Introduction to Flexible Pipe

The Life Cycle of Flexible Risers and Flowlines

Marius Martens, Floating Systems Manager, INTECSEA

June 2019

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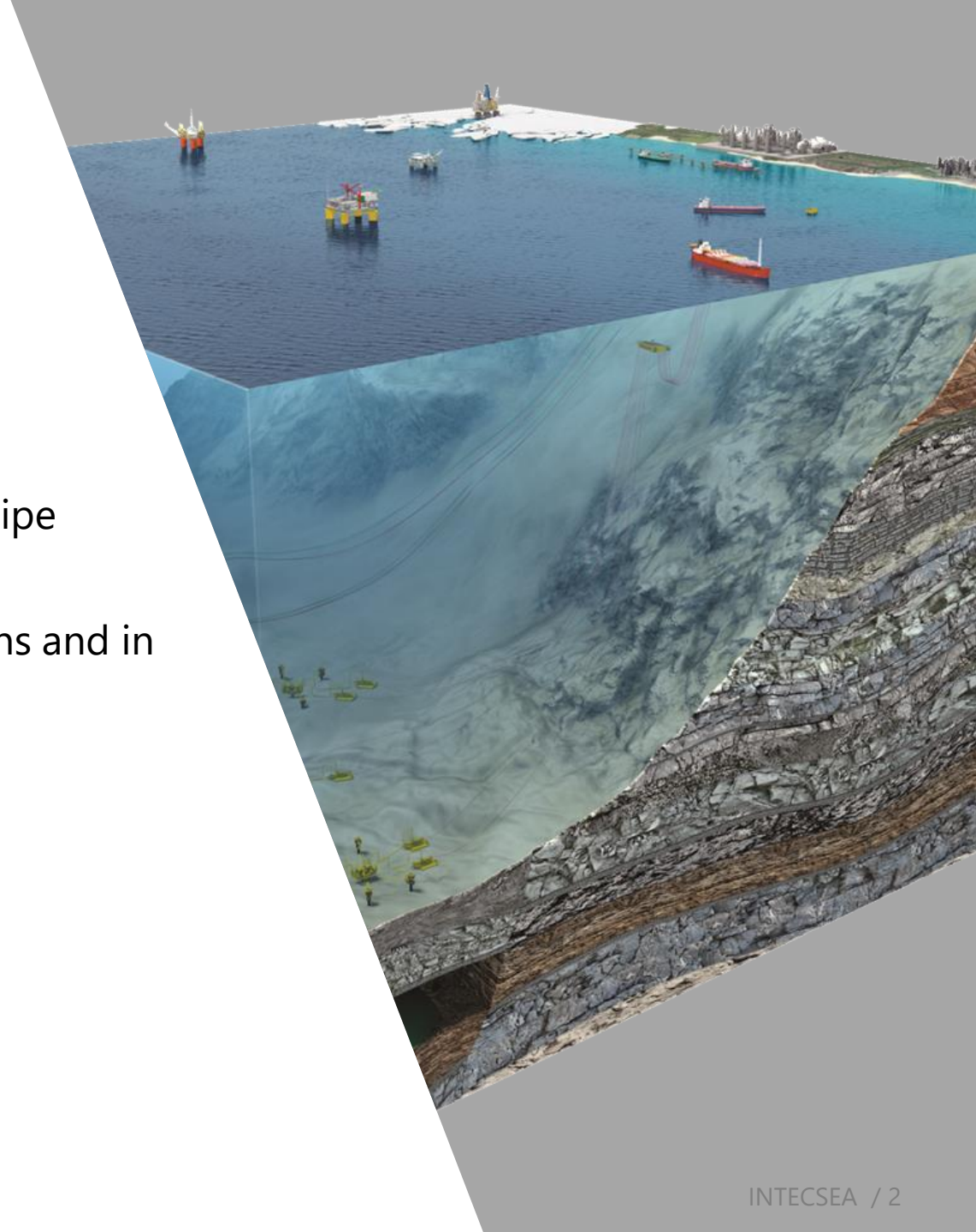
Agenda

- Rigid vs. Flexible Pipe
- Different Types of Flexible Pipe
- Flexible Risers Configurations and in Australian Conditions
- Flexible Riser Design



