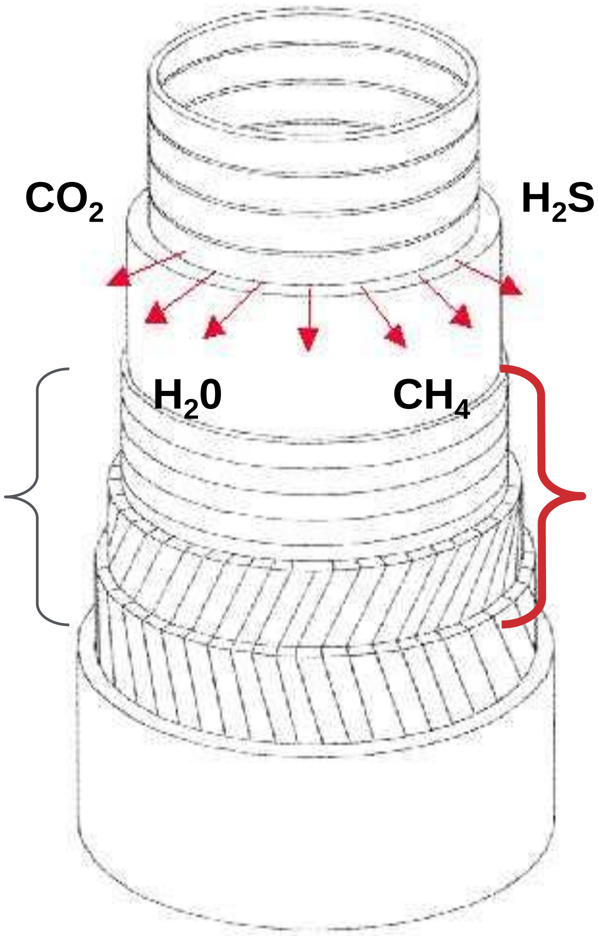


Figure 48 – Diffusion Process

OUTPUT DATA

ANNULUS
- Liquid H_20 ?
- pCO2
- pH_2S
- pH

Metallic Material Selection – Annulus Wires

Volume of annulus in a flexible pipe

- 70%-80% of carbon steel wires
- 10%-20% of polymers
- 10%-20% of free space for environment (gas and/or water)

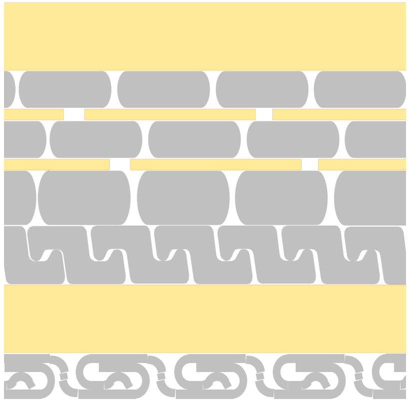


Figure 49 – Annulus: high confinement

Main specifics

- HIGH CONFINEMENT – STAGNANT CONDITIONS
- R = Volume of environment/Total surface of steels = 0.01-0.06 ml/cm2
- Quickly: solution saturated with Fe^{2+} (even oversaturated) as soon as there is a corrosion process
- Formation of protective corrosion scale decreasing corrosion rate

Paper available on the subject:

- OMAE 2003 -37193 : MOLDI™: a fluid permeation model to calculate the annulus composition in flexible pipes: validation with medium scale tests, full scale tests and field cases.

Metallic Material Selection – Annulus Wires

- **Corrosion in Flexible Pipe Annulus**
  - Uniform corrosion
  - Wires thickness reduction
  - To be accounted for in wires dimensioning
  - API 17J requirement

Metallic Material Selection – Annulus Wires

- **H2S corrosion in Flexible Pipe Annulus**
  - In presence of water (external sheath breached/ water diffusion):
    - Hydrogen Induced Cracking (HIC)
    - Sulphide Stress Cracking (SSC)
    - HIC and SSC can result in cracking in the steel wires
  - Severity of sour environment will depend on:
    - pH
    - Partial pressure/ fugacity of H2S
    - Temperature
    - Steel grade characteristics
- For dynamic application, appropriate S-N curves selected – Conditions must cover annulus environment

Corrosion Considerations

- **Cathodic Protection (CP)**
  - If outer sheath damaged during installation or in service, pipe annulus becomes flooded with sea water
    - Far from damage - high level of confinement (O2 is not renewed – negligible corrosion rate)
    - Damaged area - seawater and O2 renewal: sensitive to general corrosion
    - Steel wires corrosion at damaged area prevented by CP (anodes)
    - Anodes material: Al/ Zn alloy

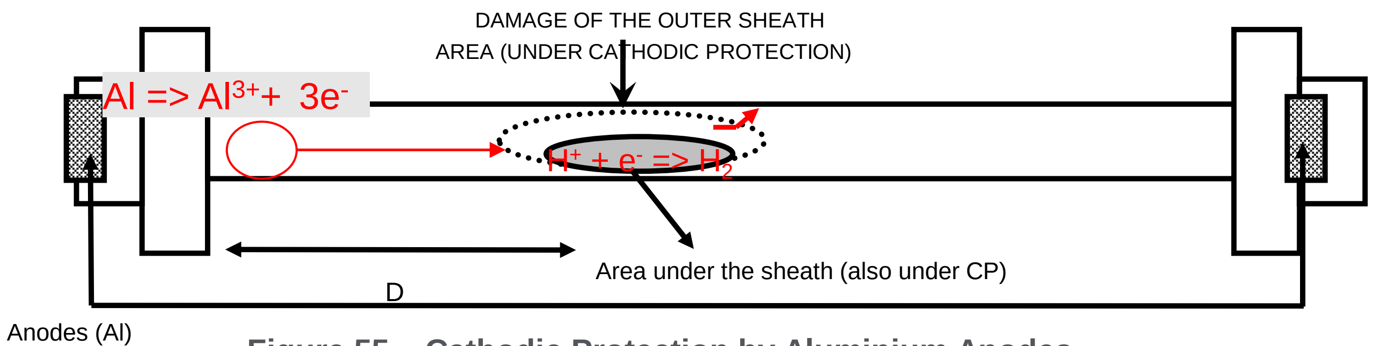


Figure 55 – Cathodic Protection by Aluminium Anodes

Corrosion Considerations

- **Typical Anode Arrangement**
  - Anodes connected to end fittings via continuity cables (or direct to end fitting)
  - Electrical continuity in pipe provided by tensile armour wires

Figure 56 – Anodes fitted to pipe and connected to EF

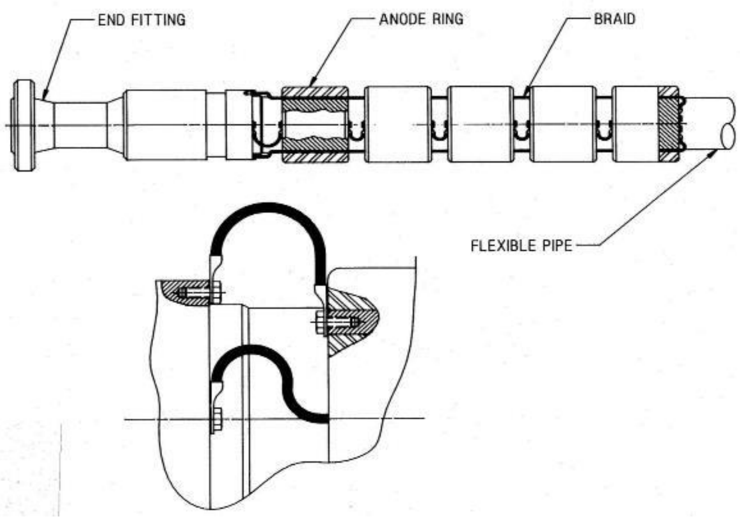


Figure 57 – Anodes Arrangement

Driving Parameters for Flexible Pipe Design

- **For Material Selection**
  - Pressure and Temperature (Material selection)
  - Design Life (Sheathes ageing and steel layers corrosion)
  - H_2S/ CO_2 Content (Material selection)
  - Transported Fluid Composition (Chloride content …) (Material selection)
  - Water Depth (Insulation/ Carcass Dimensions)
  - ….

- **ITERATIVE PROCESS**

Flexible Pipe Track Record

Flexible Pipe Capabilities

Pressure	**0 to 20,000 psi for 4" ID** **0 to 5,000 psi for 12" ID (sour service)**
Temperature	**- 50°C to +150°C (up to 170°C thermal screen)**
Internal diameters	**2" to 22"**
Single length max	**>5000 m for 4" ID** **850 m for 12" ID for reel manufacture** **3500 m for 12" ID for carousel manufacture**
Water depth	**3000 m for 7" & 9" ID** **2500 m for 11" ID** **2000 m for 16" ID**

OTC 2011 – 21490 (Qualification Testing of Flexible Pipe for 3000m WD)

Flexible Pipe Water Depths

Installation records

- Deepest flexible pipes installed:
  - 6” and 9” Prod Riser 2140m WD (Lula)
  - 6” Prod Riser 2180m WD (Sapinhoa Norte)
  - 6” WI Riser 2230m WD (Iracema Sul)

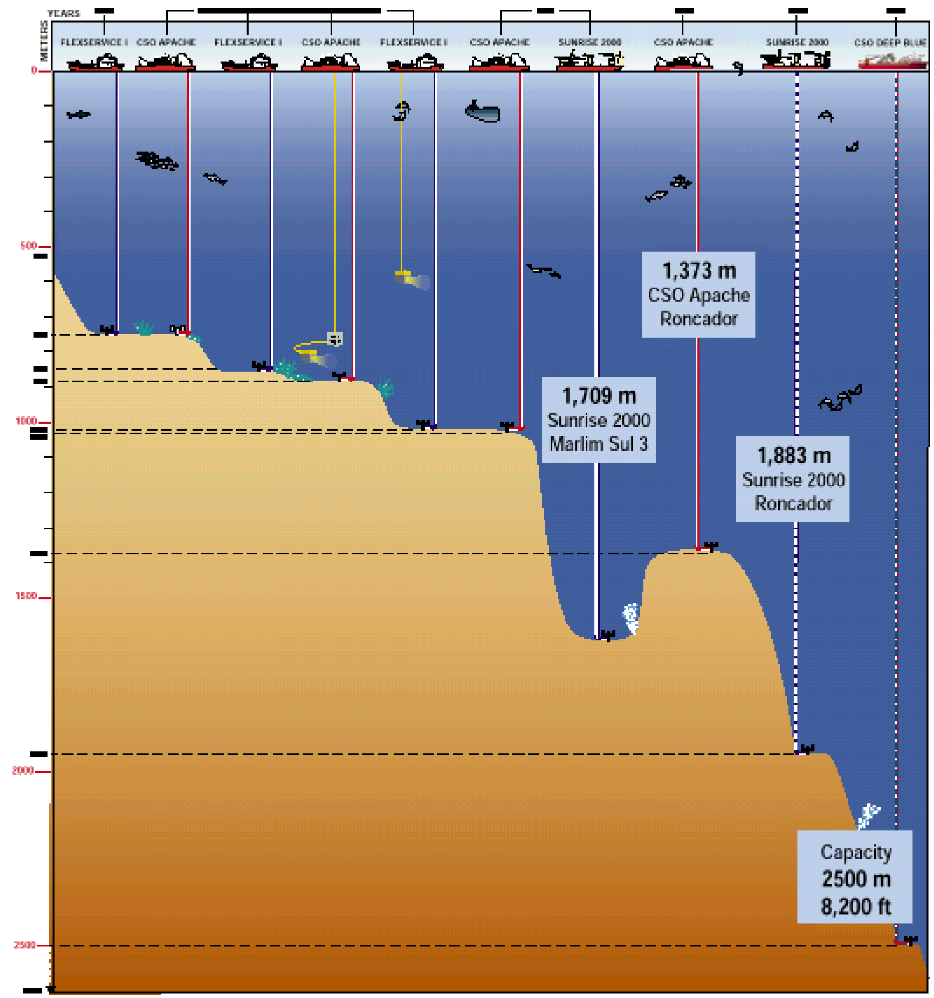


Figure 58 – Vessels Water Depths Installation Capacities

TechnipFMC

Flexible Pipe Track Record

As-built and in service

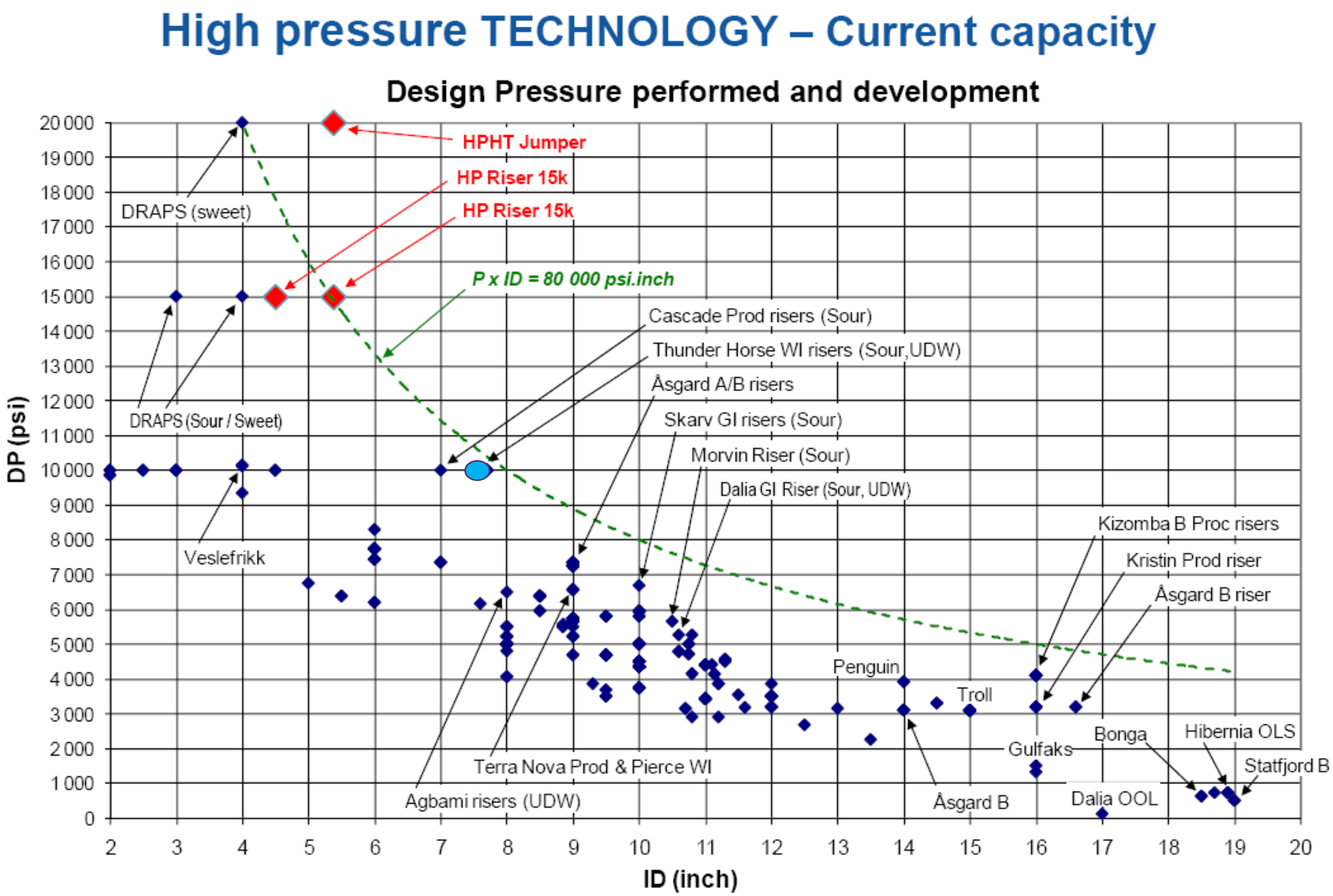


Figure 59 – ID x DP Current Capacity

- Deepest (1890m WD) and highest ID x P: 7.5” ID x 10,000 psi – Thunder Horse (Gulf of Mexico)

Static and Dynamic Systems

Agenda

- Static Flowline System
- Dynamic Riser System
- Flexible Riser Configurations
- Shallow Water Projects (Water depth < 100m)
- Deep Water Projects (100m < Water depth < 1000m)
- Ultra Deep Water Projects (Water depth > 1000m)

Static and Dynamic Systems

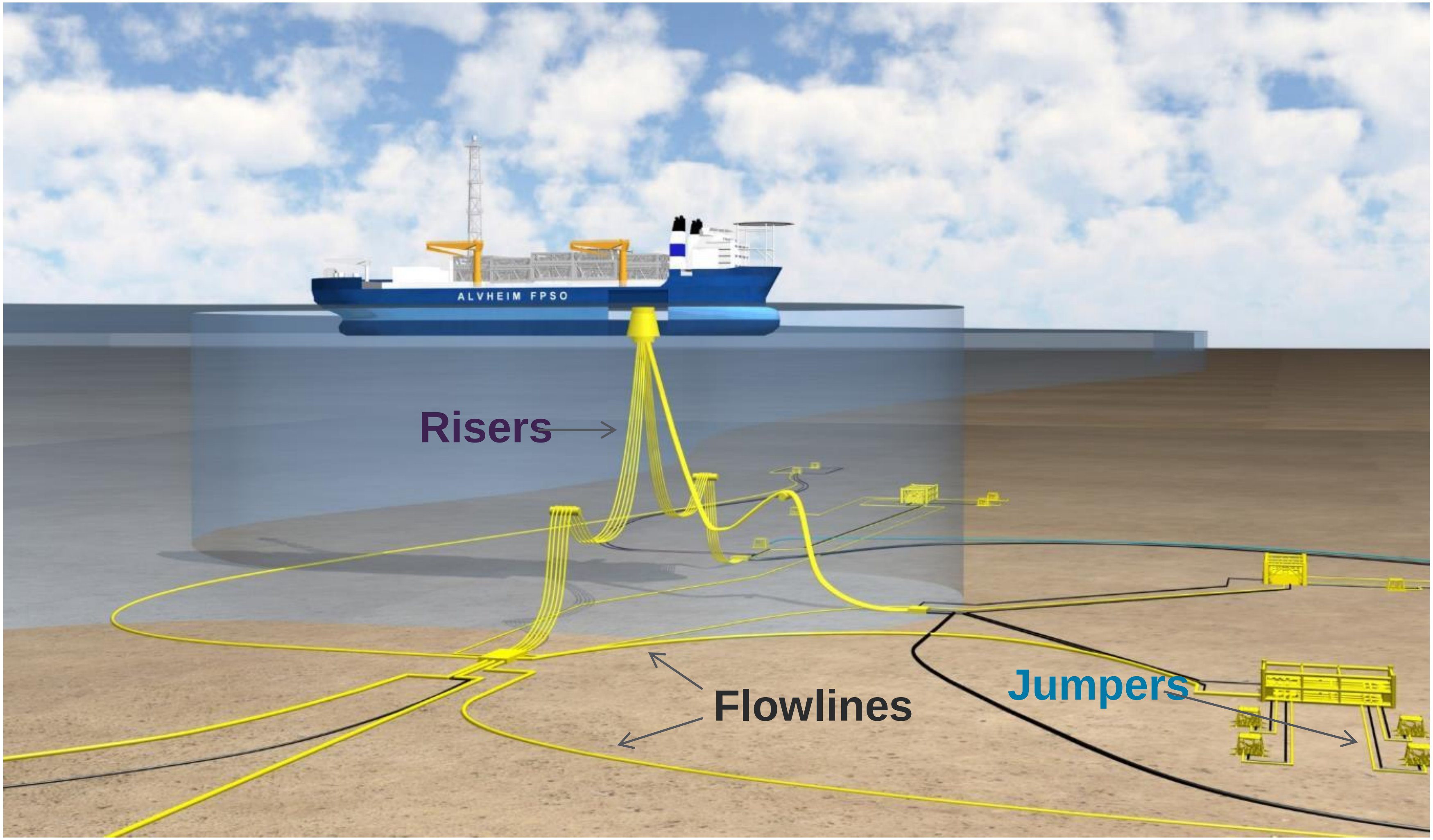


Figure 8 – Alvheim field FPSO vessel

Static Flowline Considerations

- **Flexible Flowline/Jumper Benefits vs. Rigid Pipeline**
  - Flexibility:
    - Simplified route/tighter bends
    - Shorter crossings
    - No free spans correction
  - Excellent built-in insulation
  - Corrosion resistance
  - No metrology required (jumpers)
  - Shorter installation time
  - Easy wet store
  - Reusability:
    - Flowlines and Risers often stored on the seabed and re-used by Petrobras
  - Recovery of the 6" Insulated lines after the P36 sinking:
    - Line in perfect condition
    - Can be re installed

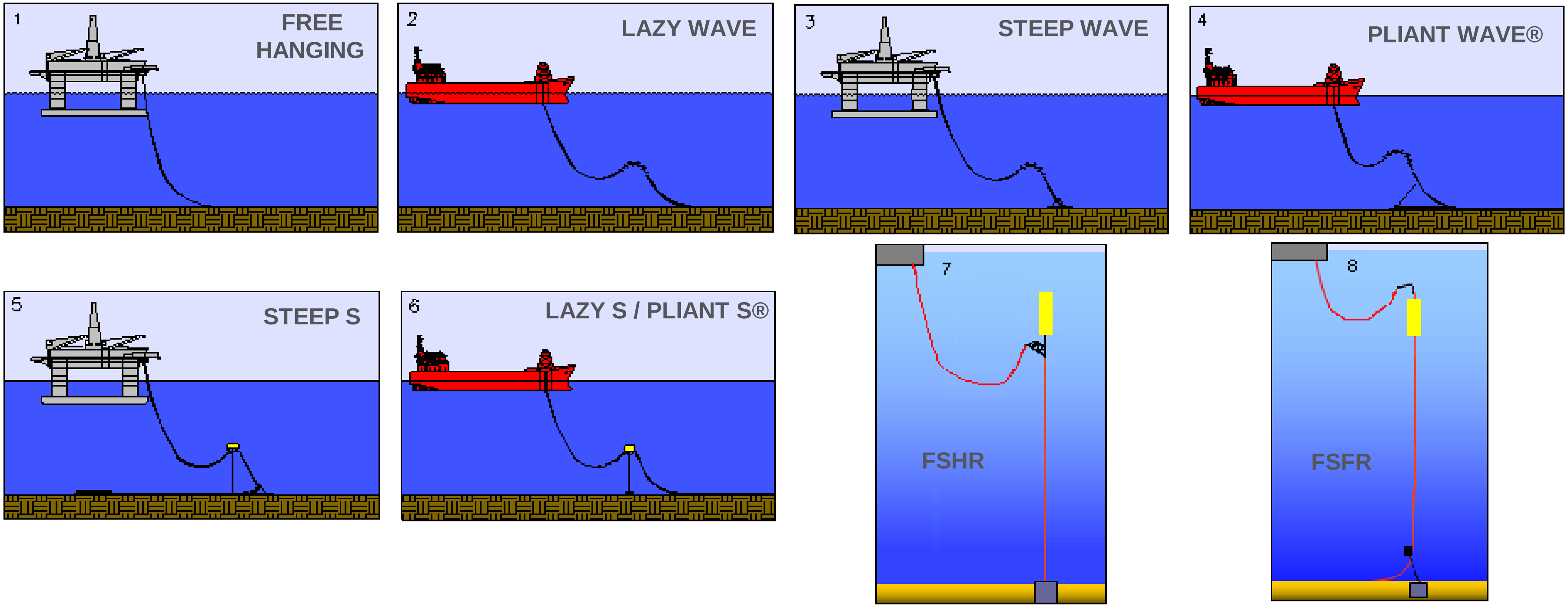
Static Flowline Considerations

- **On-Bottom Stability**
  - Similar approach as for rigid pipeline.
    - Installation conditions / design conditions.
    - Assessment based on existing codes DNV RP F109.
  - Current driven (deep water) vs. wave driven (shallow water).
  - Trench: shielding effect significantly reduces hydrodynamic loading.
  - Flexible pipe movement acceptable in extreme storm conditions without affecting pipe integrity.