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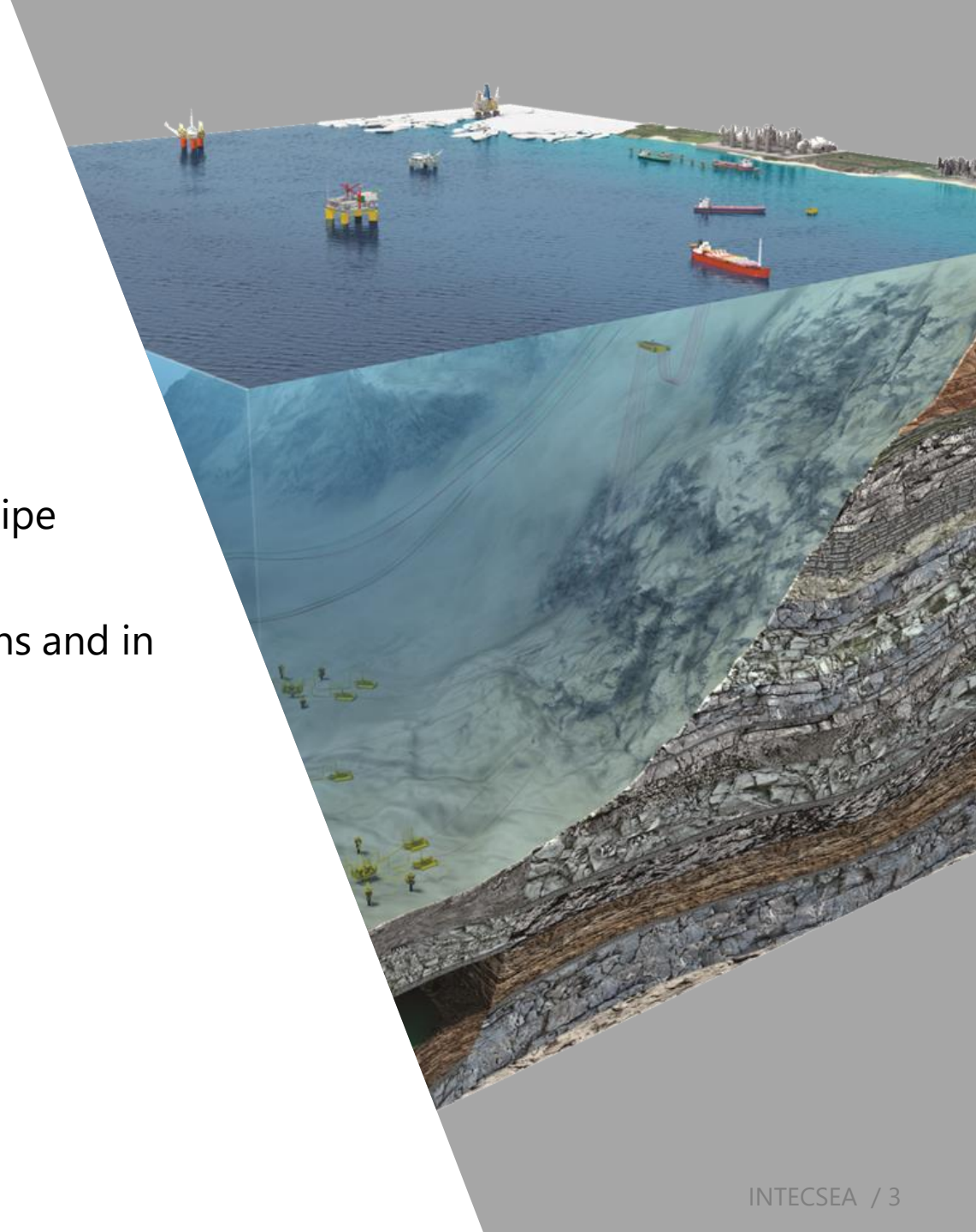

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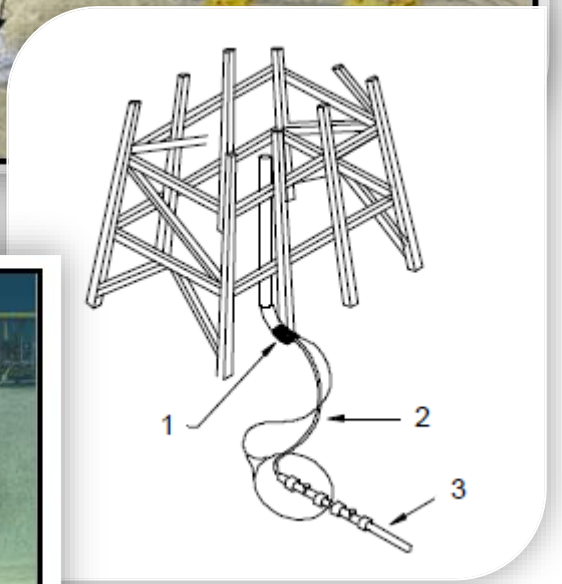
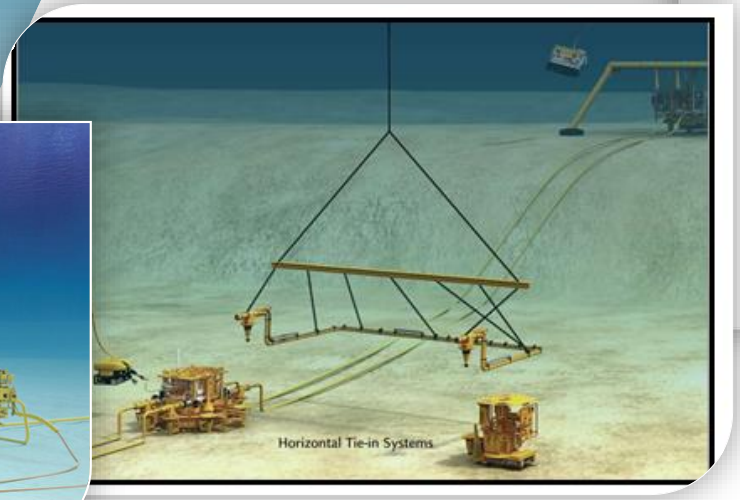
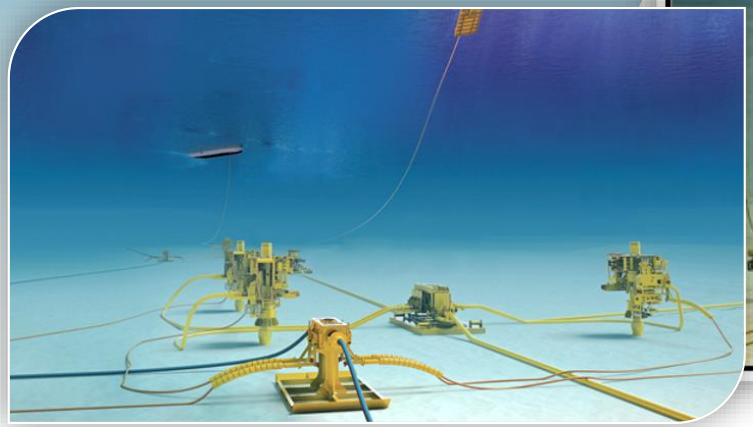
Static Applications for Flexible Pipe:

- Pipelines or Flowlines
- Flexible Jumpers
- J-tube Pull-ins

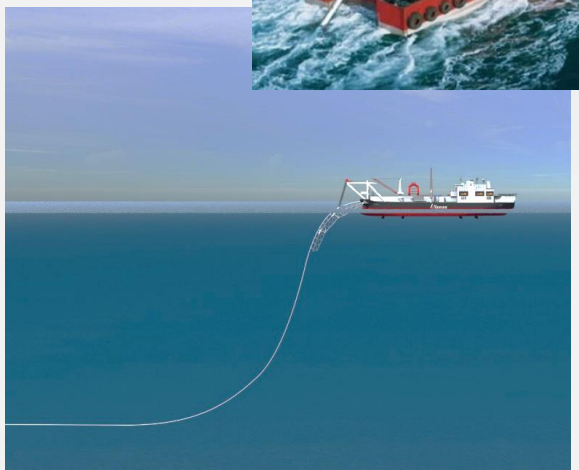






Size Comparison

- Flexible pipe is always referred to by ID
- Flexible pipe for oil & gas is generally limited to 16″ ID - can be up to 22″ ID
- Reeled Rigid Pipe can be installed up to 16″ OD - Depending upon Wall Thickness
- Rigid Pipe can be up to 48″ OD for Subsea Oil & Gas. Relies on J or S-Lay vessels.



Cost Comparison – Rigid vs. Flexible Pipe

- The cost of the flexible pipe can be in the range of

  ~ $1500 - 4000 per metre of 10" ID

- Rigid CRA pipe is cheaper:

  ~ $850/m for 12" OD Stainless Steel (316) lined

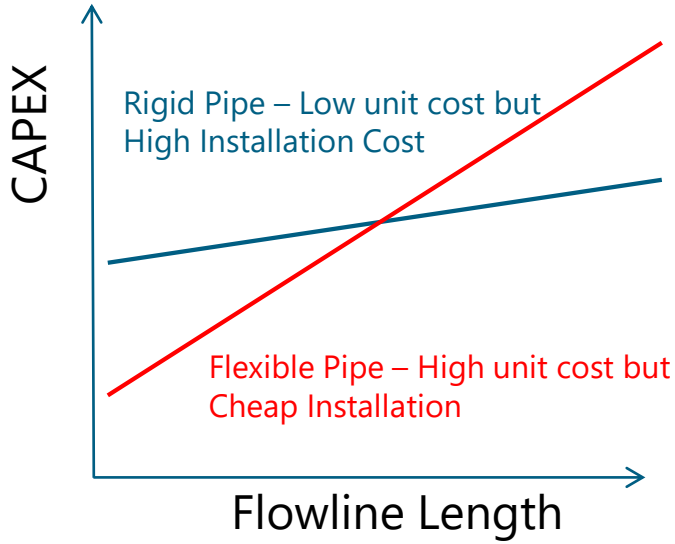
  ~ $1250/m for 12" OD Inconel (625) lined

- Rigid Carbon steel pipe is much cheaper:

  ~ $250/m for 12" OD CS pipe

Why Use Flexible Pipe for Static Applications?

- A flexible pipe installation spread can easily be placed on a construction vessel
- Specialised laybarges not required.
- Flexibility makes tie-ins much quicker.