Dynamic Riser System

- **Link subsea infrastructure to floating production unit.**
- **Can accommodate large deflection without affecting pipe performance / pressure holding capacity:**
  - Floating Unit offset dynamic movement – 1st order motion.
  - Floating Unit offset variation – 2nd order motion.
  - Wave and current loading.
- **Different system configurations can be used depending on:**
  - Water depth.
  - Environmental conditions – North Sea vs West of Africa, Australia.
  - Field layout.

Flexible Riser Configurations

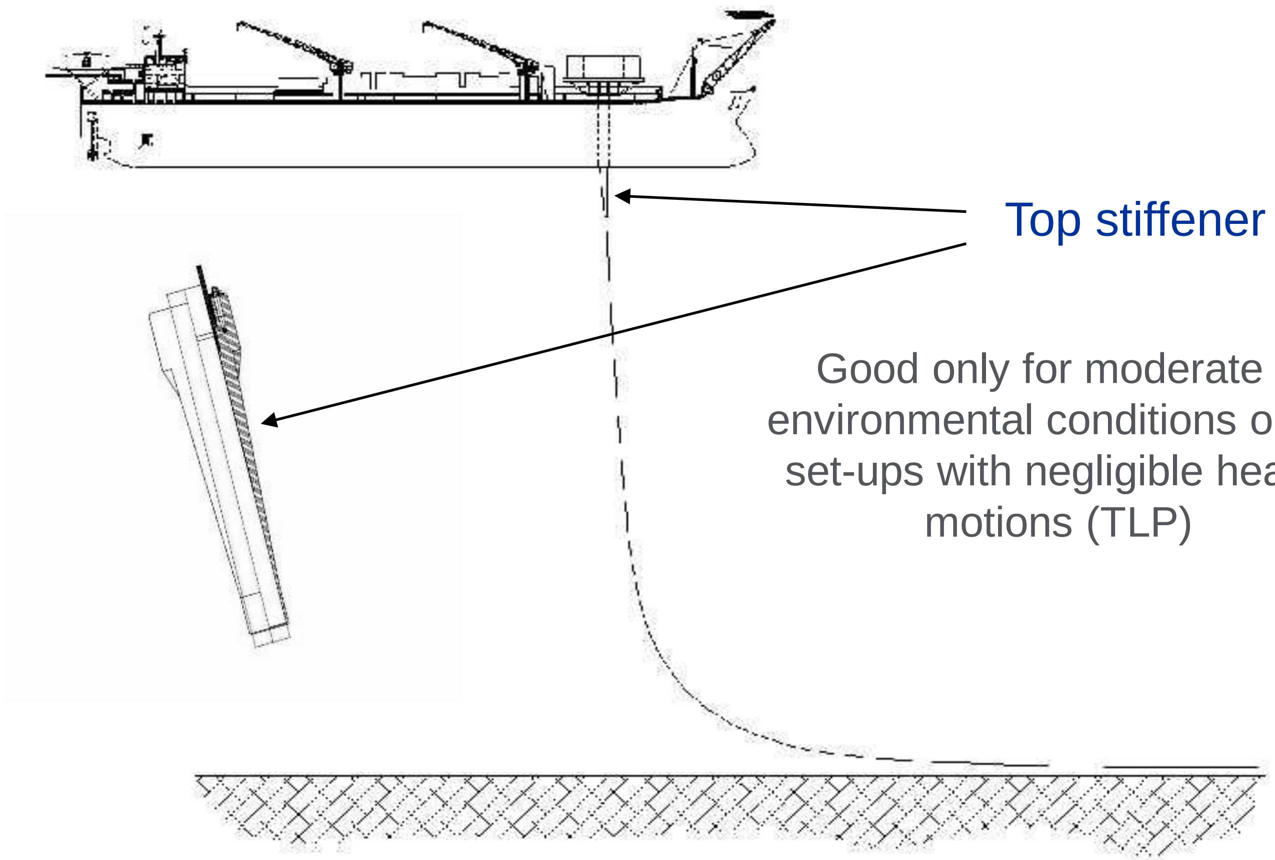


	Flexible Riser Configuration	Main Advantages
1	Free-Hanging (medium to deep water)	Good for moderate to medium environmental conditions, easiest to install
2	Lazy-Wave (shallow to deep water	Good for deep water diverless installation; lower payload on host
3	Steep-Wave (shallow to deep water)	Good for congested seabed developments; very good dynamic response
4	Pliant-Wave (shallow to deep water)	Retains both lazy-wave and steep-wave advantages
5	Steep-S (shallow water)	Good for congested seabed developments; very good dynamic response
6	Lazy-S (shallow water)	Good for satellite tie-backs with several risers; very good dynamic response
7	Free-Standing Hybrid Riser	Good for deep water; lower payload on host
8	Free-Standing Flexible Riser	Good for deep water; lower payload on host; less complex and easier to install than hybrid

Figure 60 – Flexible Riser Configurations

Dynamic Riser System

FREE HANGING



Good only for moderate environmental conditions or for set-ups with negligible heave motions (TLP)

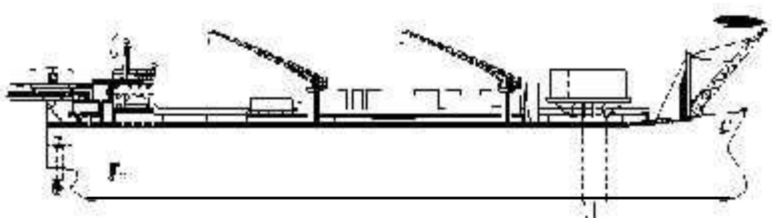
Figure 61 – Free Hanging Configuration

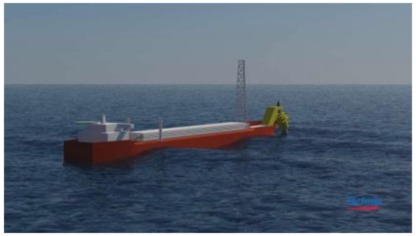
- Typical deep water configuration Brazil, WoA, GOM

TechnipFMC

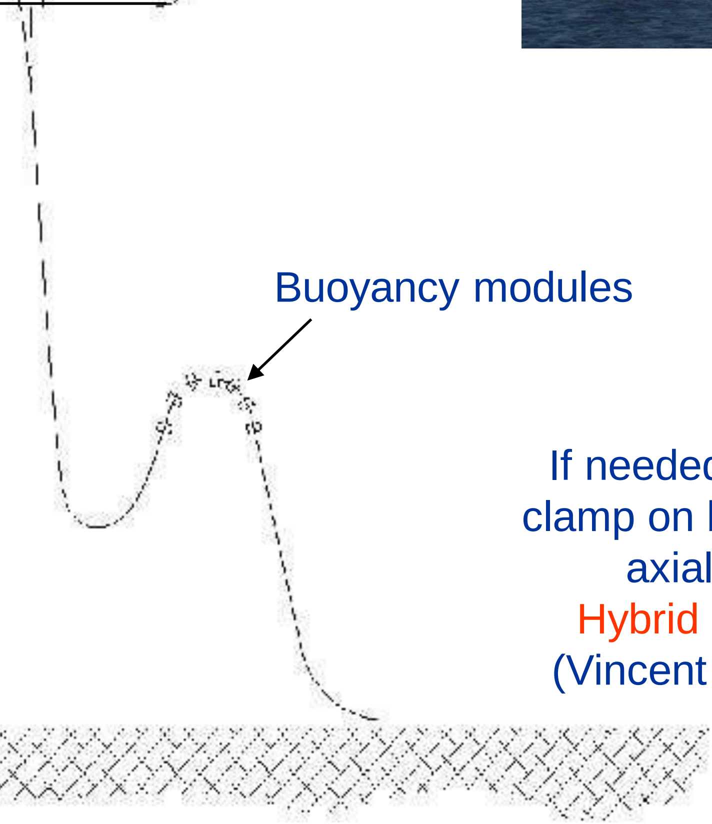
Dynamic Riser System

LAZY-WAVE





- Good for deep water diverless installation.
- Dynamic response is very sensitive to cross currents due to lack of any anchoring.
- Not recommended if a large number of individual risers must be accommodated within a single anchoring sector.



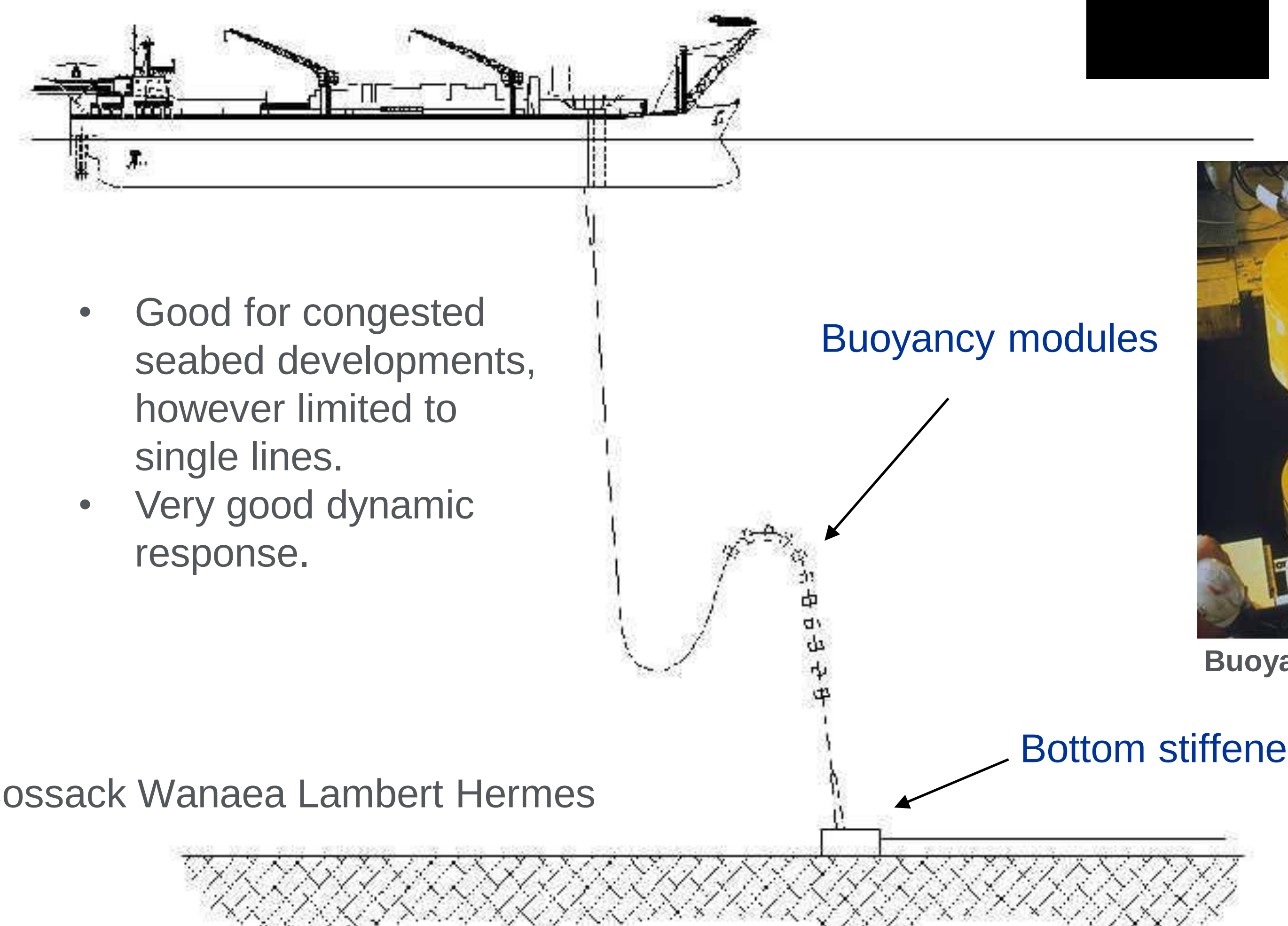
If needed, Tether and clamp on bottom to take axial tension:
Hybrid Lazy Wave
(Vincent / Stybarrow)

Figure 62 – Lazy-Wave Configuration

Dynamic Riser System

STEEP WAVE

- Good for congested seabed developments, however limited to single lines.
- Very good dynamic response.



Buoyancy Modules

- Cossack Wanaea Lambert Hermes

Figure 64 – Steep Wave Configuration

Dynamic Riser System

PLIANT-WAVE™

Developed as an hybrid between lazy wave and steep wave. Retains advantages of lazy wave and dynamic behaviour of steep wave.

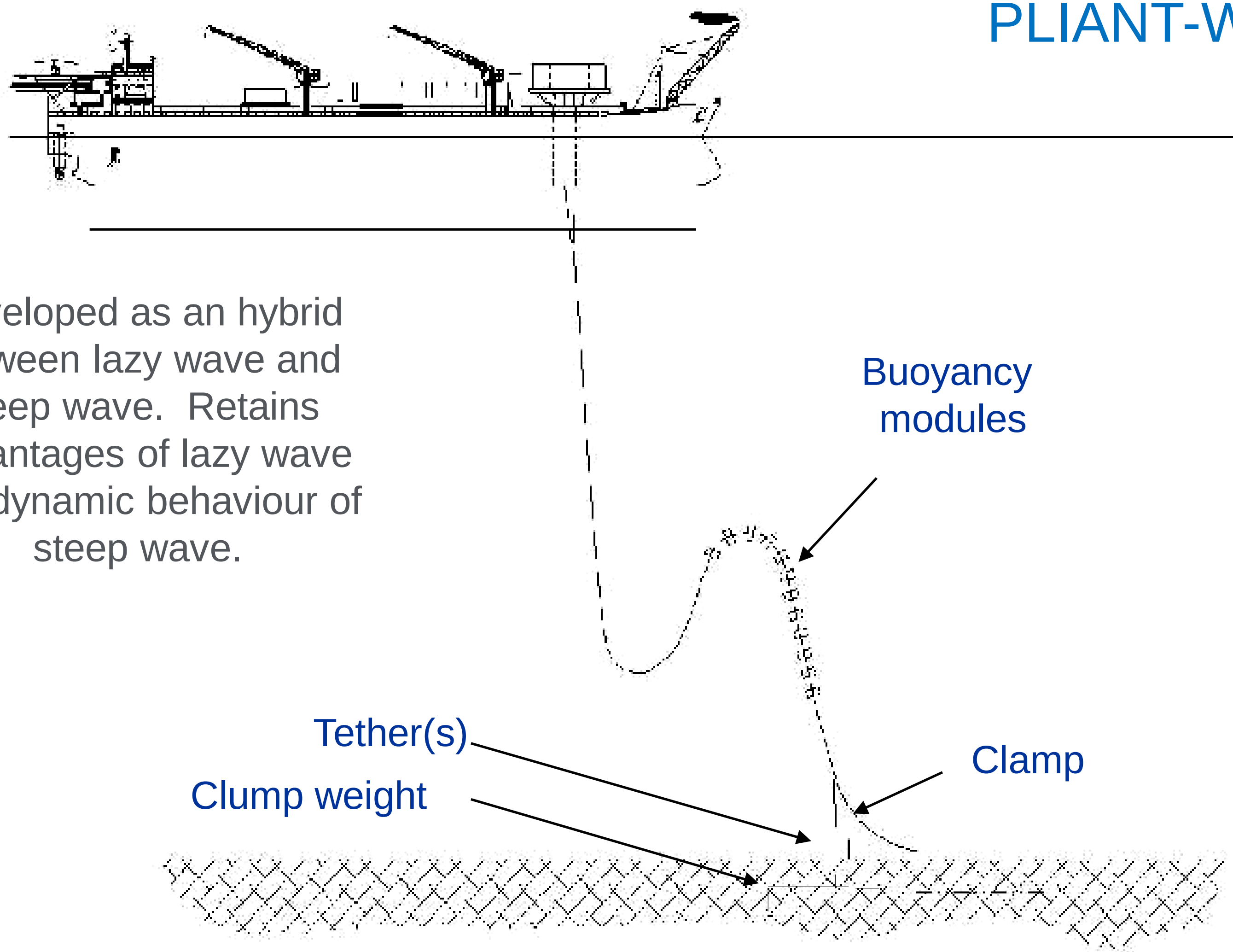


Figure 66 – Pliant-Wave Configuration

Tether Clamp

- In the UK : Foinaven, Schiehallion, in Australia Laminaria / Balnaves

Dynamic Riser System

LAZY-S

- Very good dynamic response but arch behaviour may compromise its use in shallow waters (<90m).
- Good for satellite tie-backs.
- Good for congested fields

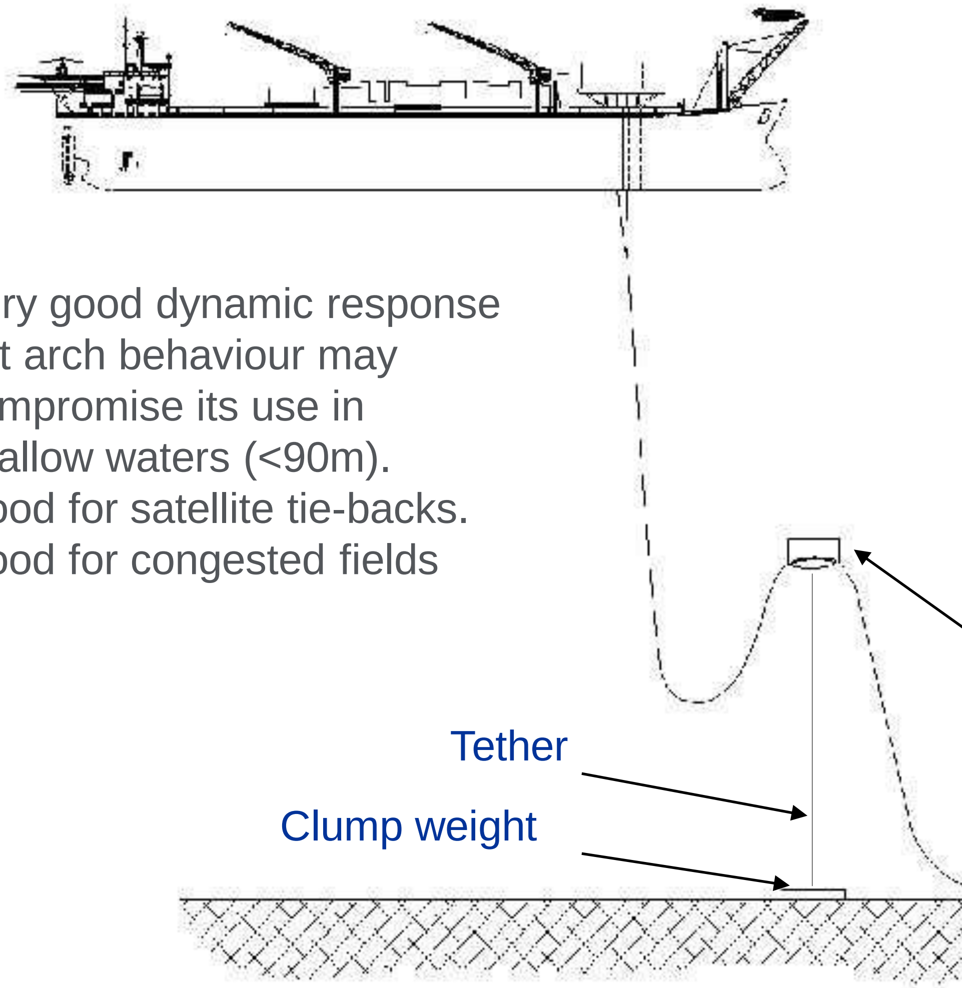


Figure 68 – Lazy-S Configuration

Mid Water Arch

- In Asia: CNOOC Lufeng, Alpha TUI, Jangkrik, Ichthys

TechnipFMC

Dynamic Riser System

STEEP-S

- Good for congested seabed developments.
- Good dynamic response but arch stability issues may compromise its use in shallow waters (<90m)

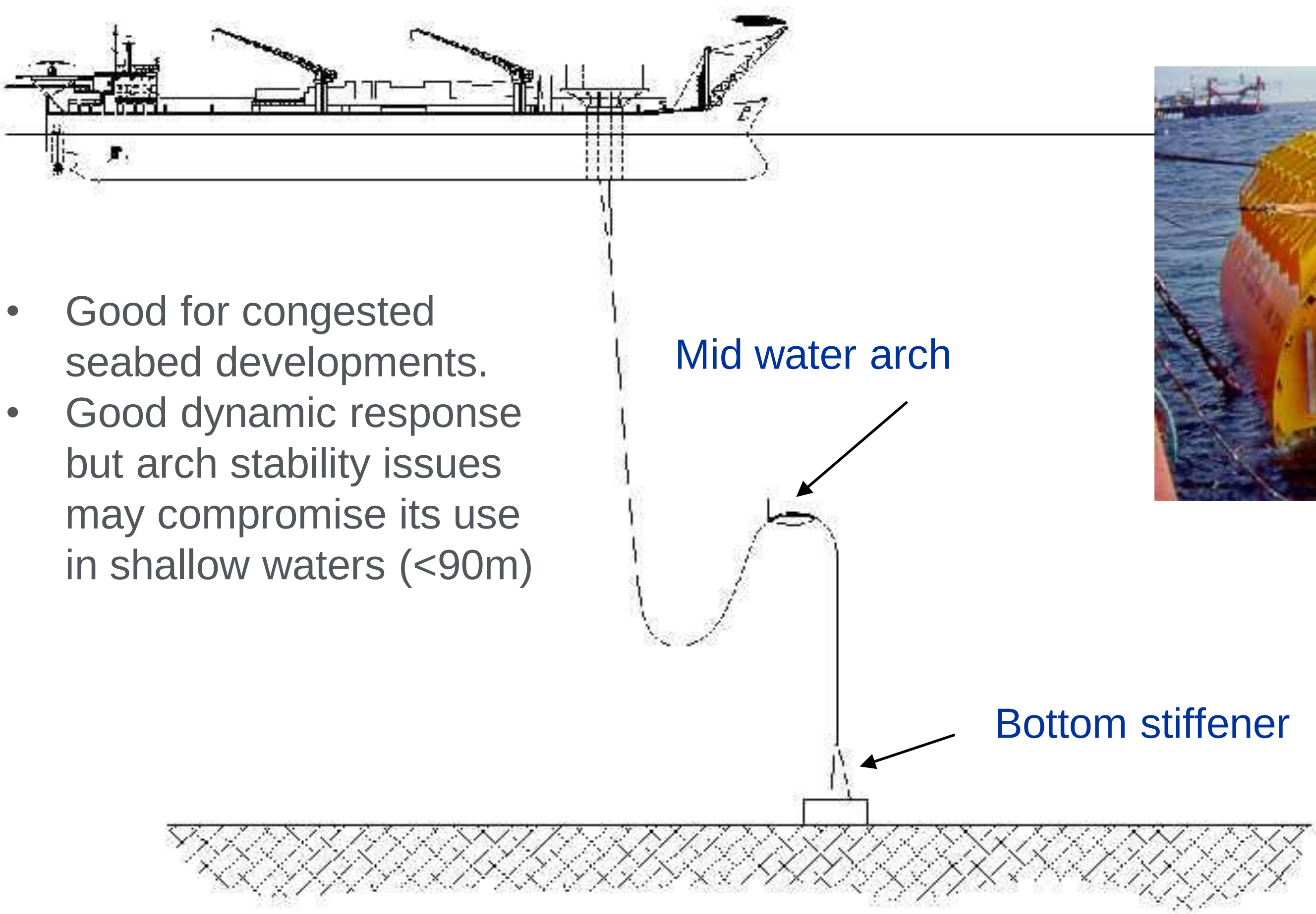


Figure 70 – Steep-S Configuration

Mid Water Ar

- In the UK : Agip Balmoral, Kerr-McGee Gryphon

TechnipFMC

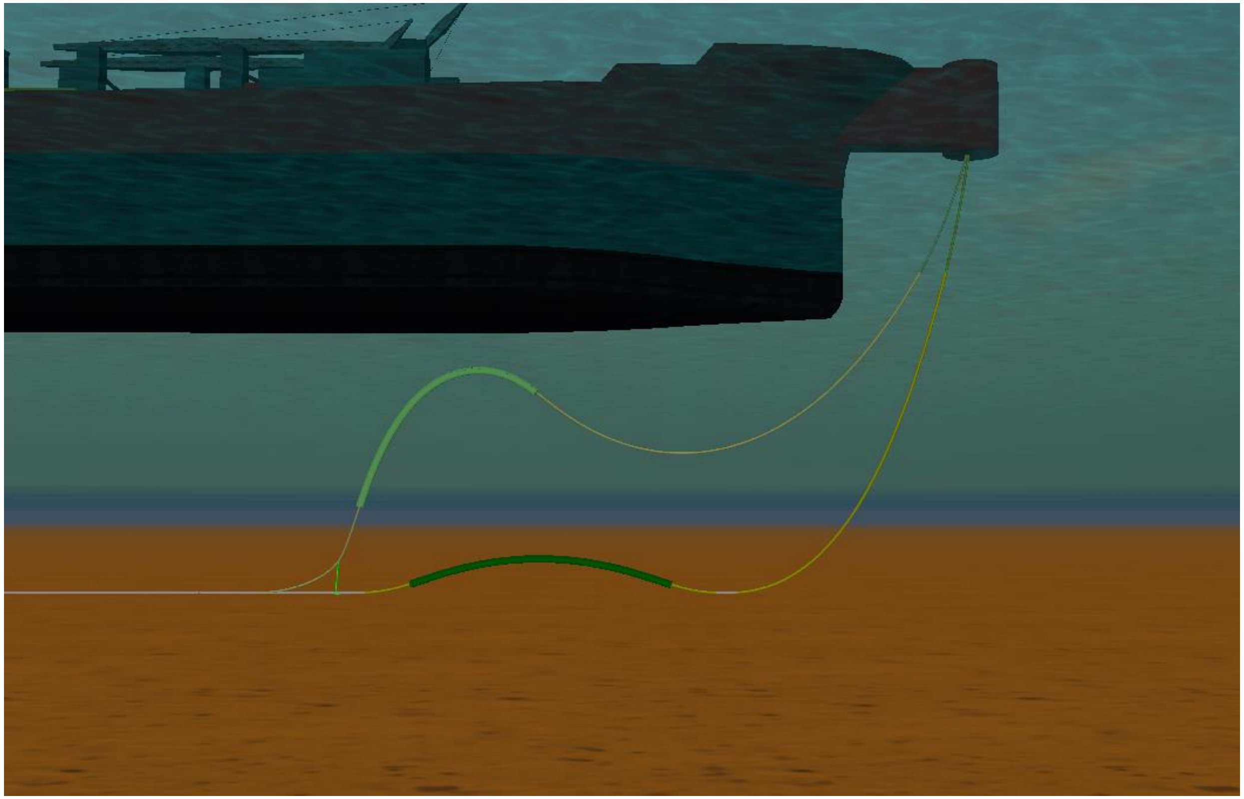
Dynamic Riser System

- **Key Drivers for Riser System Design.**
  - Water Depth.
  - Environmental Data:
    - Current.
    - Design wave conditions (maximum wave height / associated period range).
    - Wave Spectrum for fatigue assessment.
  - Floating Unit Characteristics:
    - Response Amplitude Operators (RAO).
    - Mooring system.
    - Range of offset to be accommodated.
    - Sector spacing for riser layout.
    - Riser connection location – distance to COG.
  - Field layout

Dynamic Riser System

SHALLOW WATER PROJECTS

(Water depth < 100m)



Shallow Water Field

What are the main challenges 1/2

Vessel offset:

Project 1:

- Wd = 850m
- Offset = 70m (8.2%)

Project 2:

- Wd = 345m
- Offset = 34m (9.8%)

Project 3:

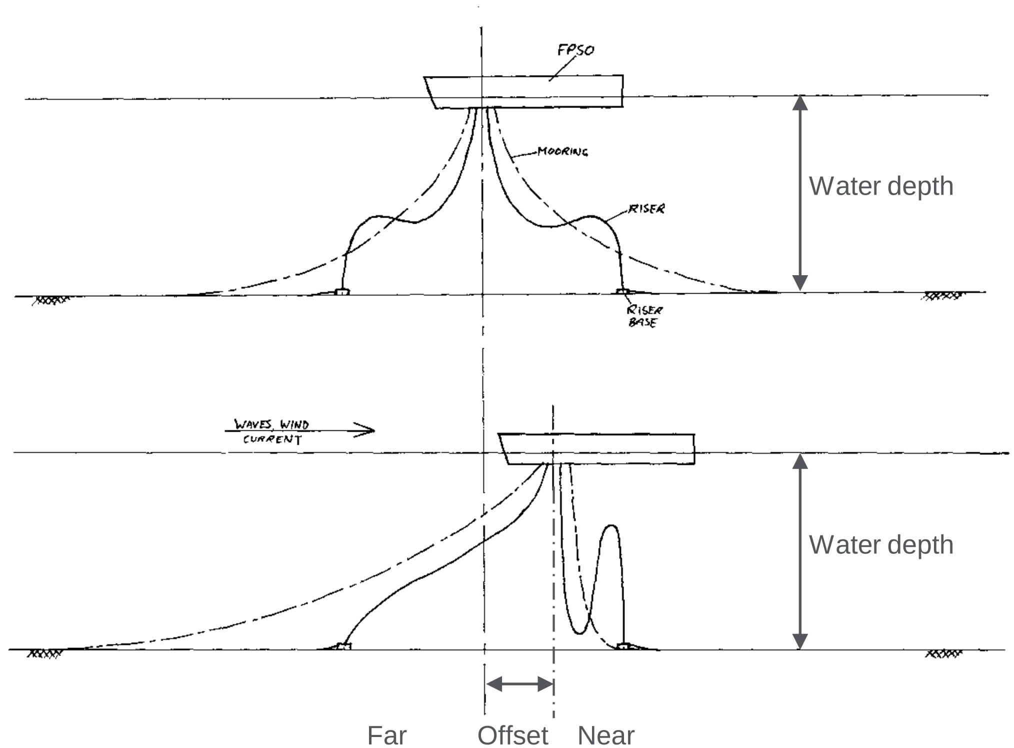
- Wd = 82m
- Offset = 12m (14.6%)

Project 4:

- Wd = 50m
- Offset = 14m (27.7%)

Project 5:

- Wd = 42m
- Offset = 15m (35.7%)



Offsets

Offset impact is much more challenging for shallow water

What are the main challenges 2/2

Large waves / High Current

- Increase the effect of the static offset
- Increased particle velocities
- Problem of stability on the seabed
- More curvature issues in Near

Marine growth

- Present on all the water depth, including buoyancy modules section

Fluid density

- High fluid density variation has important impact

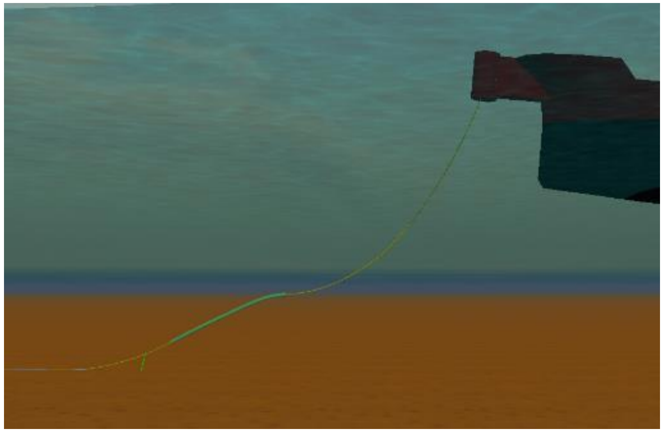


Figure 75 - Impact of waves and current

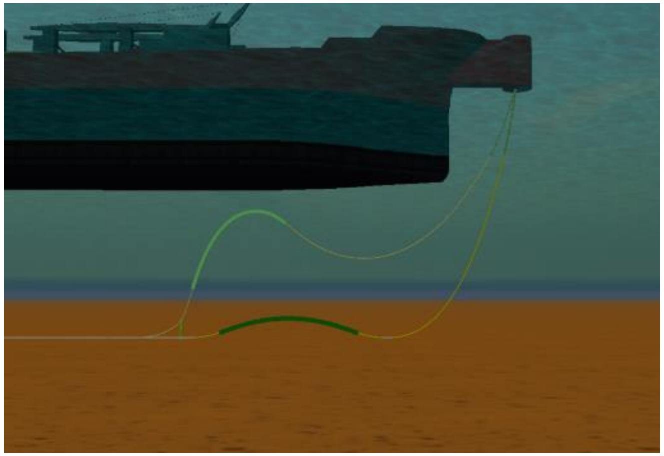


Figure 76 - Impact of fluid density/marine growth

Dynamic riser configuration selection

Configuration

Modified Pliant Wave® "Double hump" configuration

- Greater pliancy due to double sag and hog bends
- Allowing contact with seabed by adding protection

Ruby Project, Vietnam

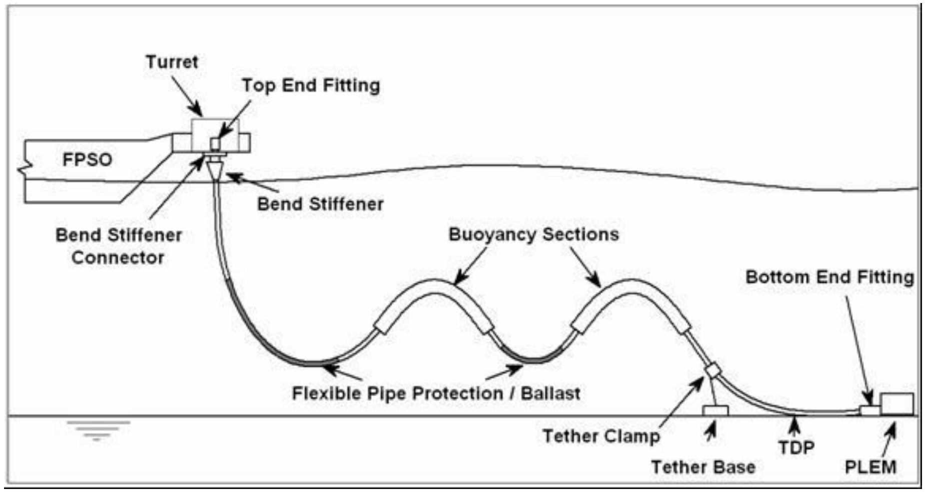
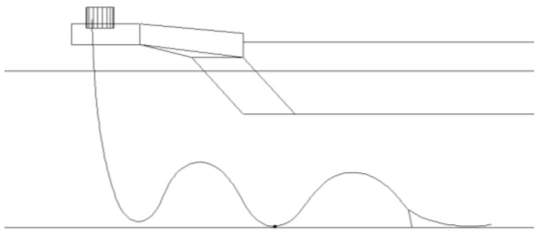
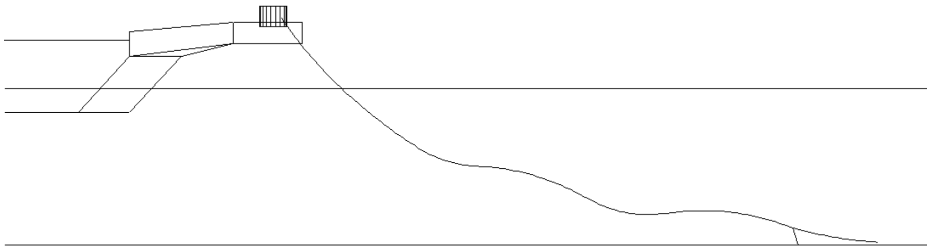


Figure 77 - Modified Pliant Wave® "Double hump" configuration



Near



Far

Figure 78 – Near and Far

Shallow water and mid water arches

Mid water arch issues:

- Require large radius and large deflectors to prevent pipe over-bending
- Heavy and large structure
- High response to the displayed wave loading
- Slack issue in the mooring chains

Figure 79 – Mid Water Arch

Not compatible with shallow water and severe waves

TechnipFMC

Lazy wave or Lazy S configurations

When large transverse displacement

- Unstable configuration
- Risk of pipe over-bending (in arch location or at seabed)
- Risk of clashing in buoyancy module sections for lazy wave configuration

Need to restrain the riser at the touch down point

- Use of Pliant-wave® configuration with clamp, tether and clump weight
- Steep Wave
  - Angular variation and tension too high at bottom

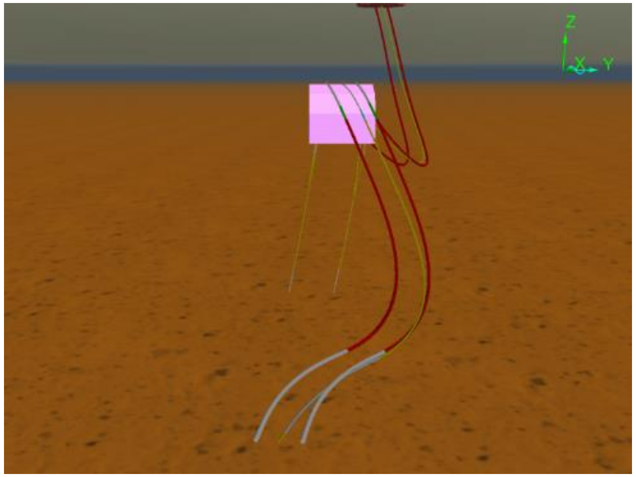


Figure 80 – Configuration subjected to large transverse displacement

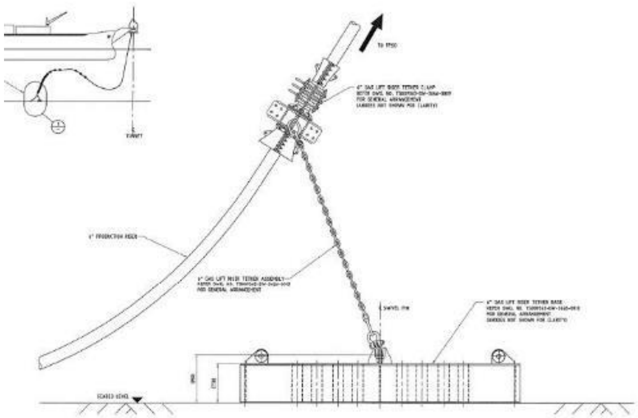


Figure 81 – Flexible Riser restrained at seabed

TechnipFMC

Clashing

- **Clashing with seabed, with mooring lines or with other risers**
  - Impact energy must be quantified
  - This can be compared with previous impact test on similar structures
- **If necessary new specific impact tests can be performed with criteria on:**
  - Acceptable residual ovalization
  - External sheath damage
- **If necessary the flexible pipe structure can be reinforced with:**
  - Kevlar tapes and external protective sheath
  - Half shelf polymer protection

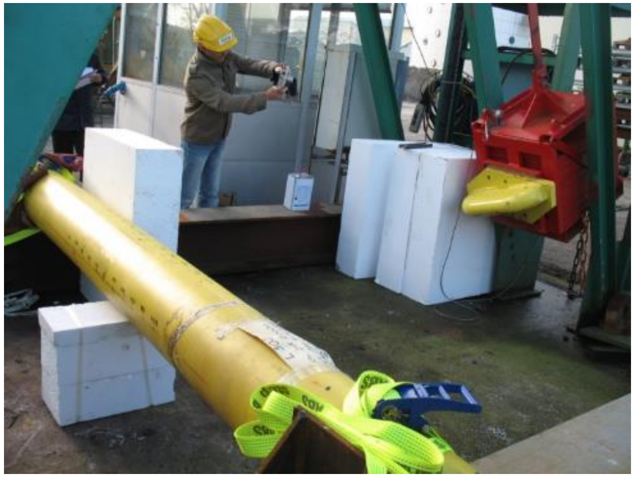


Figure 82 – Impact Test

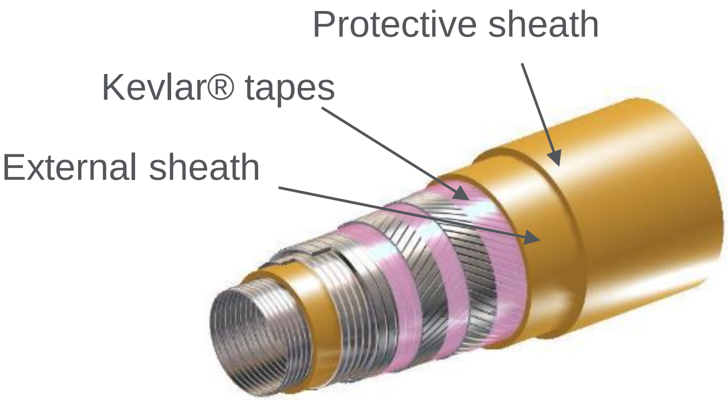


Figure 83 – Structure (Kevlar + Protective Sheath)

Flexible pipe can be designed to better resist impact

In Summary… in shallow water

- **Riser configuration selection is complex:**
  - MWA is not an option in shallow water
  - Pipe must be restrained in the seabed area
  - May require multiple humps/waves
- **A workable solution has been optimised for the Ruby project:**
  - Pliant-Wave® with optimised buoyancy modules design and location
  - Use of pipe protection
- **Could we go even shallower?**
  - FEED study is compulsory
  - New configuration can be proposed with:
    - Turret as close to centre of motion as possible
    - Marine growth inspection and cleaning plan
    - Flexible pipe designed with better resistance to clashing

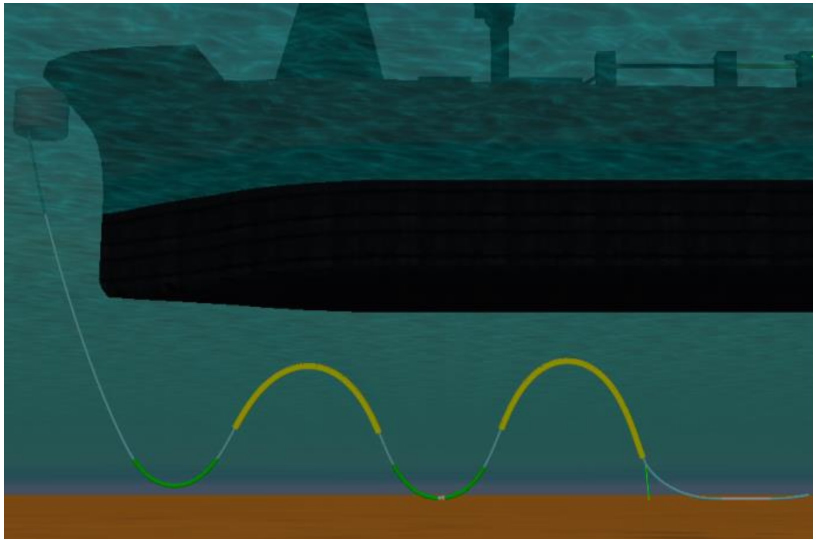


Figure 84 – Configuration in Shallow Water

Challenging but feasible

Dynamic Riser System

DEEPER WATER PROJECTS

(100m < Water depth < 1000m)

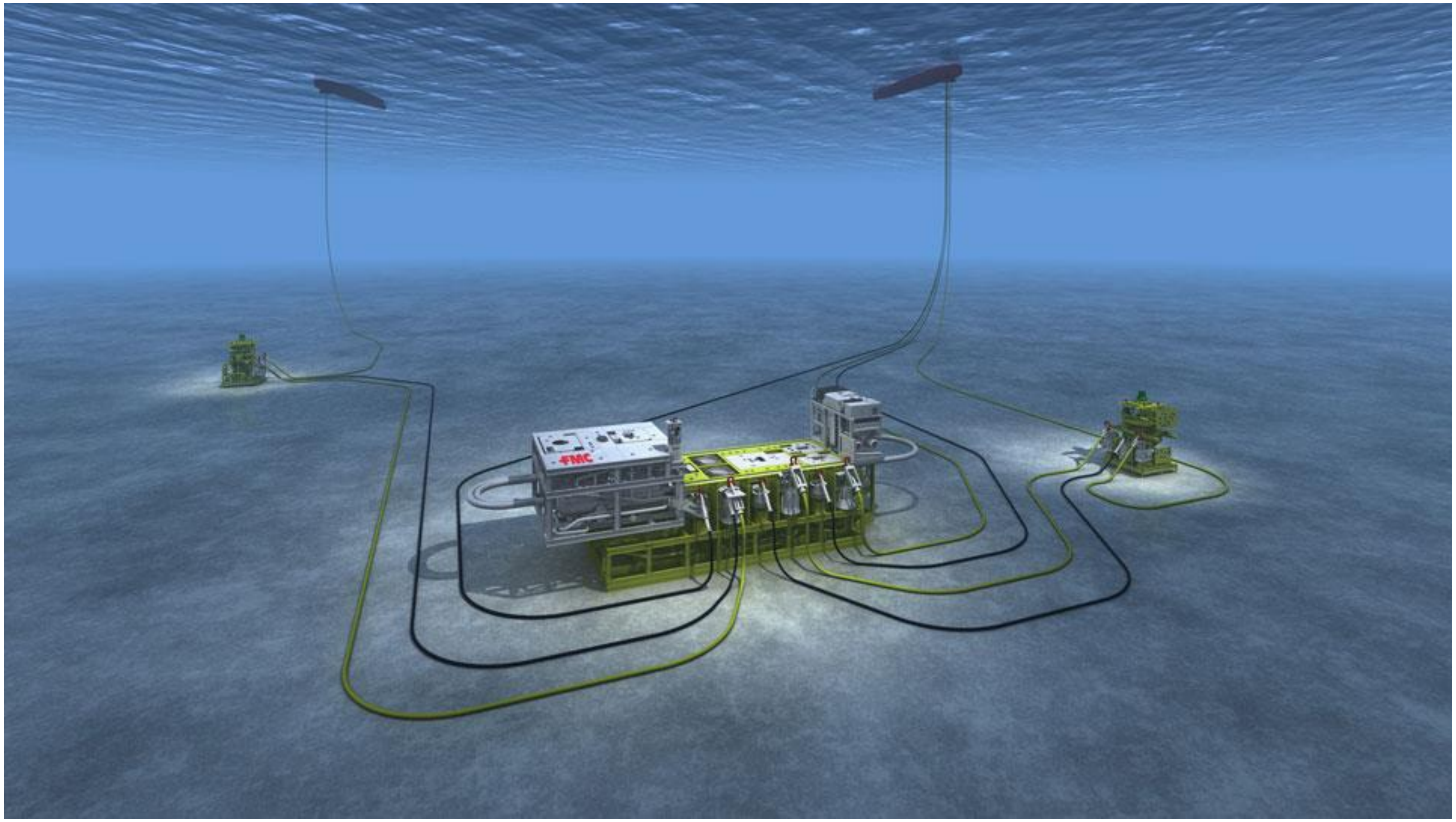


Figure 85 – Deep Water Field

TechnipFMC

Dynamic Riser System

- **Riser configuration selection is easier:**
  - Midwater arch is definitely an option
  - Pipe may not be restrained in the seabed area (Lazy)
  - No need for multiple waves
  - Can be driven by cost and layout
  - Higher tension at the top, can be reduced by more buoyancy modules (bigger and higher wave)