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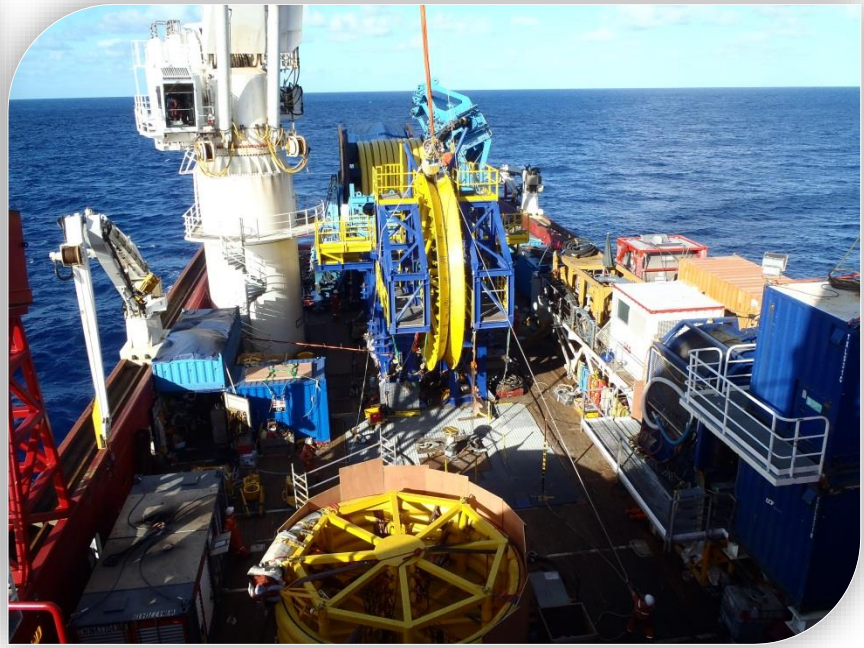
Why Use Flexible Pipe for Static Applications?

Even a relatively small vessel of opportunity…



Why Use Flexible Pipe for Static Applications?

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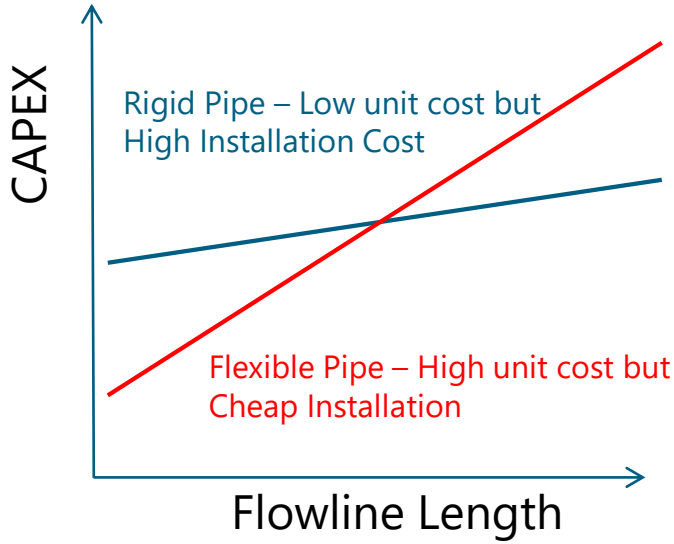
- Flexibility makes tie-ins much quicker.

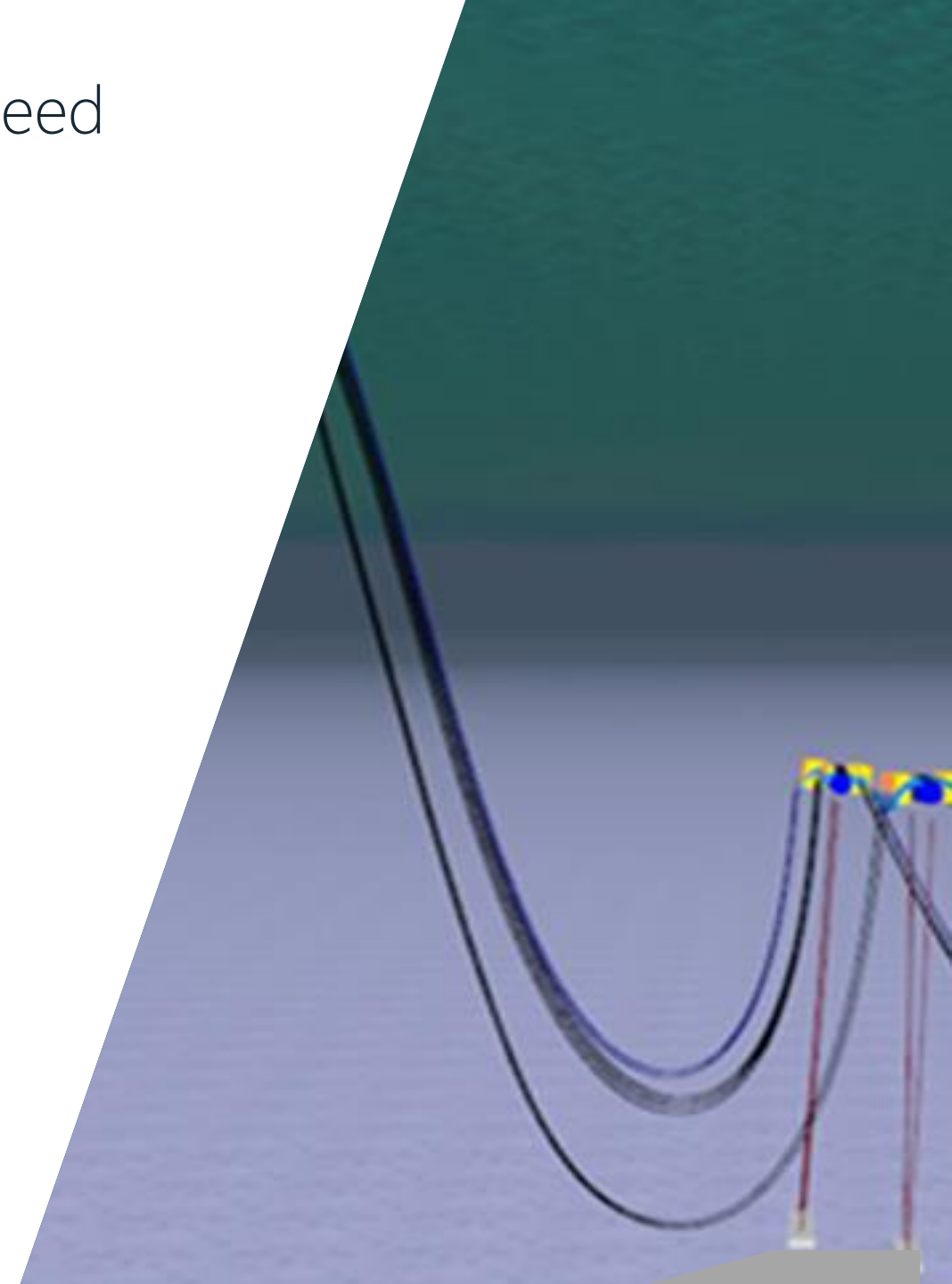
The Installed Cost is the driver for selection of flexible pipe for Static Applications.



Dynamic Service: We Need the Flexibility

Flexible riser systems required for floating facilities:

- Decouples surface facility motions from fixed facilities on the seabed
- Accommodates large amplitude motions and offsets
- In less than 500m water depth fatigue is prohibitive for SCRs or Steel Lazy Wave Risers



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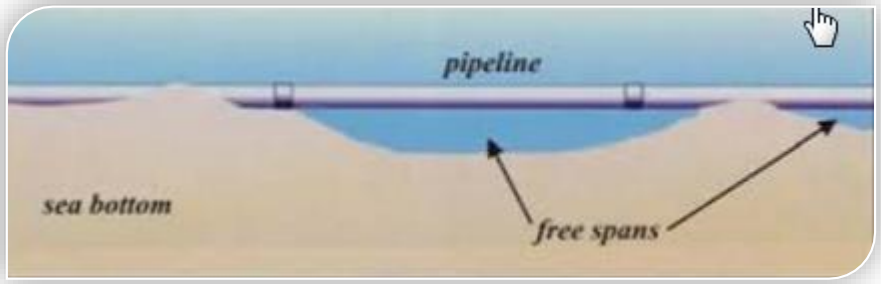
Other Benefits of Flexibles

- Can accommodate large changes in seabed profile that would otherwise require remediation.
- Potential for recovery and re-use for other applications.
- Well insulated, which may offer flow assurance benefits.