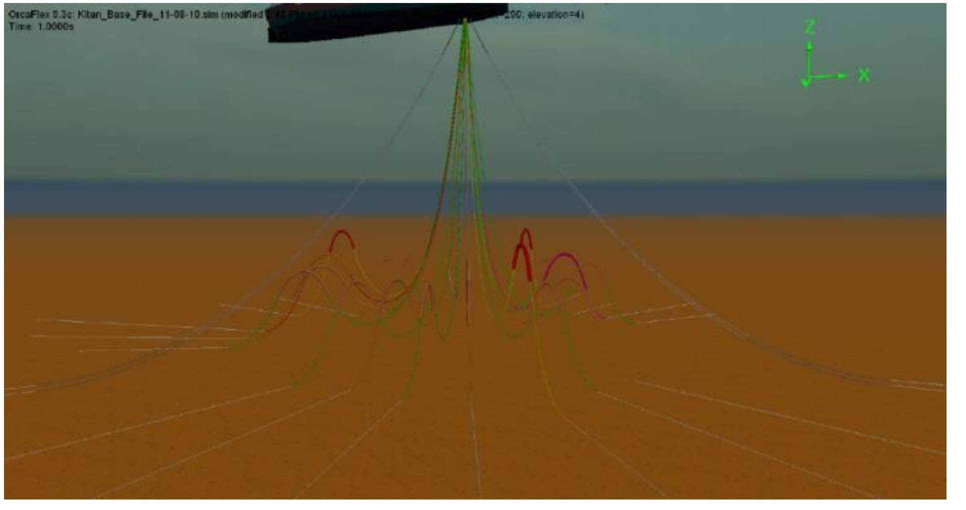


Figure 86 – Risers in Lazy Wave Configuration

Dynamic Riser System

DEEP OR ULTRA DEEP WATER PROJECTS

(Water depth > 1000m)

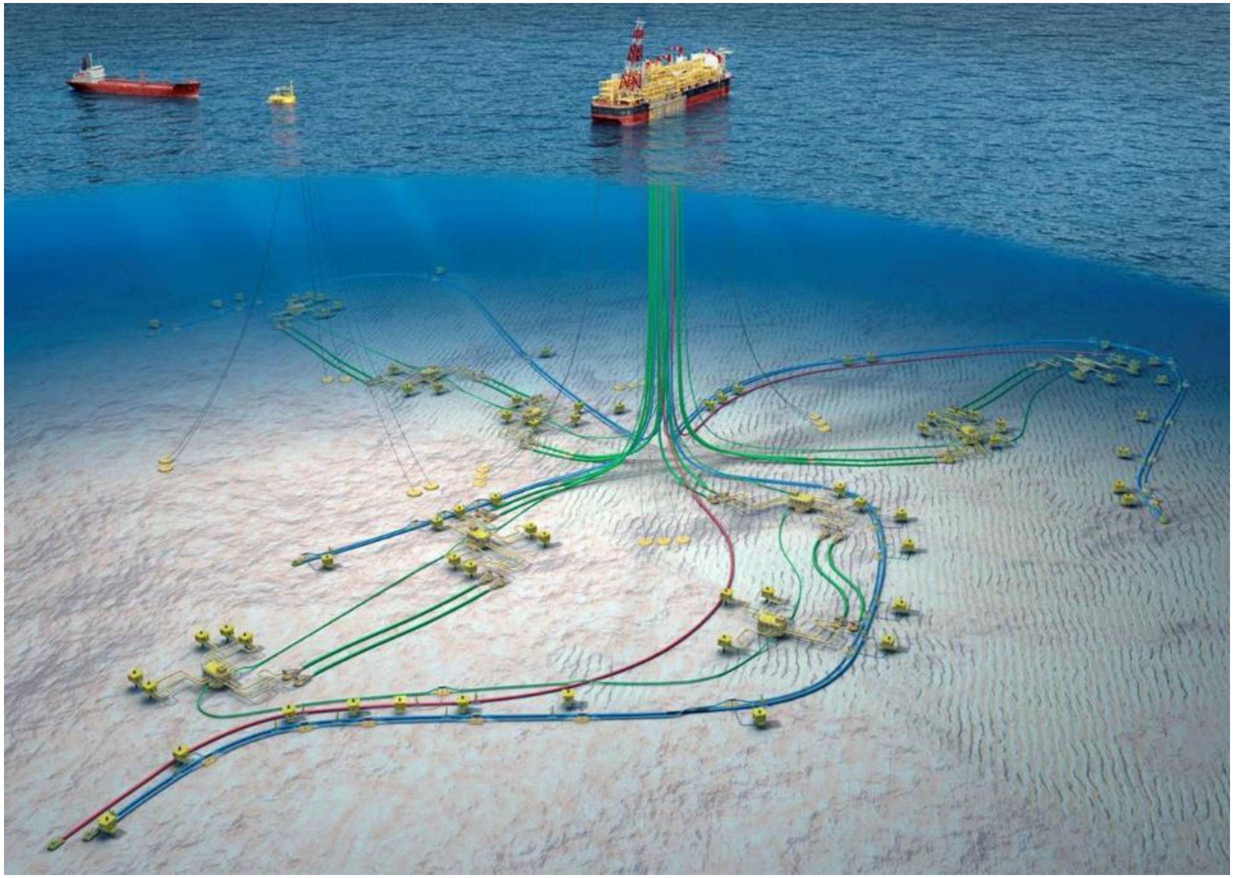
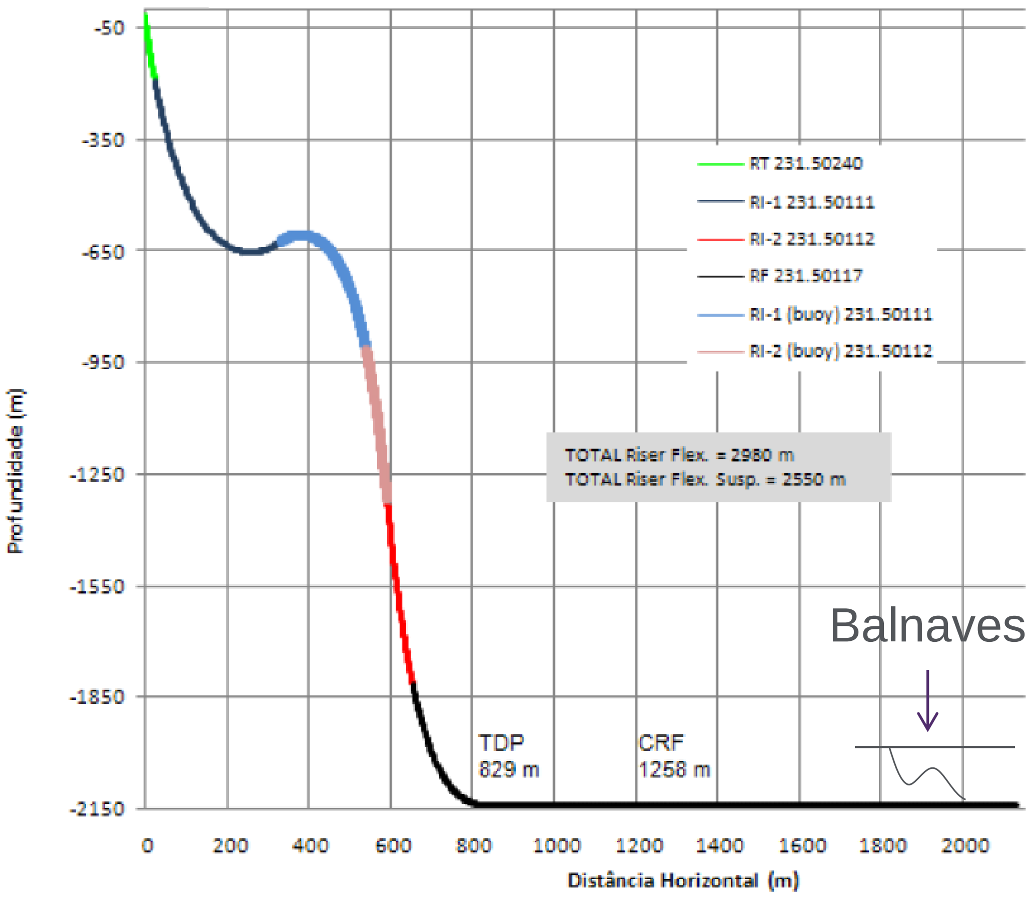


Figure 87 – Ultra-Deep Water Field

Riser In Deep Water

Field: Sapinhoa
FPSO: Cidade de Sao Paulo

Water Depth: 2150 m



- Top tension and external pressure drive the design
- Multiple section risers

TechnipFMC

Dynamic Riser System – Example Kikeh

- **1400m water depth in Malaysia**
- **Free hanging configuration**
  - Total length: 1775m
    - Top : 875m
    - Bottom : 900m
  - Cost effective for DW fields
  - Intermediate connection at 850m below sea level
  - Hold back system for the bottom connection with the flowlines
  - No major fatigue issues

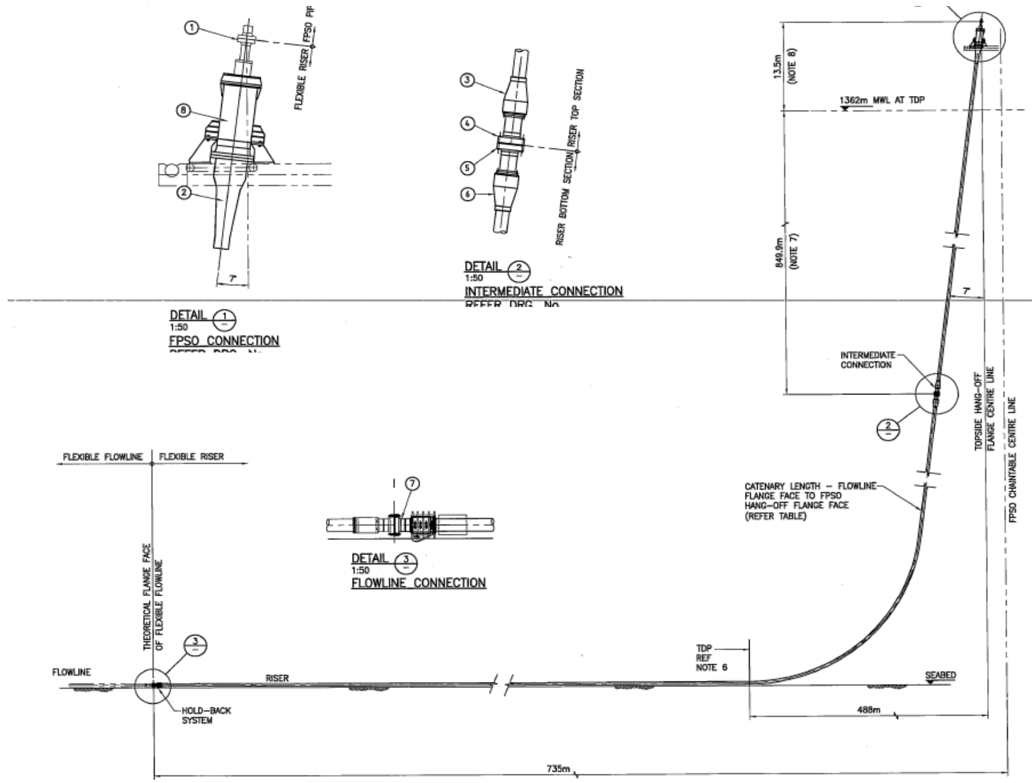
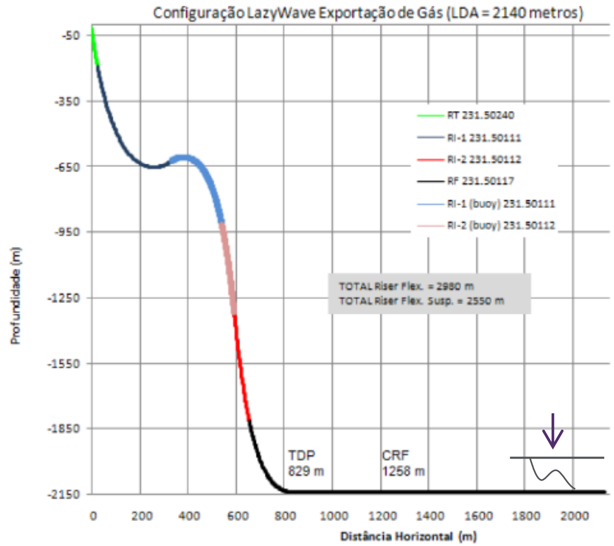


Figure 88 – Free Hanging Configuration

TechnipFMC

Summary – Deep vs Shallow Water

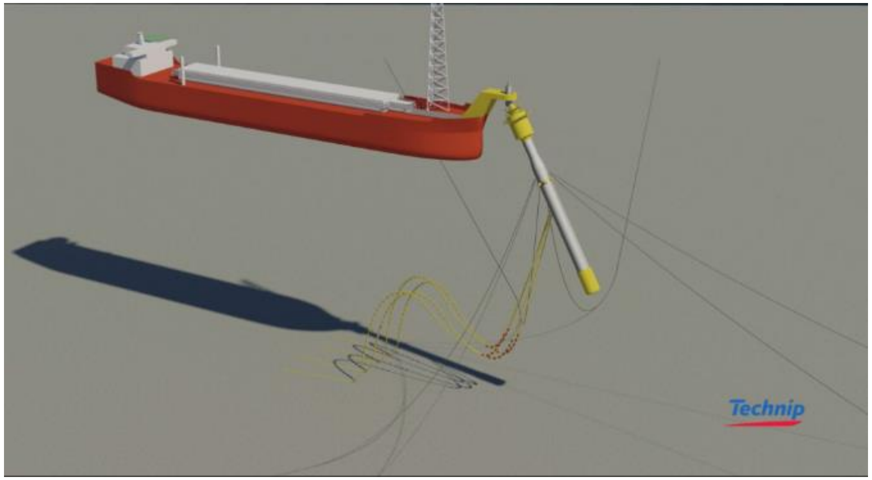
Deep Water



Drivers:

- Weight
- External Pressure

Shallow Water



Drivers:

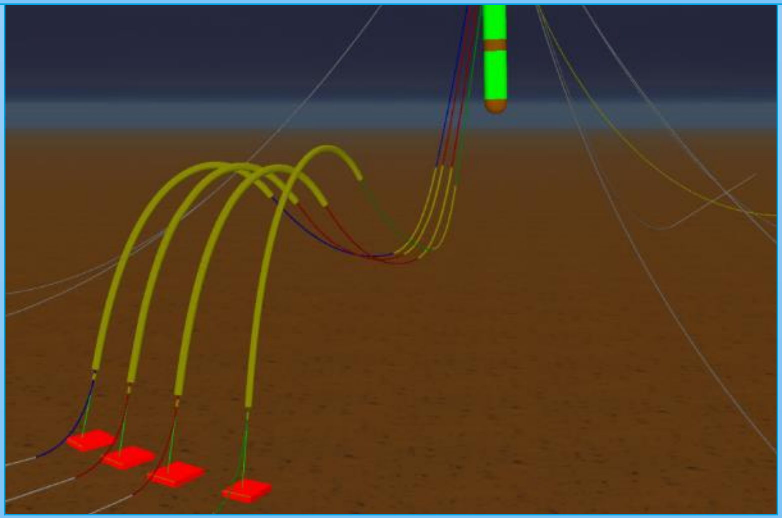
- Dynamics
- Stability

Dynamic Riser Analysis - Inputs

1. Modelling inputs
- Pipe length
- Pipe properties (weight, OD, bending stiffness)
- Equipment (buoyancy, MWA, tethers)
- Vessel characteristics

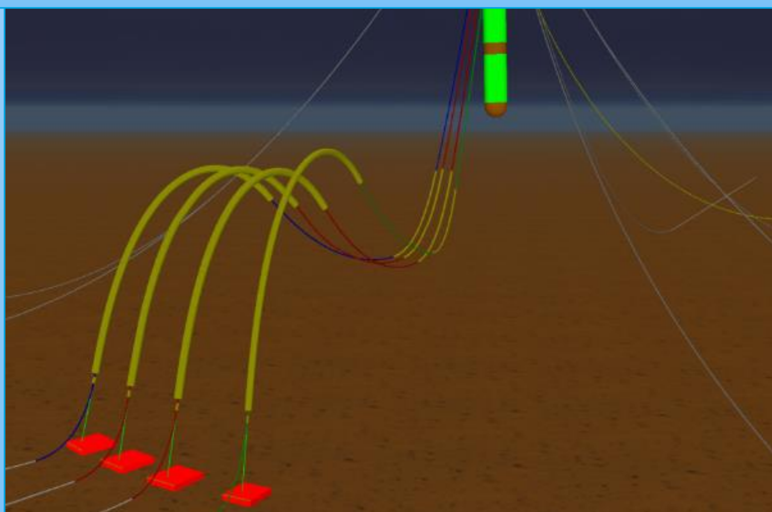
2. Variables (Load Case Matrix)
- Environment (wave, current, direction)
- Vessel offsets and draft
- Pipe internal density (full/empty)
- Marine growth

Finite Element Analysis (Orcaflex, Deeplines, Flexcom)



Dynamic Riser Analysis - Outputs

Finite Element Analysis
(Orcaflex, Deeplines, Flexcom)



Extreme Loads Analysis
- Maximum loads
- Minimum bend radius
- Clashing (with other risers, vessel, mooring lines, etc)

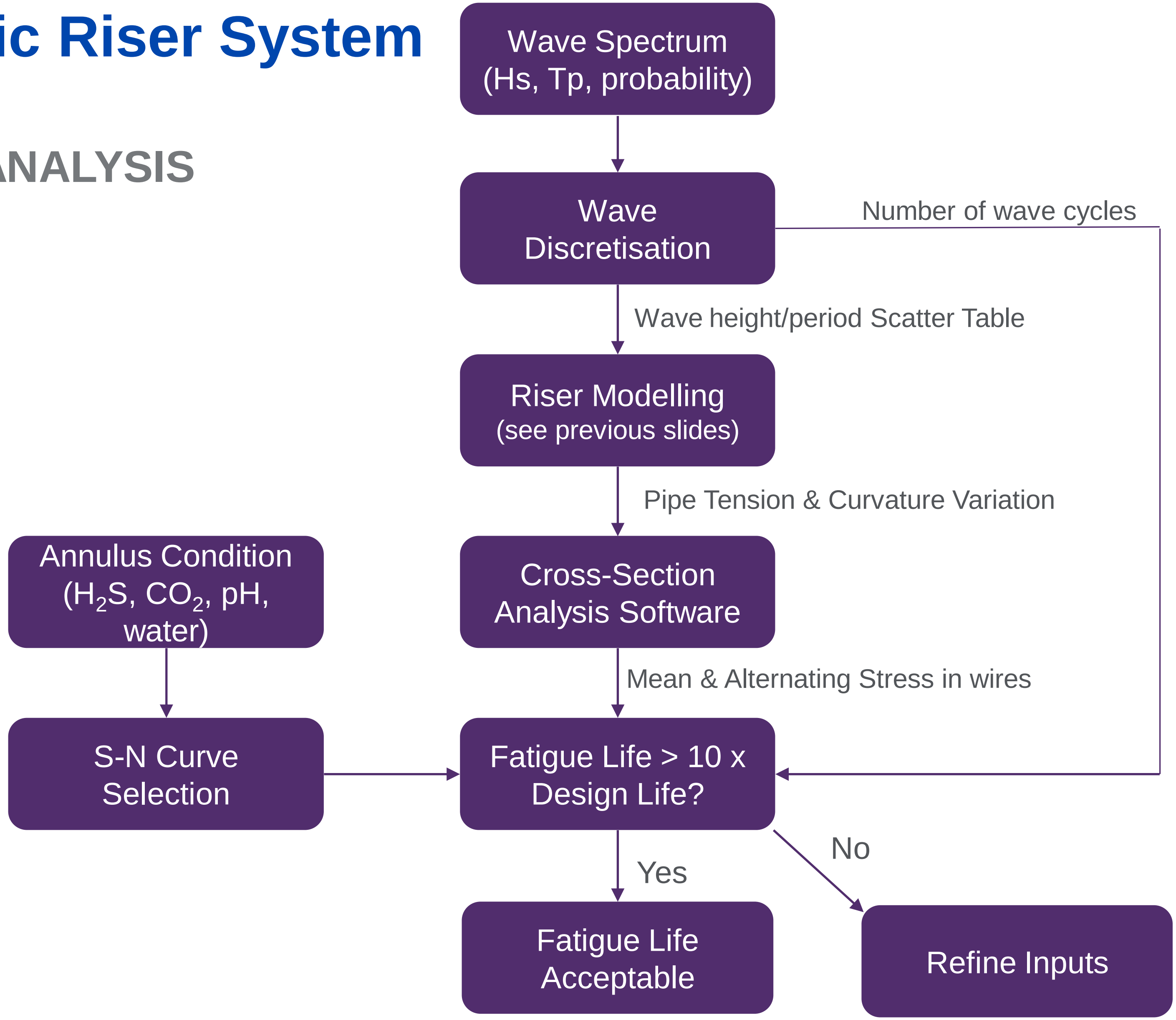
Equipment Design Loads
- Tethers
- Clump weight
- Clamp
- Stiffener