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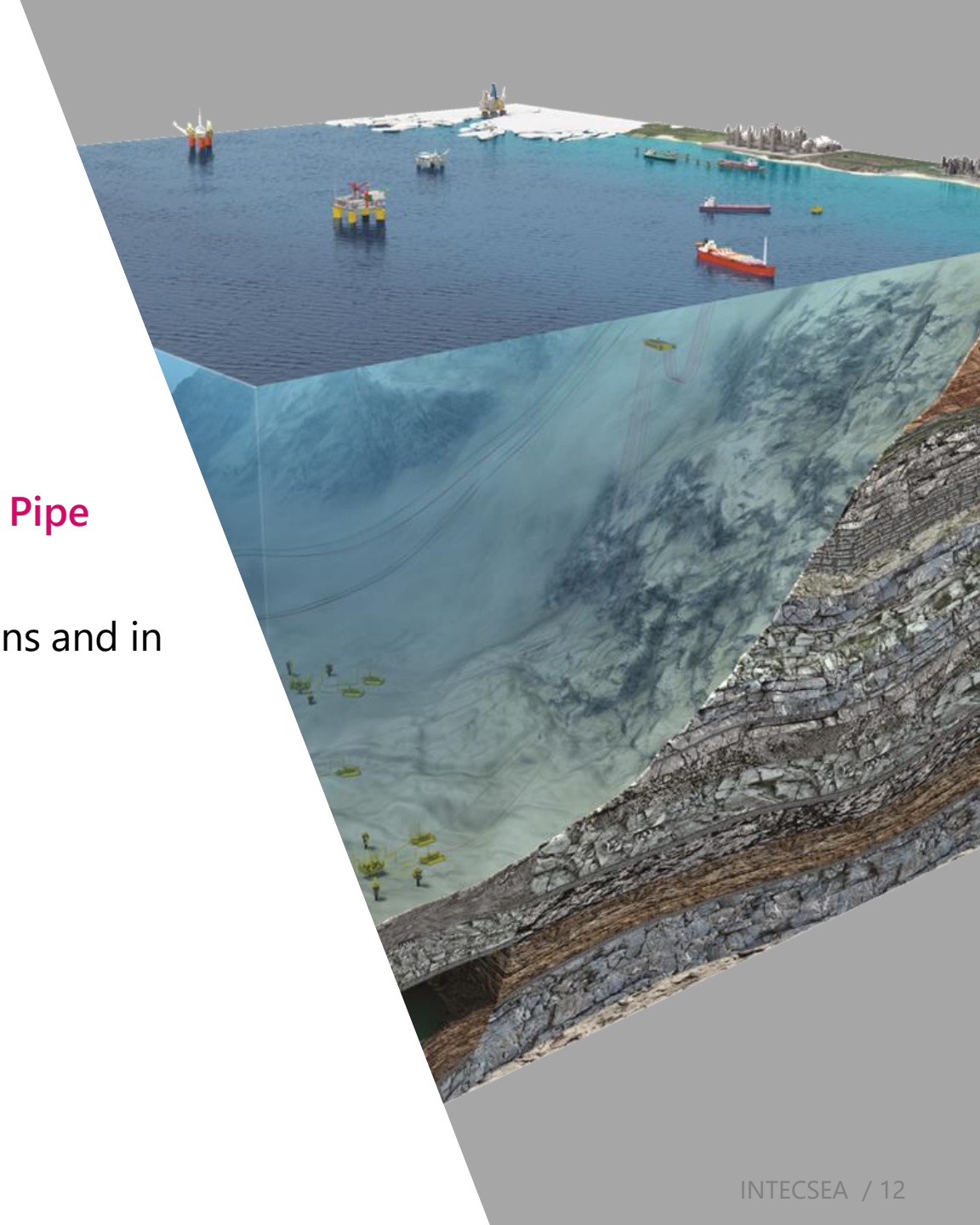

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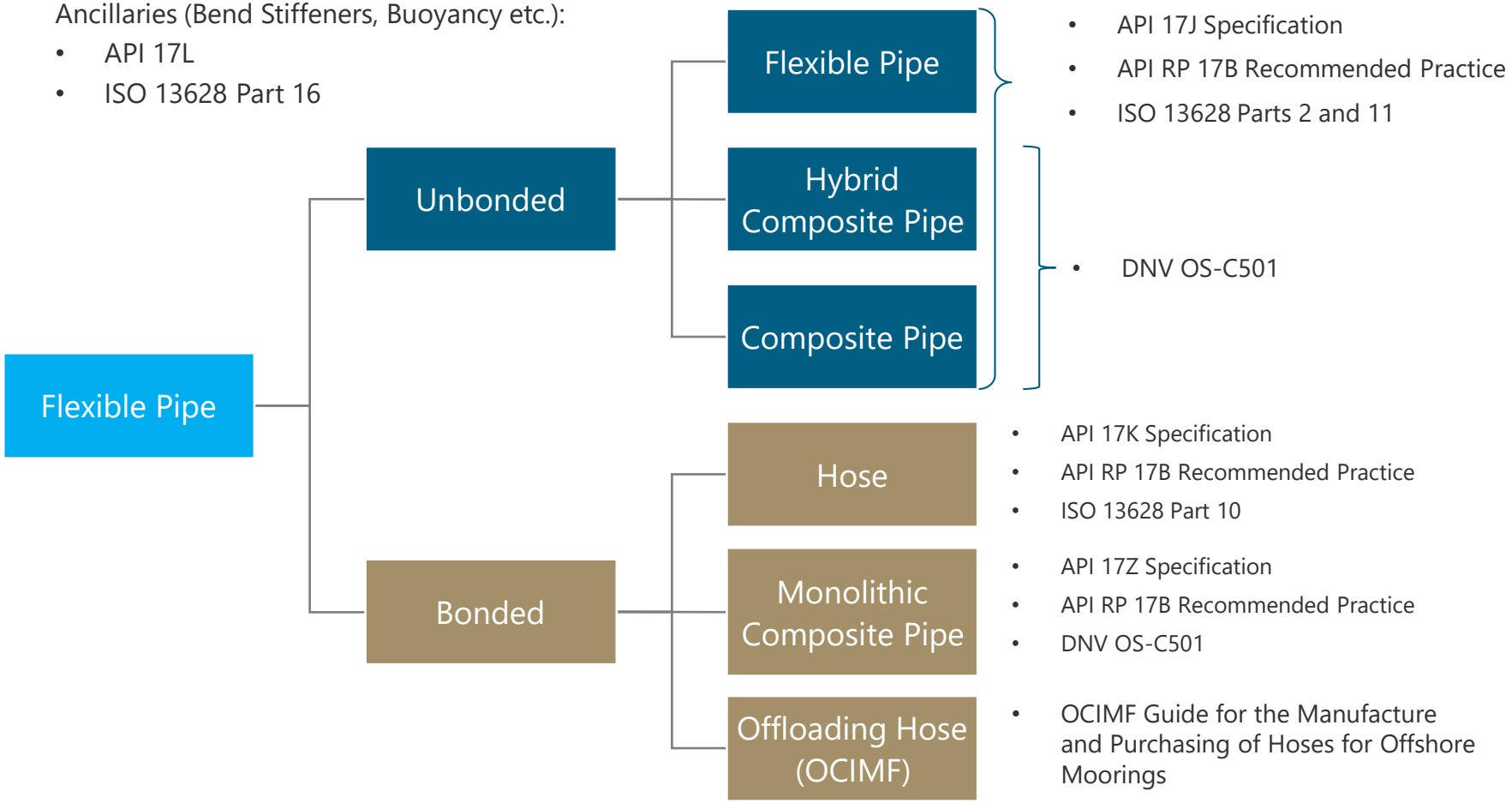
Types of Flexible Pipe