Fatigue Analysis
- Service life

Iterative design process

Dynamic Riser System

FATIGUE ANALYSIS



TechnipFMC

Figure 90 – Fatigue Analysis Process

Dynamic Riser System

Wave/Period Scatter Table example

H (m) \ T (secs)	1	2	3	4	5	6	7	8	9	10	11	12	13
0.2	2,323,429	2,087,419	1,612,213	1,219,587	892,176	633,272	443,842	312,168	222,583	161,690	119,851	90,626	69,825
0.4	383,400	1,401,666	1,485,431	1,467,229	1,438,713	1,281,826	1,038,450	788,358	578,074	418,814	304,219	223,406	166,545
0.6	109,961	984,335	1,288,436	1,237,008	1,381,323	1,459,473	1,341,711	1,096,447	828,972	600,870	428,688	306,245	221,237
0.8	27,992	580,298	1,030,846	960,928	1,093,807	1,309,840	1,340,461	1,169,537	911,193	663,548	468,000	327,587	230,978
1.0	6,155	308,536	751,767	737,493	803,629	1,047,631	1,180,341	1,096,284	881,291	647,390	453,848	313,042	216,552
1.2	1,213	154,570	507,101	559,571	575,583	784,832	964,895	953,897	793,255	590,055	412,890	281,765	191,908
1.4	223	74,340	322,357	415,386	410,930	565,011	750,579	790,216	681,781	515,365	361,254	244,693	164,523
1.6	38	34,616	196,014	299,876	294,658	397,076	563,353	631,748	567,113	437,097	307,896	207,563	138,069
1.8	6	15,667	115,210	210,291	212,121	275,320	411,598	491,371	460,108	362,686	257,470	173,160	114,169
2.0	1	6,906	65,938	143,459	152,743	189,745	294,585	373,839	365,901	295,791	212,162	142,659	93,382
2.2		2,970	36,942	95,445	109,554	130,634	207,535	279,297	286,200	237,836	172,763	116,365	75,732
2.4		1,249	20,338	62,093	77,999	90,120	144,482	205,527	220,736	188,953	139,282	94,135	60,989
2.6		516	11,033	39,599	54,997	62,390	99,722	149,335	168,204	148,565	111,325	75,609	48,822
2.8		210	5,911	24,810	38,351	43,353	68,426	107,361	126,840	115,749	88,302	60,346	38,873
3.0		85	3,131	15,301	26,433	30,218	46,787	76,509	94,783	89,457	69,564	47,889	30,801
3.2		34	1,643	9,303	18,005	21,104	31,940	54,131	70,271	68,641	54,463	37,803	24,295
3.4		14	854	5,585	12,123	14,748	21,805	38,078	51,744	52,331	42,400	29,697	19,081
3.6		6	441	3,314	8,071	10,299	14,904	26,666	37,878	39,669	32,839	23,223	14,927
3.8		2	226	1,946	5,317	7,178	10,209	18,612	27,590	29,918	25,314	18,083	11,632
4.0		1	115	1,132	3,467	4,989	7,012	12,961	20,012	22,462	19,428	14,025	9,032
4.2		0	58	653	2,240	3,455	4,830	9,013	14,464	16,796	14,853	10,838	6,989
4.4		0	29	373	1,434	2,383	3,338	6,265	10,425	12,516	11,313	8,346	5,391
4.6			14	212	910	1,636	2,313	4,355	7,497	9,297	8,589	6,406	4,145
4.8			7	119	574	1,119	1,607	3,030	5,382	6,888	6,502	4,902	3,178
5.0			4	67	359	762	1,120	2,110	3,858	5,091	4,908	3,740	2,430
5.2			2	37	223	516	782	1,472	2,764	3,756	3,696	2,847	1,853
5.4			1	21	138	349	547	1,029	1,979	2,766	2,777	2,162	1,410
5.6			0	11	85	235	383	721	1,416	2,034	2,082	1,637	1,070
5.8			0	6	52	158	269	506	1,014	1,494	1,558	1,238	811
6.0				3	32	106	189	356	726	1,096	1,165	934	613
6.2				2	19	71	133	251	520	804	869	704	462
6.4				1	12	47	94	178	372	589	648	529	348
6.6				1	7	32	66	126	267	431	482	397	262
6.8				0	4	21	47	90	191	316	359	298	197
7.0				0	3	14	33	64	137	231	266	223	147

Figure 90 – Fatigue Analysis Process

Dynamic Riser System

- **Fatigue in Air, example:**
  - Wave class 1: Smax = 150 MPa / n = 1 e+05 => N = 2 e+09, dmg = 0.000

Total fatigue damage = ∑individual wave class damage

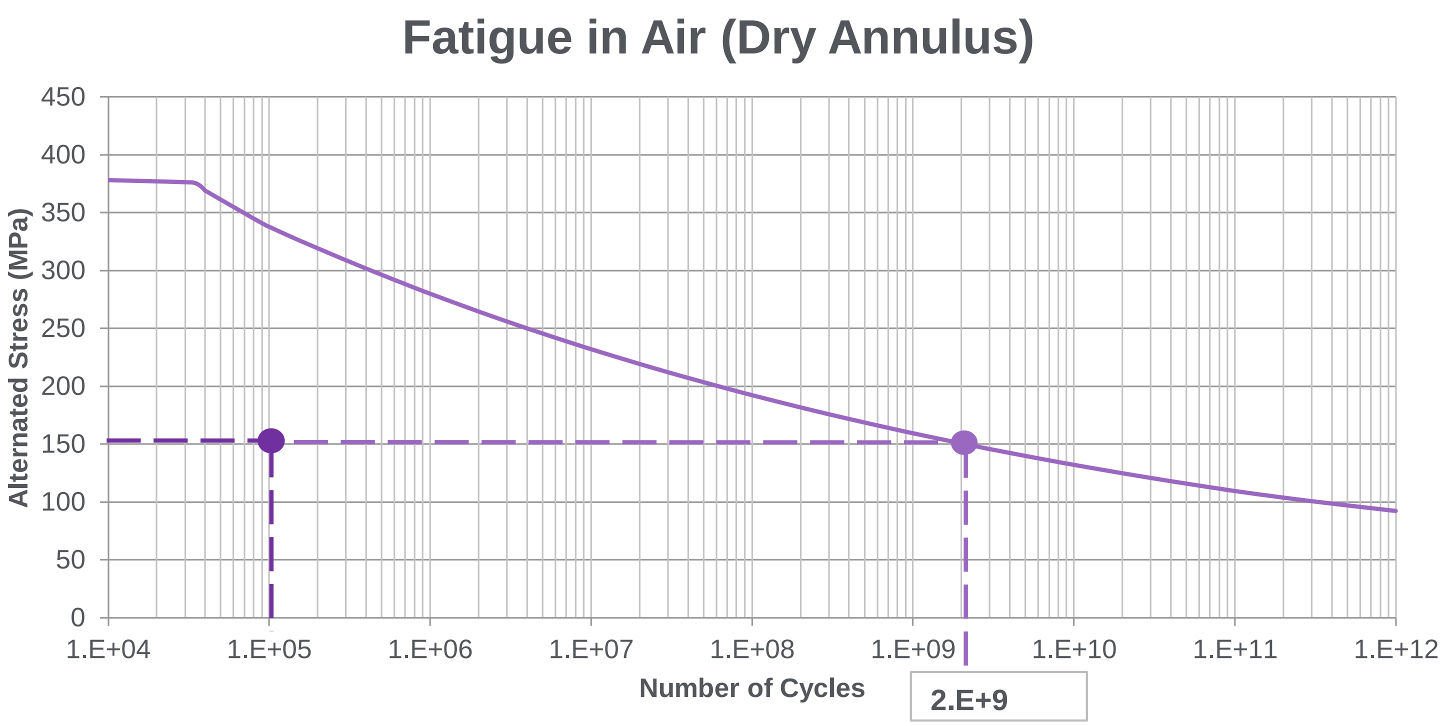


Figure 91 – SN Curve Example (Air)

Dynamic Riser System

- **Corrosion Fatigue, example:**
  - Wave class 1: S_{alt} = 150 MPa / n = 1 e+05
  - Blue curve : 10mbar H2S / 0.99 bar CO2 => N = 4 e+05, dmg = 0.25
  - Red curve : CO2 only => N = 2.5 e+06, dmg = 0.04
  - High influence of the fatigue curve selection

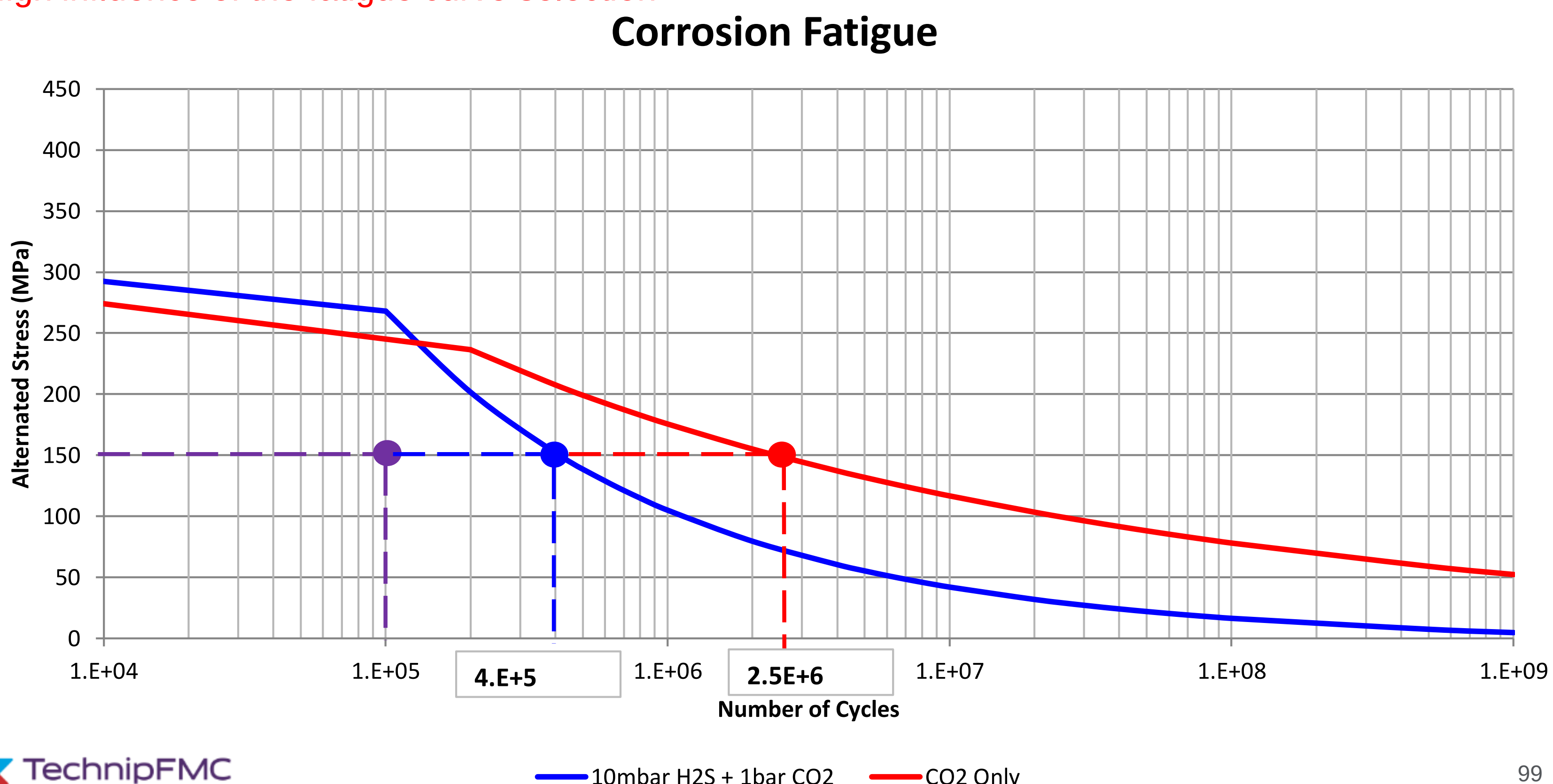


Figure 92 – Corrosion Fatigue SN Curve Example

Dynamic Riser System

- **Corrosion Fatigue Assessment**
  - Occurs when annulus is flooded (outer sheath damaged or due to water diffusion / condensation)
  - Water + H_2S + CO_2: corrosive environment
  - Much more severe compared to fatigue in a dry environment
- **Corrosion Fatigue Calculations**
  - SN curve of wire steel grade in appropriate environment must be used
  - Calculation of time to failure performed for pressure armour and tensile armour

Dynamic Riser System

- **Fatigue Service Life Driving Parameters**
  - Operating pressure.
  - Steel wire SN curves.
  - Riser dynamic response: curvature variations vs No of cycles.
  - Most severe location generally at connection with floating unit (FPSO).
- **Fatigue calculations performed for:**
  - Pressure armour.
  - Tensile armour.

- **Damage = 1 ⇔ Wire crack.**
  API 17J criteria: cumulated damage over design life < 0.1
- **Riser structure must be designed accordingly**
  - For high pressure riser this can drive the design:
    - Thicker pressure vault.
    - 4 tensile armour layers, (opposed to 2).
    - Larger bending stiffener.

Figure 93 – Fatigue Test Bench

Ancillary Equipment

Ancillary Equipment

Ancillary: “provides necessary support to the primary activities of a system.”

Purpose:

- Configure the flexible
- Stabilise the flexible
- Protect the flexible

Design/installed as required to support the flexible pipeline system:

- End Fittings (covered previously)
- Bending Stiffener
- Bending Stiffener Connector
- Buoyancy Module
- Anodes
- Tether Clamp
- End fitting Insulation Cover
- Flexible Pipe Polymer Protection
- Ballast
- Hang off clamp / Handling collar
- Vortex Induced Vibration Strakes
- Pulling head
- Reels & Cradles (including overdrums, partitions and gates)

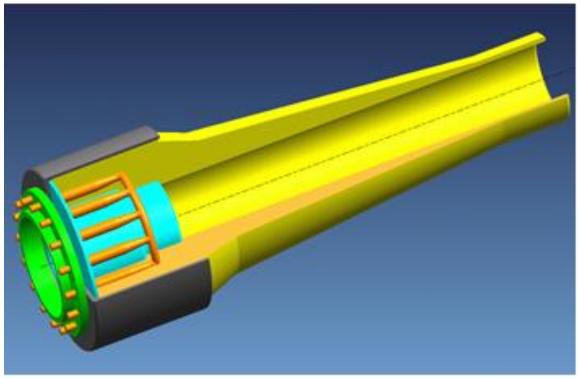
API Spec 17L1 - Specification for Flexible Pipe Ancillary Equipment
API RP 17L2 – Recommended Practice for Flexible Pipe Ancillary Equipment

Ancillary Equipment: Bending Stiffener

Figure 95 – Topside Bending Stiffeners (in air)

Main functions:

- Limit the curvature variations of the flexible risers close to their top connections.
- Withstand external loads and transfer them to the connector.
- Polyurethane cone with metal toroid.

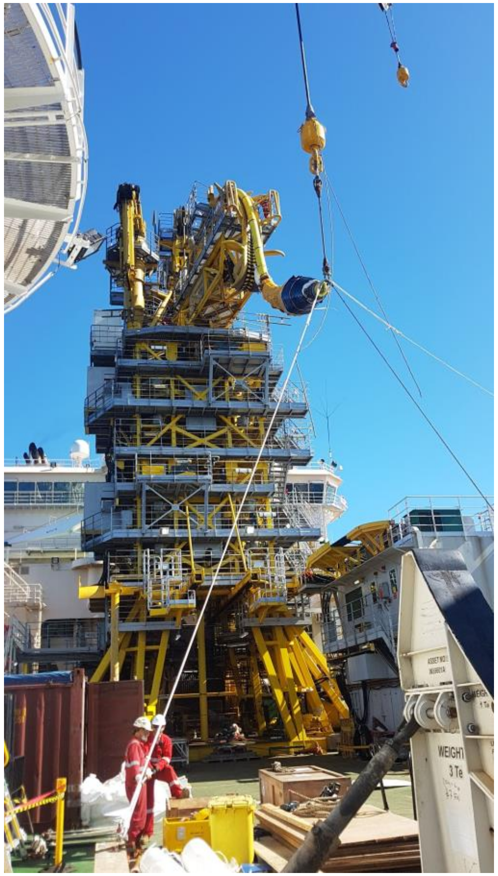


TechnipFMC

Ancillary Equipment: Bending Stiffener

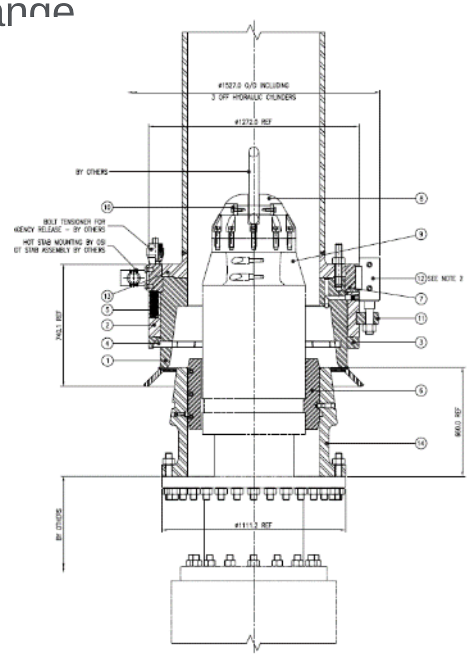
Design Considerations:

- Top interface with vessel/structure.
- Maximum tension and angle from dynamic analysis.
- Temperature resistance.
- Fatigue.
- Connection system (diver or diverless)
- Additional Protection (subsea/handling).
- Dual component stiffeners (for large stiffeners)



Ancillary Equipment: Bending Stiffener Connector

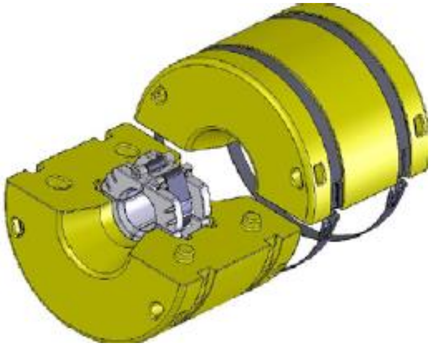
- **Bending Stiffener Connectors**
  - Interface between vessel / riser.
  - Structural link between bend stiffener and vessel.
  - Several types (diver/diverless) and various vendors, most basic is a flange



Bending Stiffener Connectors

TechnipFMC

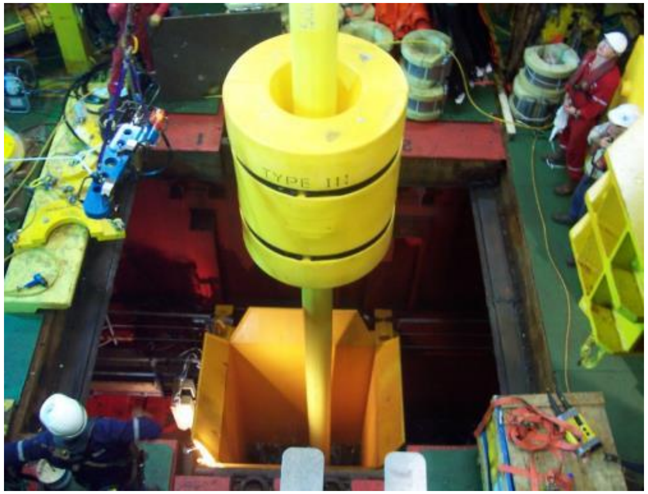
Ancillary Equipment – Buoyancy Modules



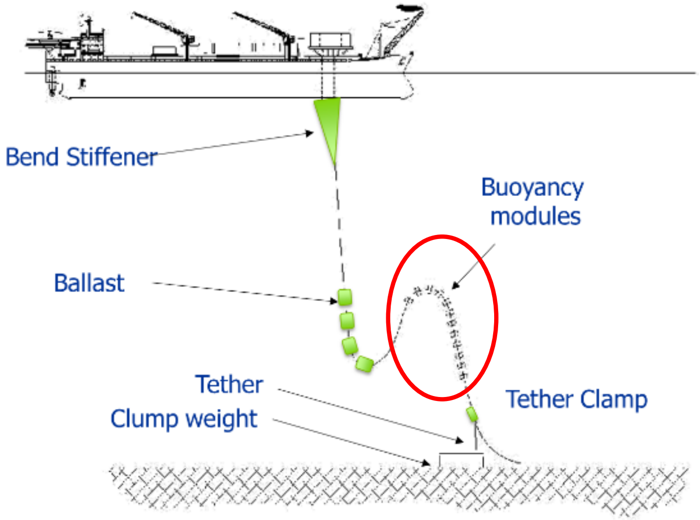
BM exploded view

BM w/ shell removed (macrospheres visible)

BM clamp



BM installed on flexible

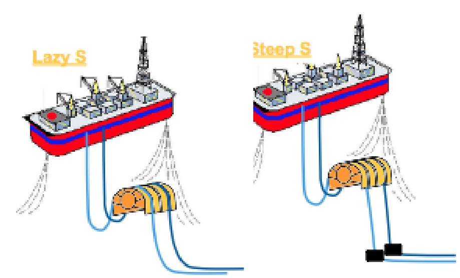


Typical construction:

- Internal syntactic clamp with aramid strap.
- 2 half shells (syntactic foam with macrospheres) with fastener straps.

Ancillary Equipment – Mid Water Arch (MWA)

- Guide (pipes laid on top)/ Buoyancy steel tanks (water depth level).
- Advantages: Several pipes (no contact).
- Useful in congested fields (space issue).



TechnipFMC

Ancillary Equipment – Clamps

4 part clamp tether Clamp with swivel and dual tether arrangement

- Bolted around outside of flexible pipe .
- Pressure causes friction which prevents slipping.
- Uses:
  - Prevent bending stiffener from sliding down pipe when disconnected (holding collar).
  - Connect tether from flexible to seabed structure (tether clamps).
  - Backup option for holding flexible during work on vessel.
  - As a stopper in a mid water arch

TechnipFMC

Ancillary Equipment – Insulation Cover

- **Function:**
  - Provide localized thermal insulation at end fitting and connections:
- **Design:**
  - Cool down time
  - Hydrate formation
  - Installation
  - Annulus venting & Cathodic protection

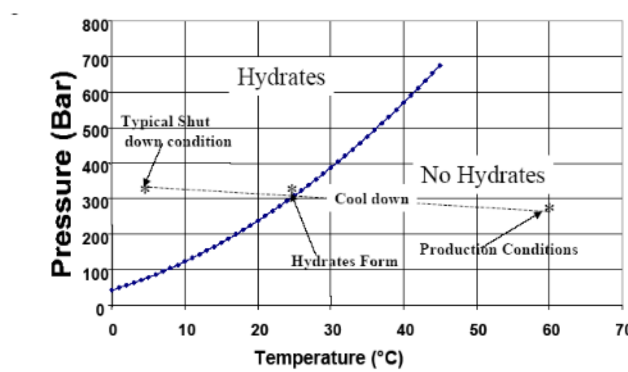


Figure 1. Phase Diagram showing the conditions under which hydrates will form[1].

Figure 100 – Hydrates Formation

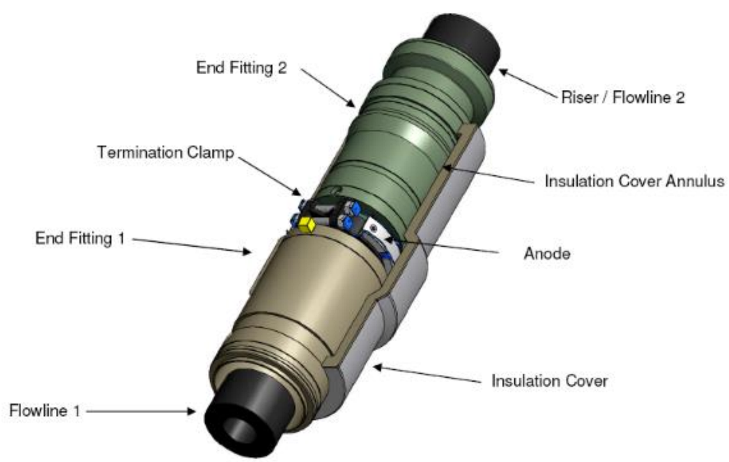
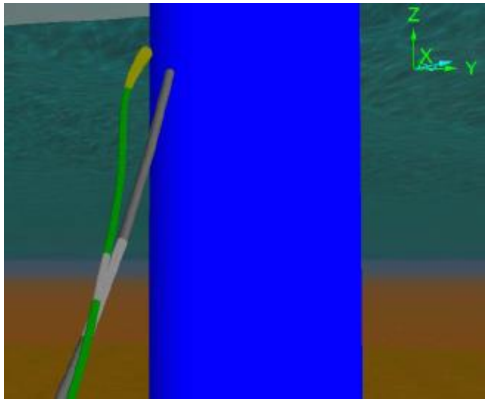


Figure 101 – Insulation Cover

Ancillary Equipment – Pipe Protection

- **Flexible Pipe Protection**
  - To eliminate damage from clashing:
    - Structures.
    - Other pipe.
    - Mooring lines.
  - Can also add weight (Ballast – see next):
    - Change configuration profile to avoid clashing.
    - Reduce on bottom length (tension).
  - Additional protection or stability for subsea crossing
  - Typical construction is PU or plastic held in place with stainless steel band-it straps or Kevlar straps.