Ancillaries (Bend Stiffeners, Buoyancy etc.):

- API 17L
- ISO 13628 Part 16



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Flexible Pipe

There are three traditional suppliers of Unbonded Flexible Pipe:

- TechnipFMC
- Manufacture in France, Brazil and Malaysia

- NOV ex. NKT
- Manufacture in Denmark and Brazil

- BHGE Wellstream
- Manufacture in UK and Brazil

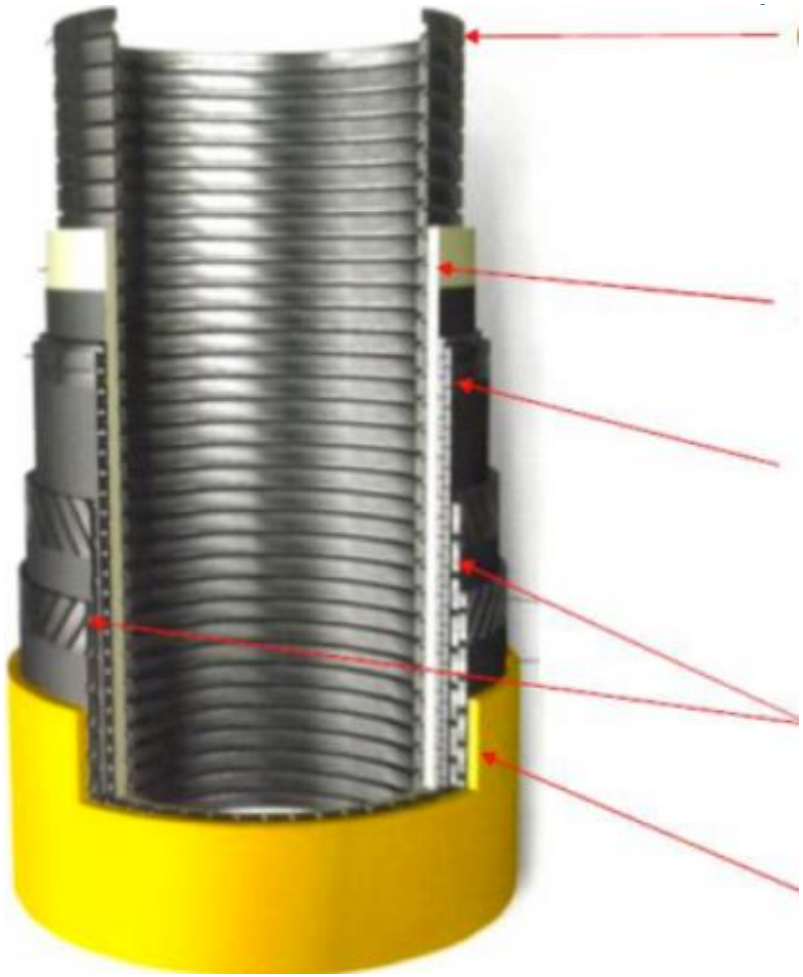
Flexible Pipe

There are now new suppliers of Unbonded Flexible Pipe:

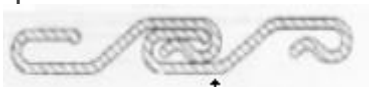
- HAT Flex
- Manufacture in China

- Neptune Offshore Engineering (NOED)
- Manufacture in China

Flexible Pipe



Carcass: Resists hydrostatic collapse of structure and prevents ovalisation during reeling. Protects sheath against e.g. sand or pigs. Typically 316L Stainless Steel, cold formed strip



Pressure Sheath: Makes pipe leakproof. Extruded polymer, e.g.: Polyamide, Polyvinyldene Fluoride (PVDF), cross linked polyethylene