Pipe protection



Pipe clashing during analysis (grey section)

Figure 102 – FPPP

TechnipFMC

Ancillary Equipment – Pipe Ballast

- **Flexible Pipe Polymer Protection**
  - Change configuration or riser response to avoid clashing.
  - Reduce fatigue (angles and response)
  - Reduce on bottom length (tension).
  - Additional seabed stability.

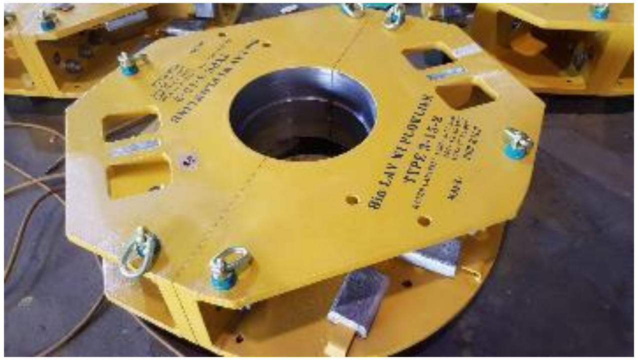
PU ballast with lead/steel inserts

2 part Steel ballast with anodes

Figure 102 – FPPP

Ancillary Equipment – Hang off / handling collars

- **Hang off collars**
  - Typically for installation to hang off the installation table (in the moonpool) of the vessel.



2 part hang-off (installation) collars
(before and after installation)

2 part collar for subsea handling

Figure 102 – FPPP

Ancillary Equipment: Pulling, Handing & Test Heads

- Used for sealing ends of flexible and handling during installation (i.e. taking off reel & over tower).
- Can be pressure rated (for doing pressure testing on the pipe)
- Tension load tested ("pulling heads" – typically for high tension – full pipe length to seabed + catenary).
- Can have filling ports for flooding and back seal test port for checking seal (as required).

Installation of SPO (flange type) pulling head

Grayloc handling head

Ancillary Equipment: Anodes

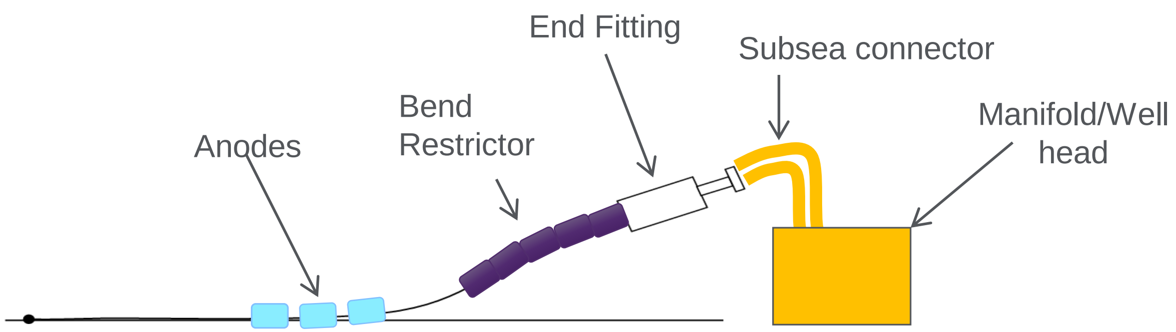
- Cathodic protection for the end fittings (for coating damage) and flexible pipeline metallic layers (for external sheath breach).
- Anodes mounted on flexible pipe behind end fitting and bending restrictors.
- Basic friction clamp (only anode weight).
- Connected to the end fittings (cables)
- Half shell bracelet type (Al-Zn-In composition)
- Material cast over clamp – Half shells bolted together

Anodes installed behind bend restrictors (note white CP cables)

Anode trial fit on mandrel

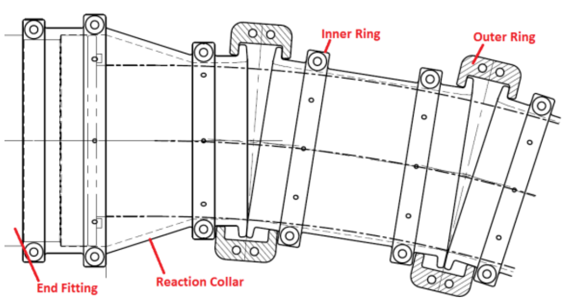
Ancillary Equipment: Bending Restrictors

- To prevent overbending (during installation or once installed).
- Static – not designed for dynamic environment (unlike a bending stiffener).
- Typically on flexible end fittings at seabed equipment connections.
- Steel or polymer.



Polymer bend restrictors

Steel is typically used for hotter lines to reduce insulation effect and due to material properties



Cross section: steel bend restrictors

Ancillary Equipment: Reels

- Used for packing, transporting and installing flexible pipe.
- Different vendors have different sizes (TechnipFMC typ 8.4, 9.6, 11.2, 12 m OD)

Packing of flexible:

- Minimum bending radius determines minimum ID of reel (overdrum may be required to pad out the reel).
- Partition can be used to divide sections – multiple jumpers on one reel or to pack a bending stiffener separately.
- Must consider capacity of reel to hold weight and lifting equipment to lift reel (HLV or quayside crane).
- Larger OD (esp. insulated lines) results in less length able to be packed.

Reel packing with partition

New Technologies / Deep Water challenges

New Technologies and Deep Water challenges

- **Monitoring**
- **Flexible Pipe Innovation**
  - Gas Smooth Bore Flexible Pipe.
  - S-Carcass.
  - UDW challenges.
  - Integrated Production Bundle.
  - Anti H_2S Sheath.
- **Delivery Capabilities**

Dynamic Riser System –Monitoring

- **Why Monitor?**
  - Check integrity
  - Early detection of faults
  - Record historical operating data
- **Monitoring**
  - Vessel excursion envelope
  - Temperature along riser
  - Curvature sensor
  - Annulus monitoring (ISAGM)
    - Pressure sensor
    - Water detection
    - Gas Composition
  - EF monitoring
  - Bore inspection tool
  - Acoustic Emission clamp
  - Condition Performance Monitoring

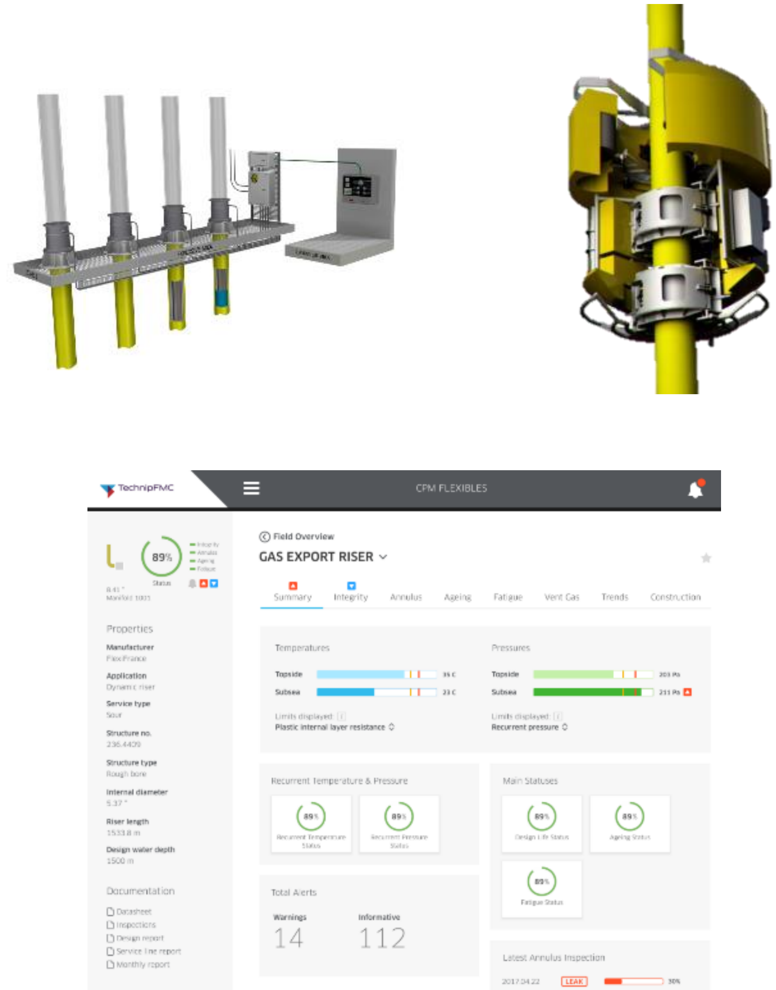


Figure 103 – Monitoring Systems

TechnipFMC Riser Annulus Test Services

Objective(s)

- Outer sheath integrity inspection (breach detection)
- Measure of pipe annulus liquid level and free volume

Principle

- Checking of vent ports
- Vacuum test
- Nitrogen test when applicable
- End-fitting visual inspection
- Interpretation by specialists

Qualification Level

- Qualified
- Field proven

Figure 104 – Riser Annulus Test

Dynamic Riser System – Monitoring

Instrumented System for Annulus Gas Monitoring (ISAGM)

Objective(s)

- Outer sheath integrity monitoring (breach detection)
- Measure pipe annulus liquid level and free volume
- Gas sampling

Principle

- Continuous monitoring of gas diffusion rates, temperature and pressure
- Re-calculation of riser annulus volume

Benefits

- Early detection of potential flexible outer sheath damage (aerial or subsea)
- Knowledge of annulus corrosive environment
- Valuable data for remaining service life assessment

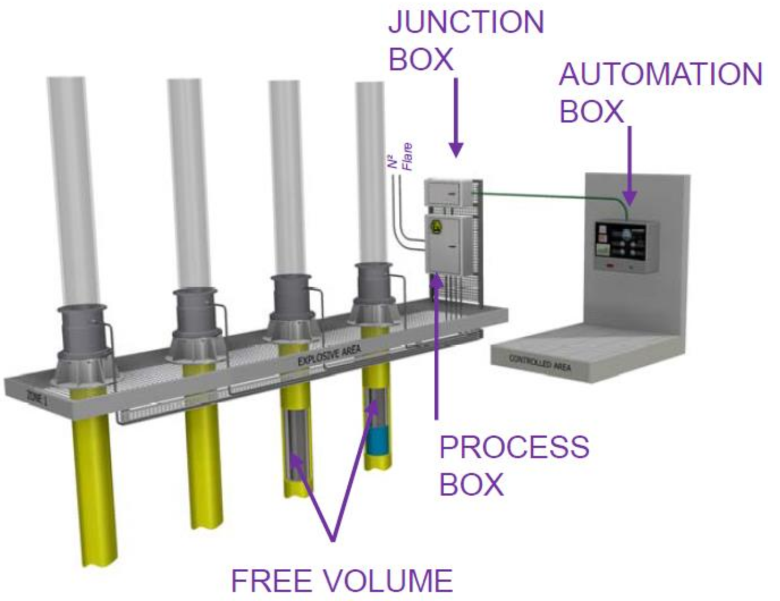


Figure 105 – Instrumented System for Annulus Gas Monitoring

Dynamic Riser System - Monitoring

Distributed Temperature Sensing (DTS)

Objective(s)

- Riser flow assurance
- Riser annulus flooding detection

Principle

- Continuous annulus temperature measurement
- Using fiber optics inserted within pipe armour layer

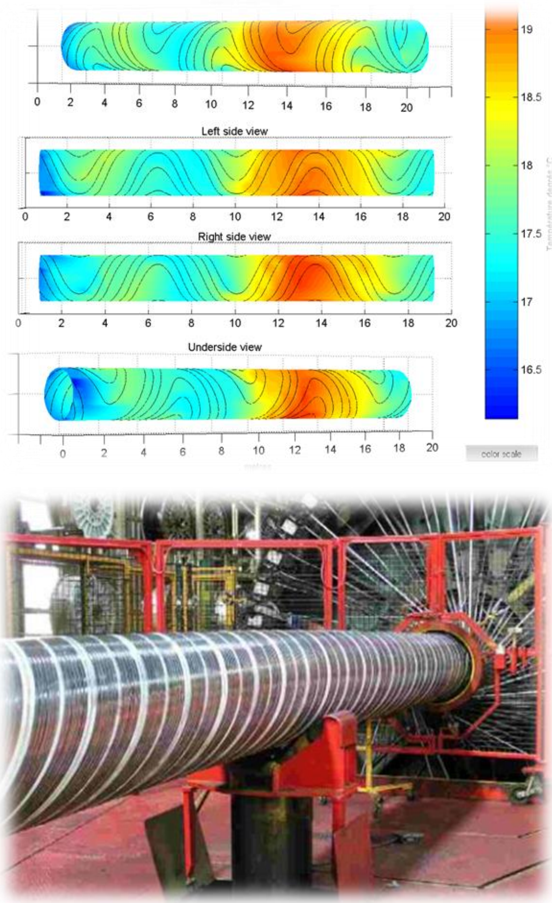
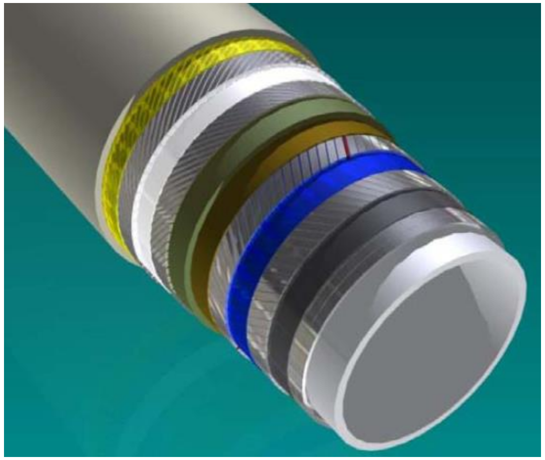


Figure 106 – DTS

Gas Smooth Bore Flexible Pipe

- **Smooth Bore Gas**
  - Smooth internal polymer tube:
    - Pressure losses are reduced
    - Flow Induced Pulsations (FLIP)
  - Independent annulus drainage w/ vent tubes



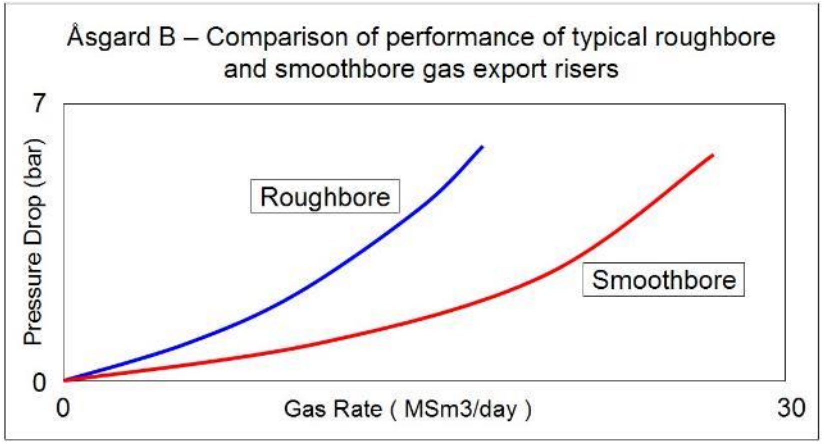


Figure 107 – Rough Bore/ Smooth Bore Comparison

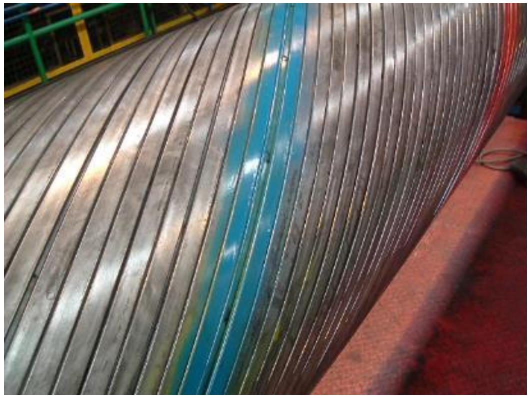


Figure 108 – Vent Tubes

OTC 18703 : Smooth bore Flexible Riser for Gas Export Tim Crome, Technip Norge, Norway; Eric Binet, Flexi France, Technip Group; and Stig Mjøen, Statoil, Stjørdal, Norway

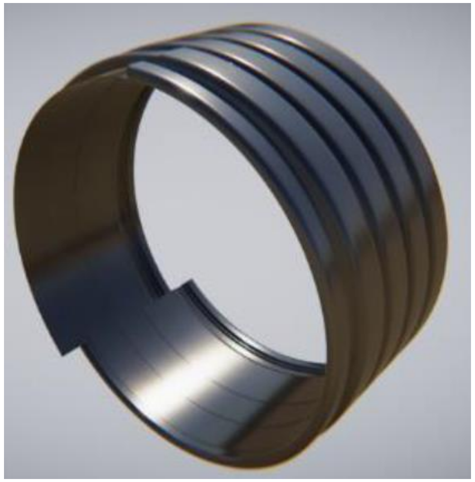
Gas Smooth Bore Flexible Pipe

- **Track Record (TechnipFMC)**
  - Aasgard Gas Export riser (Nth Sea, 1^{st} prod 2012)
  - Gjoa Gas Export Riser (Nth Sea)
  - Norne (Nth Sea, 1^{st} prod 2009)
  - Ichthys (Australia, 2016)
  - Jangkrik (Indonesia, 2017)

Figure 109 – SB pipe on reel and carousel

S-Carcass

- **Alternative to the Gas Smooth Bore Flexible Pipe**
- Insert added to standard rough bore carcass.
- Masks standard carcass corrugations
- Insert and carcass of the same material
- Improved flow properties (lower turbidity).
- Erosion also reduced.
- Similar collapse resistance capacity as per conventional carcass.
- Same manufacturing machine.



Technology / Design

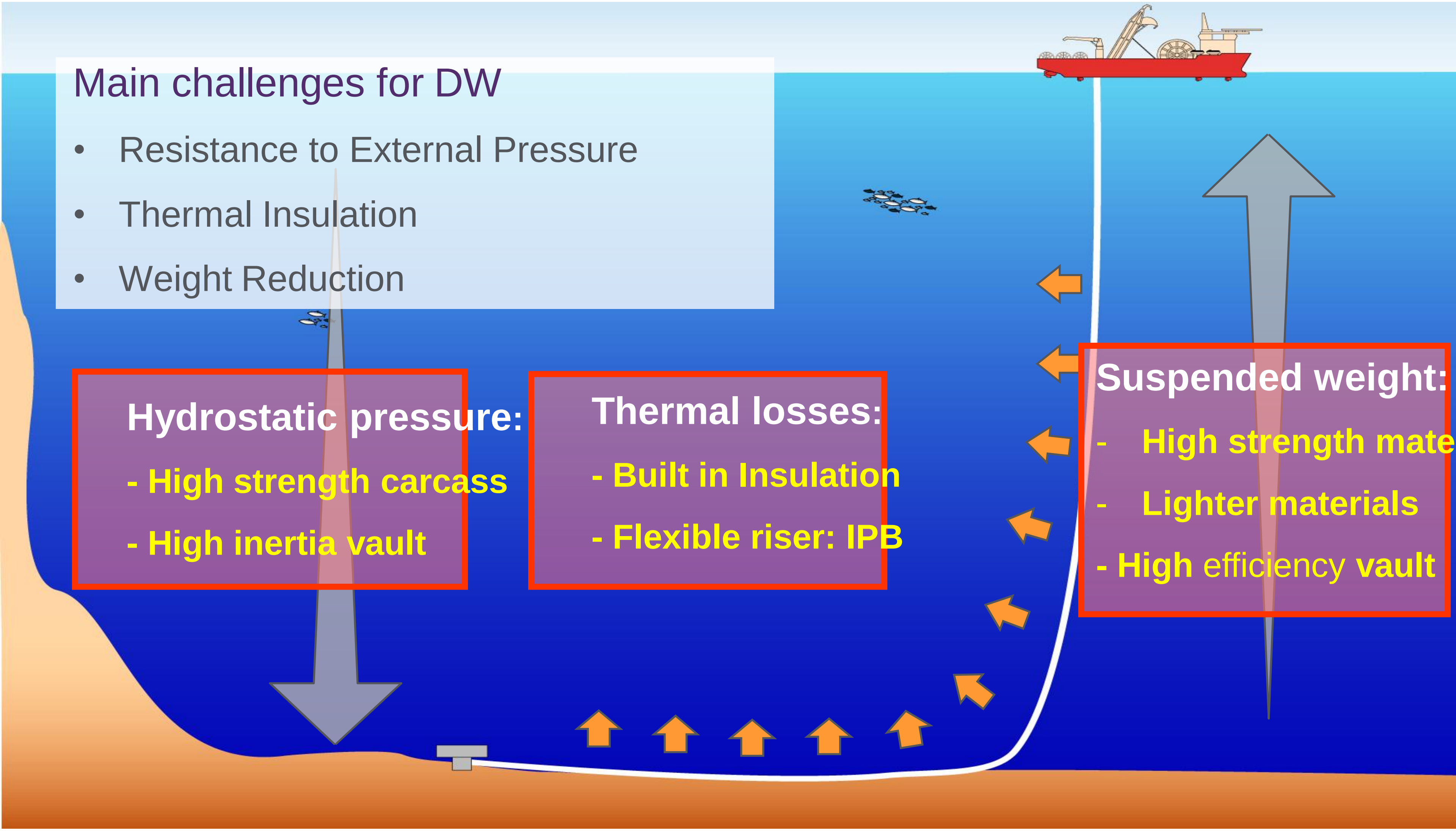


Figure 110 – Deep Water Main Challenges

TechnipFMC

Deep Water Challenges and Developments

- **Carbon steel -> carbon fibre = less weight**
- **Main properties:**
  - Density: 1.6 (5 times lighter than steel)
  - Breaking load: 2700 MPa min (twice stronger than strongest steel armours)
- **Extensive qualification program carried out**
  - Material tests
  - Flexible sample tests
  - Industrial test runs

Figure 111 – Carbon Fibre Tensile Armours Structure

Deep Water Challenges and Developments

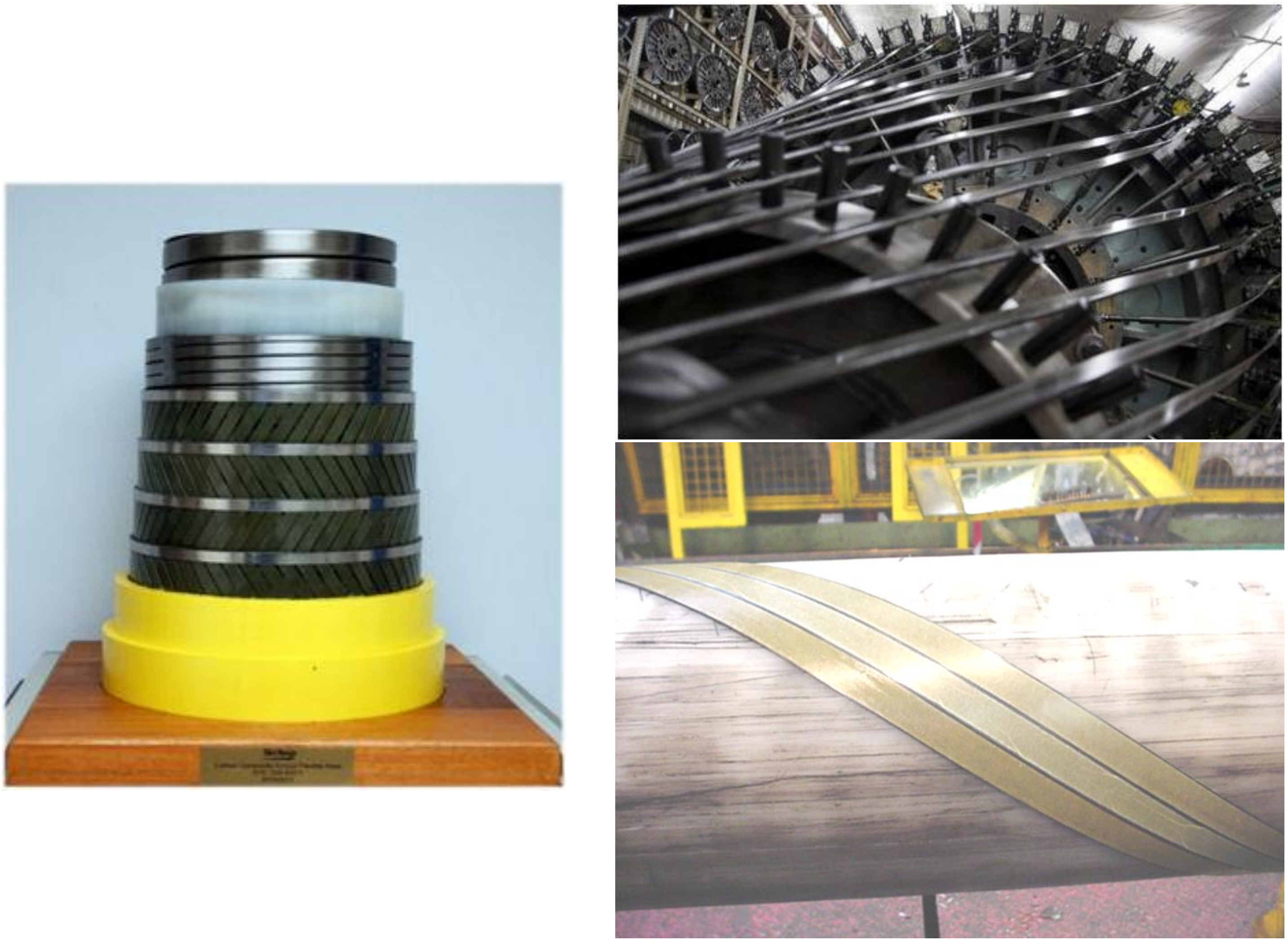


Figure 112 – Carbon Fibre Tensile Armours Structure

Deep Water Challenges and Developments

- **Riser application :**
  - Armour wires must sustain internal pressure and suspended weight
  - Highly efficient carbon fiber armours allow higher pressure and less weight
- **One example : 9" ID riser in 1500m WD, same core structure :**

	Max. allowable pressure	Suspended weight
Steel armours	225 barg	365 tonnes
Carbon fibre armours	339 barg	180 tonnes
	↓ +50%	↓ -50%

Deep Water Challenges and Developments

- **With water depth increase : Need to resist external pressure when line is emptied**

- **Effect of external pressure:**
  - Hydrostatic collapse
  - Reverse End Cap Effect
  - Lateral buckling of armour wires

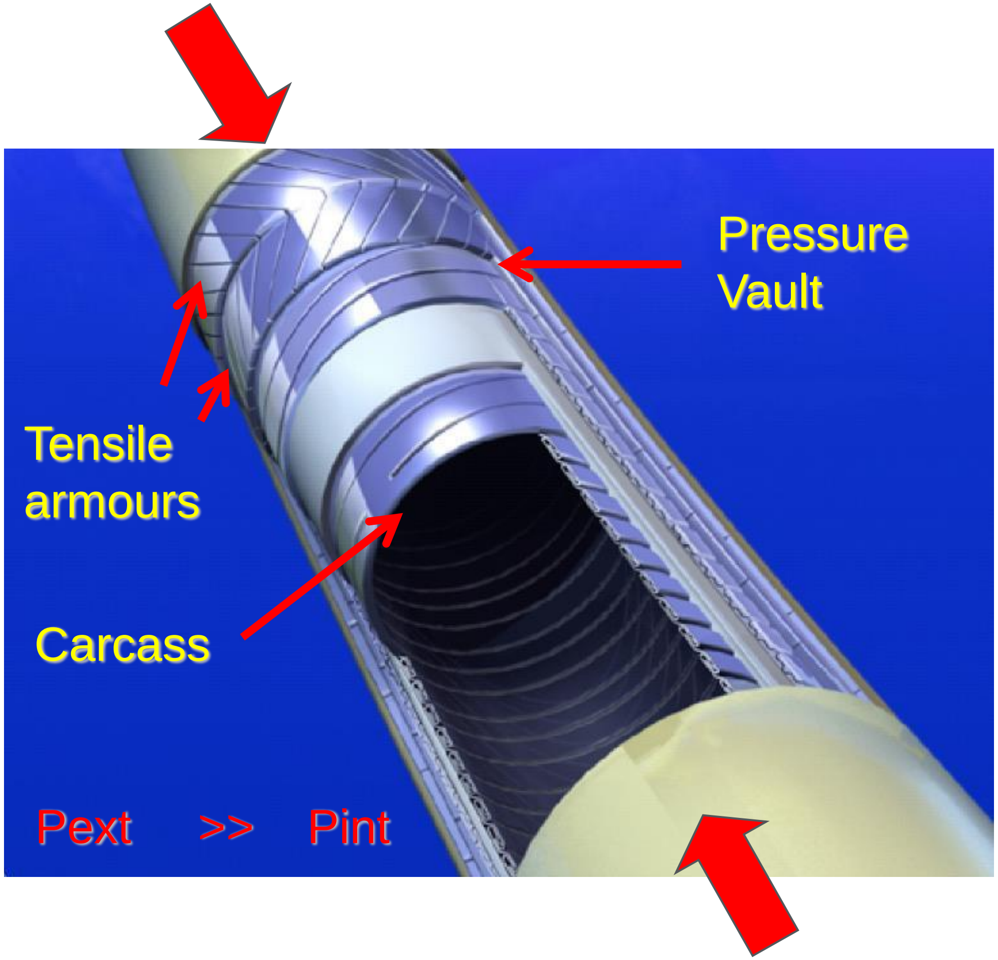


Figure 113 – Effect of External Pressure

Deep Water Challenges and Developments

- ## Reverse End Cap Effect
  - Phenomenon (well known and documented)
  - Axial compression the armour helix tends to swell
  - Radial disorganization (birdcage) of the armour layers if nothing is there to externally support them
- ## Prevention
  - Sealed, Dry annulus - No risk since external pressure provides support to armours
  - Annulus full of water (damaged, condensed water) - High strength tapes (Kevlar) wrapped around armour layers are used
- ## Driving design factors:

- Armour layer geometry (diameter,pitch..)
- Number and type of tapes.

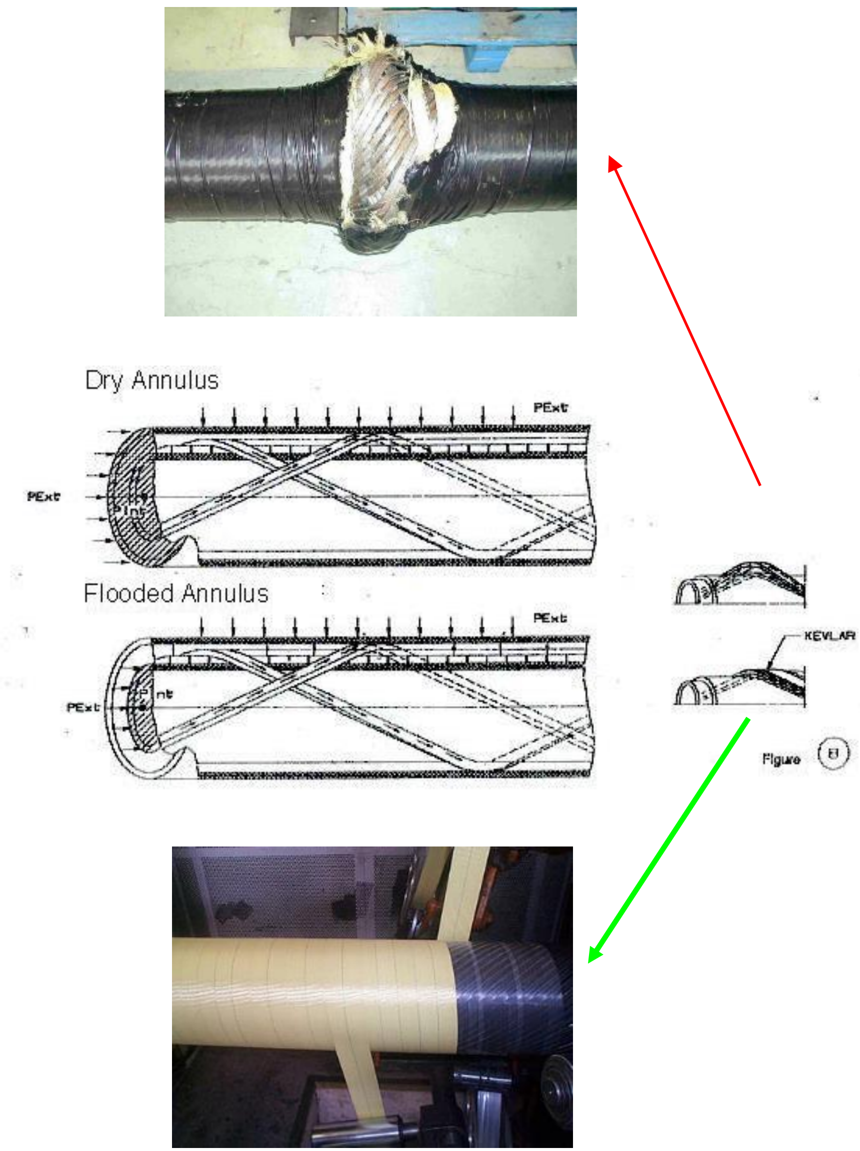


Figure 114 – Reverse End Cap Effect

Deep Water Challenges and Developments

- **Lateral buckling of armor wires:**
  - Only once observed in Brazil in 1997
  - Results from combination of high external pressure and cyclic bending
    - Compressive load
    - Lower radius
- **Failure mode depends on the annulus condition:**
  - Wire instability: when annulus close to external pressure
- **Mitigations:**
  - Wire geometry
  - Highest material strength
  - High armoring angle (but less efficient for tensile load, and more severe for bird caging)
  - Larger bending radius

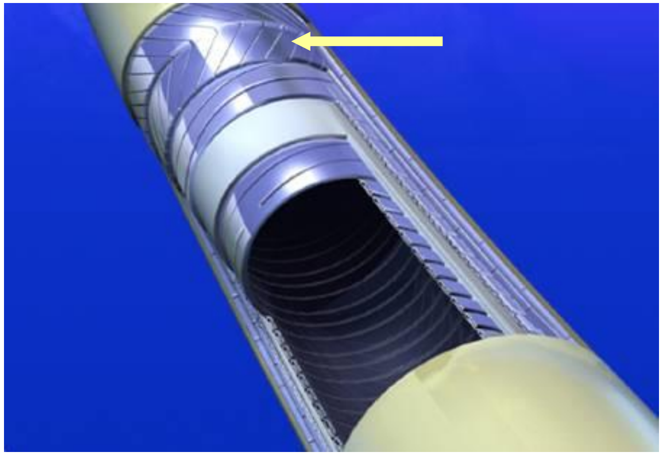
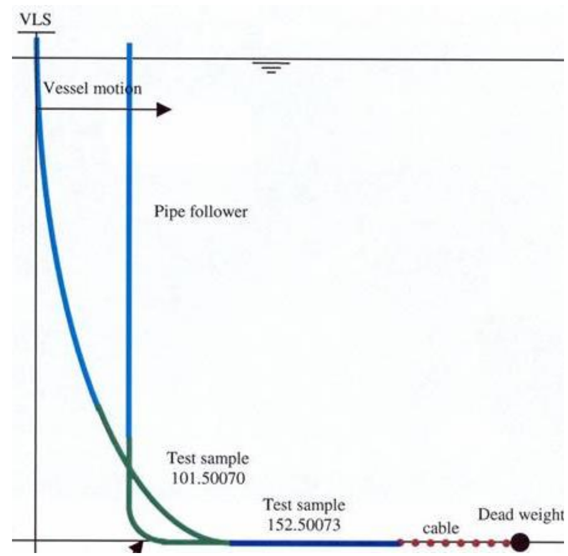


Figure 115 – Lateral Buckling

Deep Water Qualification

- **Full scale testing**
  - Principle
    - Offshore DIP tests
      - Offshore Brazil / GoM
    - Onshore Tank tests



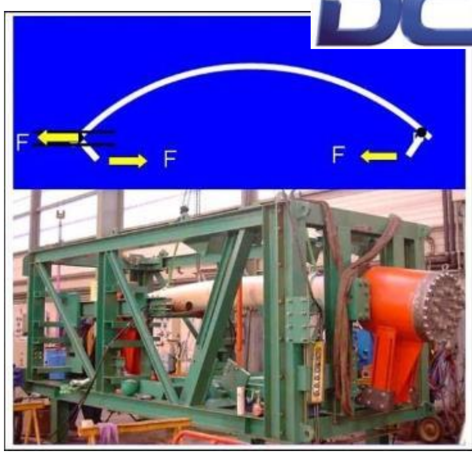


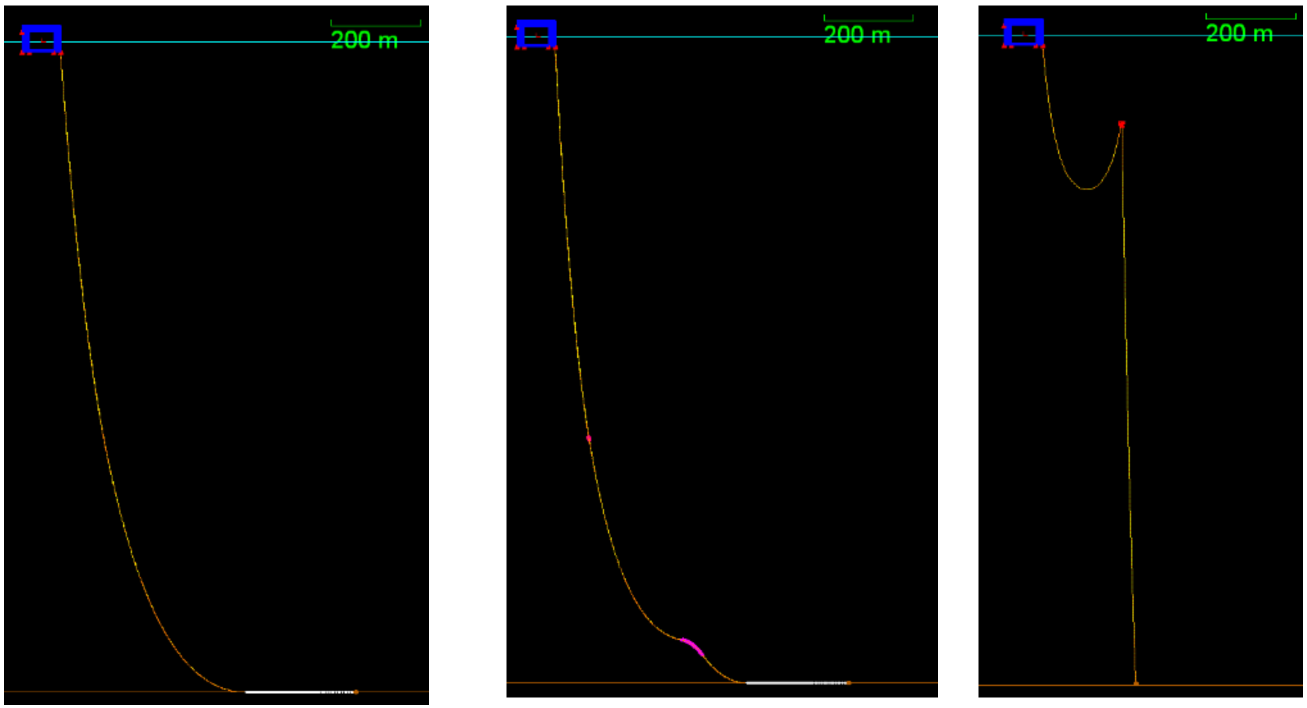
Figure 116 – Deep Water Tests

Deep Water Challenges and Developments

- **Models exist to anticipate effects of external pressure on flexible pipes, third party verified**
- **Work will continue on those models to demonstrate their validity for even deeper applications**
- **Design is optimised to limit the effect of lateral buckling (wide wires, laying angle)**
- **When applicable, configurations:**
  - With risers in several sections, each optimised for its depth range,
  - Minimise curvature at TDP will have a significant effect in reachable depth.

Deep Water Challenges and Developments

- **Deep water:**
  - Various Configuration available



Free Hanging Catenary | **Mini Lazy-Wave** | **Free Standing Flexible Riser**

Figure 117 – Deep Water Configurations

TechnipFMC

Deep Water Challenges and Developments

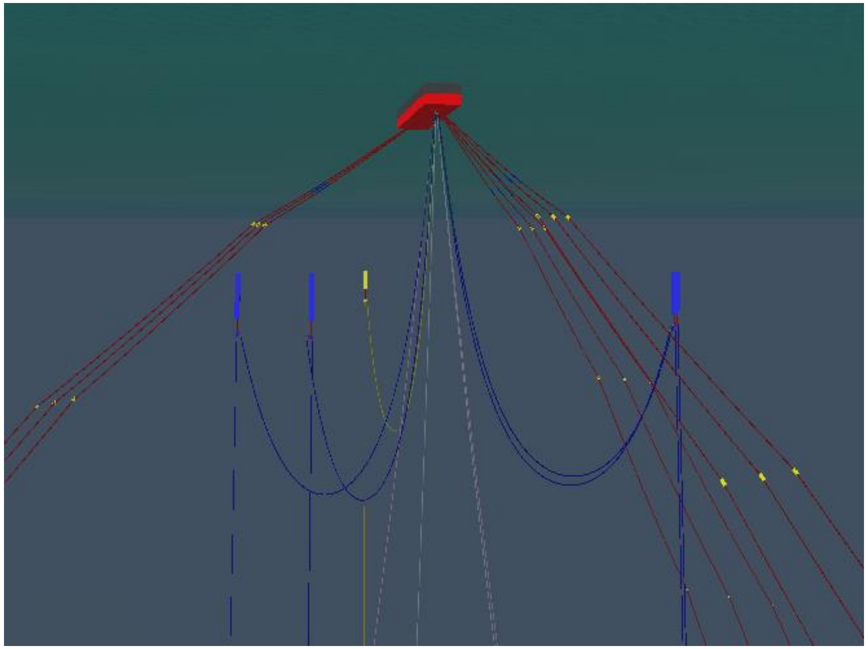


Figure 118 – Free Standing Hybrid Riser

Integrated Production Bundle

- **Integrated Production Bundle:**
- **Insulation**
  - By the plastic layers inherent to flexible pipe
  - Thin layers: spiralled strips of insulation material
  - Thick layers: extruded profiles of insulation material
- **Heating**
  - Circulation of hot water
  - Electrical Heat Tracing cables
- **Other Functions**
  - Hydraulic hoses
  - Gas Lift tubes
  - Communication, control & power cables
  - Monitoring by optical fibres sensors

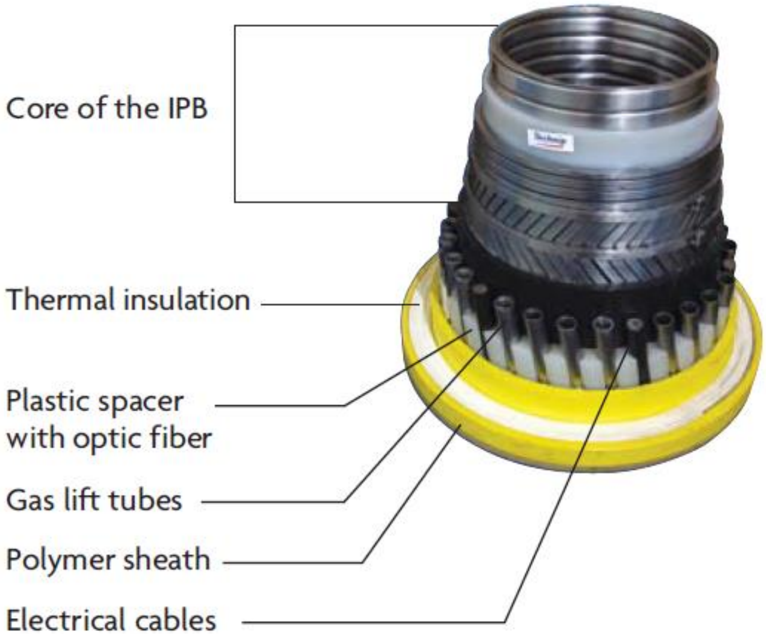


Figure 121 – IPB

Deep Water Challenges and Developments

- **IPB qualification tests**
  - Crushing test
  - Impact test
  - Fatigue test
  - Cool down test
  - Full scale thermal test :
  - 15 m IPB, vertical thermal test
    taped insulation + TPFlex® sheaths within insulated tank with circulating water regulated at 8°C.
  - Measured Thermal Exchange Coefficient 2.9 - 3.0 W/mK (3.1W/mK calculated)

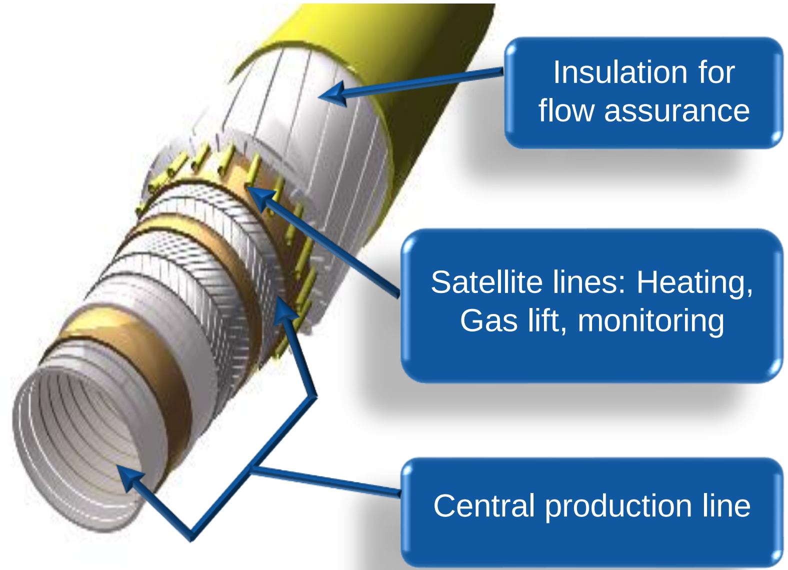


Figure 123 – IPB Projects

TechnipFMC

Deep Water Challenges and Developments

- **Integrated Production Bundle, a solution to flow assurance challenges**
  - First industrial application:
    - Qualified and commercialised on Dalia Project for Total, scope of 8 IPBs in 1350m of WD (1700m long)
    - Successfully manufactured and transferred on the Deep Blue
    - All installed and in operation
    - Ref. OTC 2007 paper from Total

[redacted]

Figure 124 – IPB in Carousel

Flexible Pipe Capability & Emerging Technologies
IPB Track record

- Dalia IPB (in Operation) - Angola
  - Electrically heated and gas lift IPB
  - Internal diameter: 10.75“ / Quantity: 8 IPBs
  - Length: 1,650 m each
  - Weight: 700 tonnes each (in air empty)

- Pazflor IPB (In Operation) - Angola
  - Gas lift IPB
  - Internal diameter: 10“ / Quantity: 2 IPBs
  - Length: 1,200m each
  - Weight: 503 tonnes each (in air empty)

- Papa Terra IPB (In Operation) - Brazil
  - Electrically heated Risers and flowline
  - Internal diameter: 6“ / Quantity: 6
  - Length: 27,4 km Total
  - Weight: 331 tonnes each riser (in air empty)

Figure 122 – IPB Projects

Anti H2S Layer

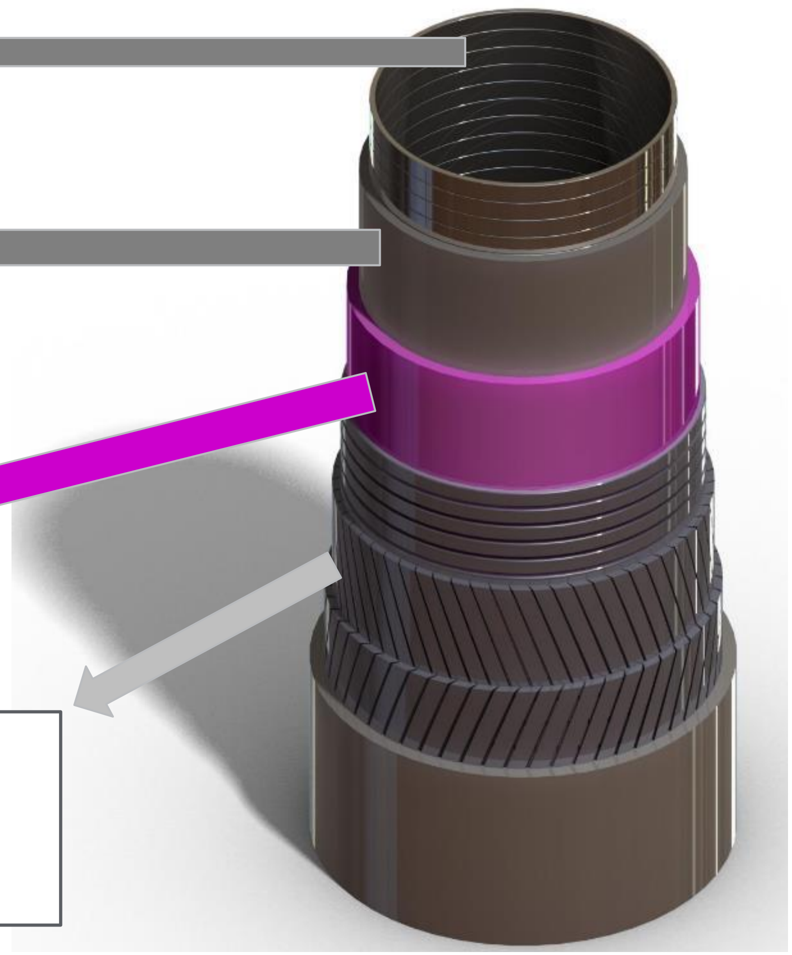
- **Objective:** **Prevent H_2S entry in the flexible pipe annulus during service life**

Bore:
Fluid with H_2S

Pressure sheath:
H_2S will permeate through this sheath
Regulate the H_2S flowrate that will arrive to the second sheath

Anti H_2S sheath
Composite material:
Polymer + Metallic oxide
The oxide will neutralize H_2S during all service life

Steel Layers in Annulus
Zero H_2S
➔Possibility to use sweet service material➔ higher strength



Patented technology

Figure 125 – Structure with Anti H2S Layer

TechnipFMC

Anti H2S Layer

- Allows use of **high strength sweet service steel grades** for vault and armour wires
- Overall structure **weight reduction**
- **Eliminates risk of SSC and HIC**
- **Less** severe environment for **corrosion fatigue**
- Efficient way to **anticipate** any unexpected **souring** of the production fluid
- Possibility to use flexible pipe in **high H_2S environment**

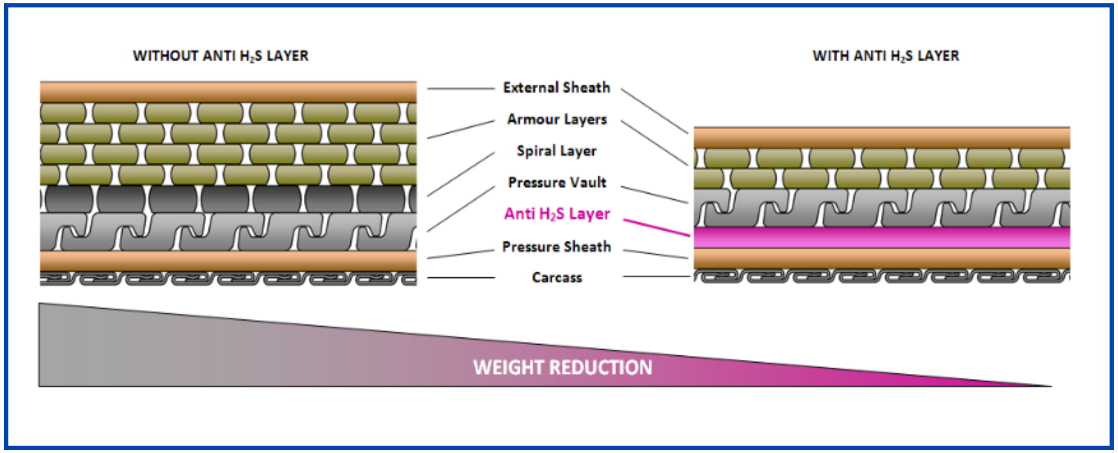


Figure 126 – Weight Reduction Comparison

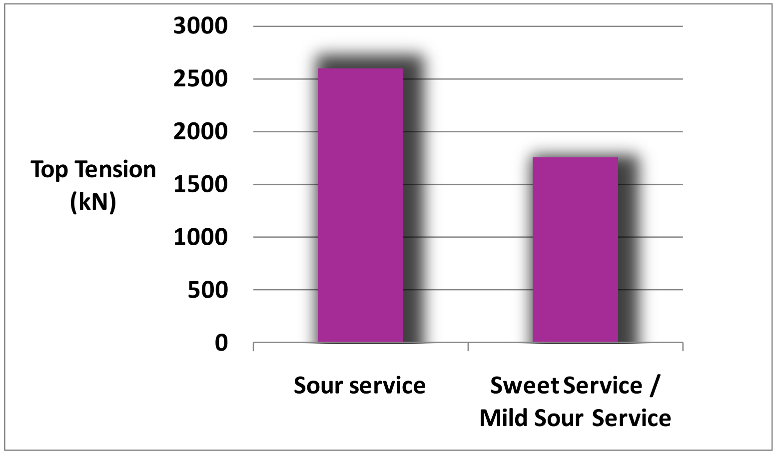


Figure 127 – Top Tension Comparison

High Temperature / High Pressure Developments

- High Temperature
  - Qualified up to 150 deg C – Coflon XD.
  - Use of thermal screen between carcass and pressure sheath
- High Pressure
  - Operators need solutions for pressure up to 20,000psi
  - Development of T Vault / spiral vault

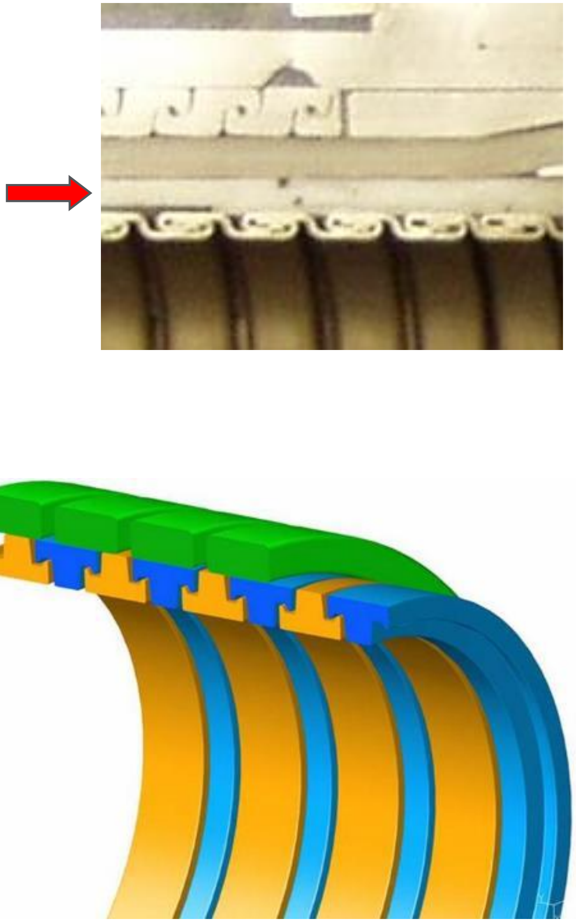


Figure 120 – Thermal Screen/ T Vault

Conclusion: Flexible Pipe Design

- **Flexible design offers tailor-made solution with optimization depending on:**
  - Application
  - Fluid
  - Operating conditions

- **Iterative design process, each layer has its own limitations and interaction with others**
- **All design tools are fully calibrated versus FEA and full scale tests and covered by IVA certification**
- **Design in accordance with standards (API17J)**
- **On-going developments to increase water depth and design pressure / temperature**

Conclusion: Some References

- OTC 18667 : Innovative Optimization of a Large-ID Sour-Service Flexible Riser for the Baobab Project in 1000m Water Depth, West of Africa. L.C.A. Decoret, D. Mullot, and J. Paterson, Technip, and T. Taylor, CNR Intl. UK
- 5th PetroMin Deepwater and Subsea Technology Conference, Kuala Lumpur 29th - 30th October 2007 : Challenges and Solutions for Deepwater Flexible Risers in the Asian Regions. Didier Hanonge, Keiron Anson, Hugues Berton, Technip
- OMAE2007-29186 : PREVENTION AND MONITORING OF FATIGUE-CORROSION OF FLEXIBLE RISERS' STEEL REINFORCEMENTS. Antoine Félix-Henry, Flexi France, Technip Group
- DOT 2005, Brasil: BENDING STIFFENER FATIGUE DESIGN USING NON LINEAR POLYURETHANE PROPERTIES. Didier Hanonge, Olivier Leclerc, Henri Morand, Frédéric Demanze, Alain Chalumeau, Technip, Flexi France.
- OMAE2008-57381 FLEXIBLE PIPE CRUSHING RESISTANCE CALCULATIONS VALIDATION OF A COMPUTER MODEL Aline Malcorps, Antoine Felix-Henry Technip, Flexi France
- 6th PetroMin Deepwater and Subsea Technology Conference, Kuala Lumpur – DESIGN AND QUALIFICATION OF HIGH PRESSURE FLEXIBLE PIPES Henri Morand, Antoine Felix-Henry, Jeroen Remery, Technip
- Offshore Asia 2012 - An Innovative Flexible Riser Solution for Large Diameter, Ultra-deepwater Asian Fields, Philip Ward, Henri Morand, Antoine Felix-Henry Technip

Minimum Bending Radius (API 17J)

Table 9—Minimum Bend Radius Design Criteria

Loading Type	Load Condition			
	Operating		Nonoperating	Survival
	Permanent	Abnormal	Temporary	
All types	1.0 × storage minimum bend radius (SR)			
Static	1.1 × locking radius (LR)			
Dynamic supported [(1)]	1.1 × 1.1 × LR	1.1 × LR		
Quasi-dynamic [(2)]	1.25 × 1.1 × LR	1.1 × 1.1 × LR		1.1 × LR
Dynamic [(3)]	1.50 × 1.1 × LR	1.25 × 1.1 × LR		

NOTE 1 Dynamic supported (i.e. a flexible pipe on an arch or in a bellmouth).

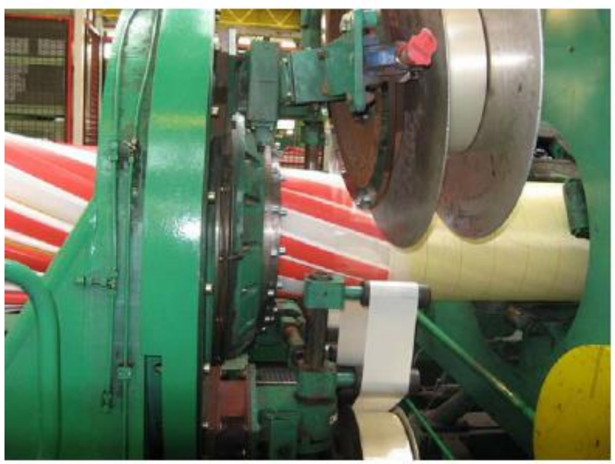
NOTE 2 Quasi-dynamic loading includes the following cases typically applying to topside jumpers:

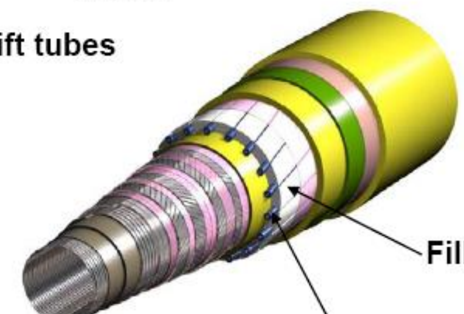
a) no direct wave load on the flexible,

b) predominantly displacement controlled.

NOTE 3 Direct wave loading on the flexible pipe.

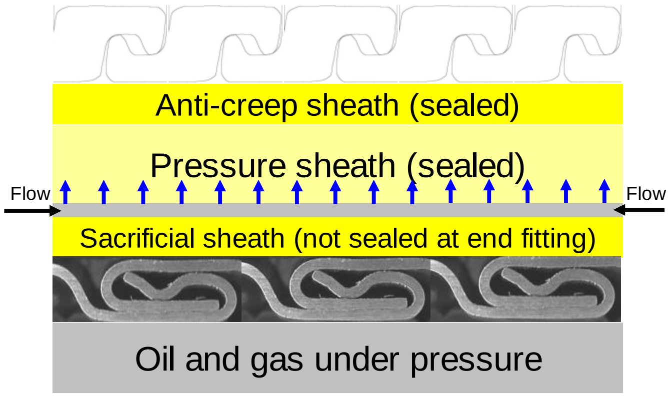
Deep Water Challenges and Developments

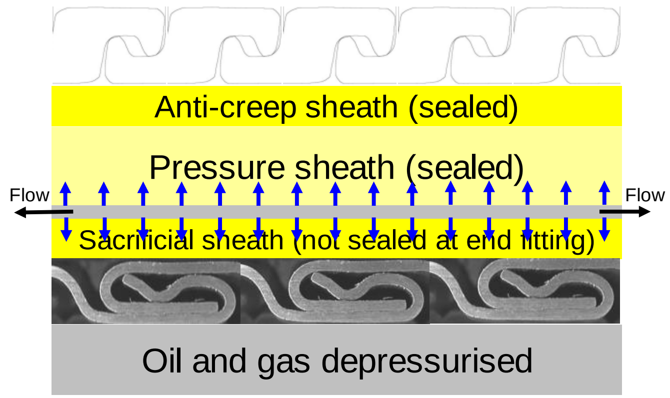




Plastic Material – Polyvinylidene Fluoride (PVDF)

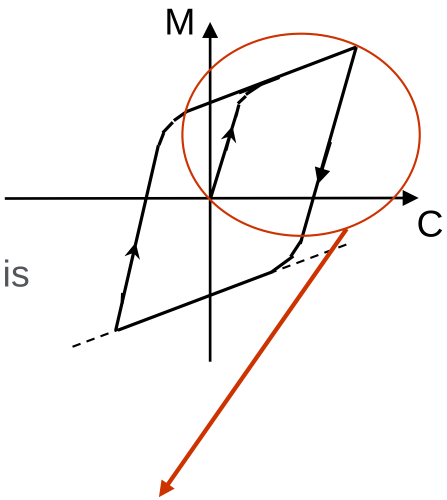
- **PVDF material can be more sensitive to fatigue crack propagation than other plastic (Model available)**
- **For dynamic application sacrificial sheath can be designed to isolate pressure sheath from contact with carcass during extrusion**
  - Warning : rapid depressurisation for 2 or 3 layers, risk of carcass collapse
    - Control depressurisation rate
- **Application with mono layer**





Dynamic Riser System

- **Numerical modelling improvement : Hysteretic behaviour**
  - For small curvature, the «rigid» stiffness EIinitial is taken into account
  - For higher curvature, sliding occurs and the elastic stiffness Eiasymptotic is taken into account
  - The transition zone is assumed to be non-linear
  - Project impact :
    - TDP configuration
    - Less curvature
    - More loads



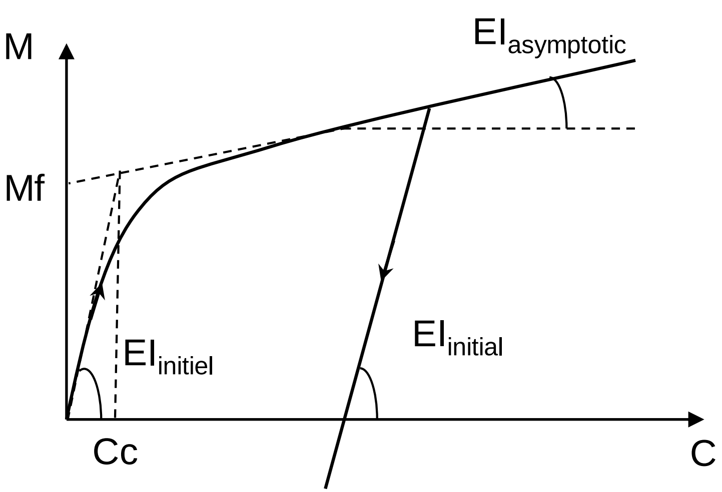
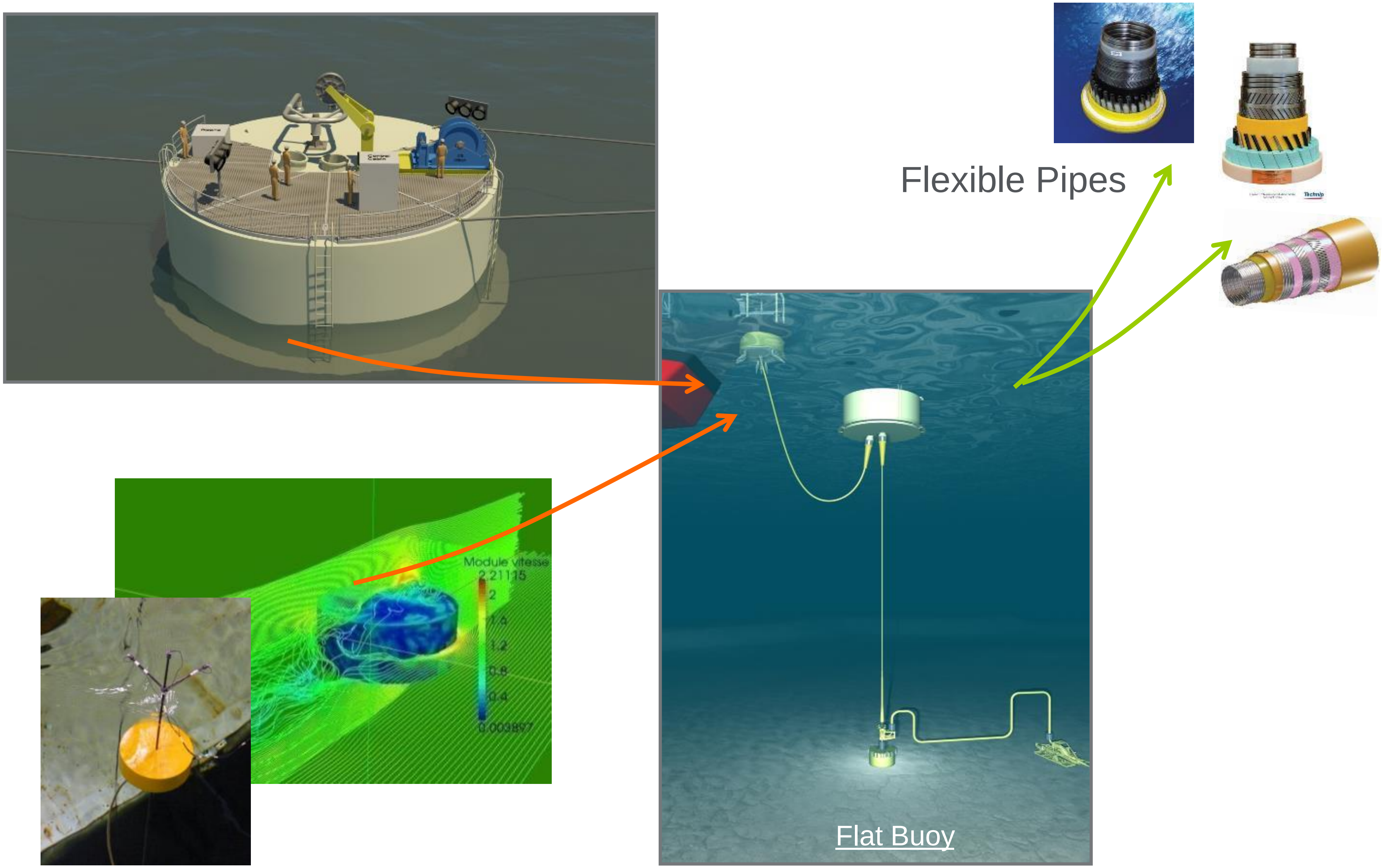


Figure 89 – Hysteretic Bending Stiffness

Deep Water Challenges and Developments



TechnipFMC

Figure 119 – Modified Free Standing Flexible Riser

Deep Water Challenges and Developments

- **High Temperature / High Pressure top side jumper applications**
  - HT
    - Qualified up to 150 deg C – Coflon XD.
    - Use of thermal screen between carcass and pressure sheath
  - HP
    - Operators need solutions for pressure up to 20,000psi
    - Development of T Vault / spiral vault

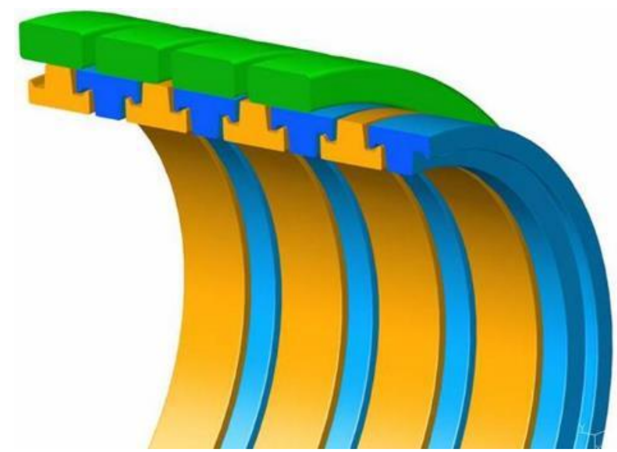


Figure 120 – Thermal Screen/ T Vault