Pressure Vault: Resists pressure (hoop stress). Carbon steel

Armour Layers: Resist axial tension and contributes some hoop stress, function of angle. Carbon steel. Contrahelically wound cold formed wire

External Sheath: Provides mechanical protection to underlying steel layers and provides first line of defence against water ingress. Extruded polymer, e.g.: HDPE or Polyamide

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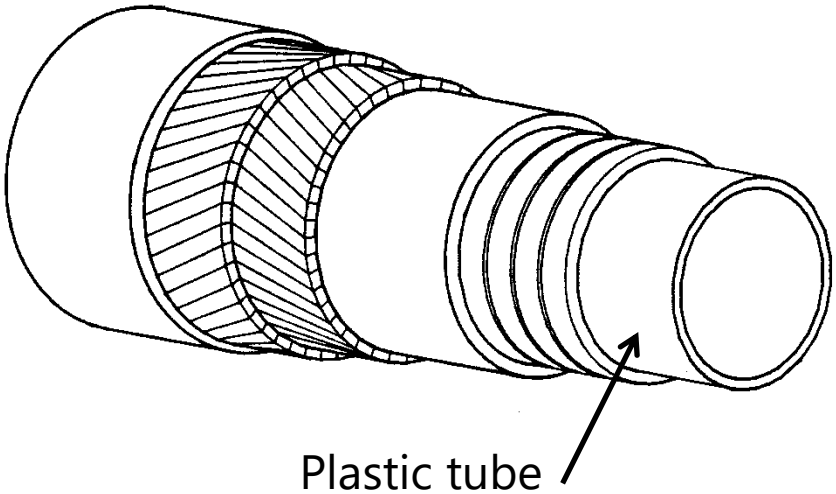
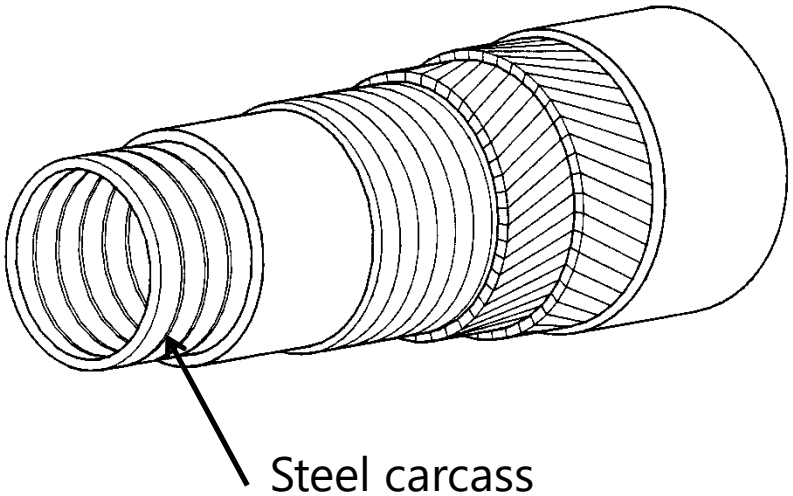
Flexible Pipeline Generic Members

SMOOTH BORE



ROUGH BORE



- A **rough bore pipe** contains an inner steel carcass and is used whenever **gas** may be present in the transported fluid.
- Smooth bore pipe is suitable for applications where gas will not diffuse through the internal thermoplastic layer such as water or chemicals.
- **Gas** Applications of **Smooth Bore** require **venting of the inner annulus**.

Flexible Risers – FLIP in Gas Export

A – Carcass
B – Inner Pressure Sheath(s)
C – Pressure Armours
D - Tensile Armours
E – High Strength Tapes
F – Outer Sheath(s)

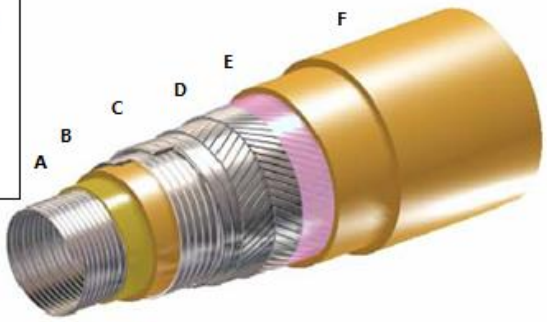
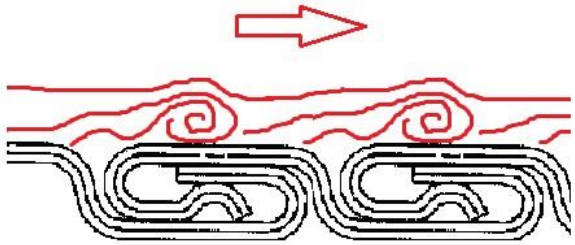


Figure 3-1 Rough Bore Flexible Pipe Cross-section



- Demonstrated issue on at least 7 projects, including instances of topsides piping failures
- Potential issue for standard rough bore pipe designs when gas has <1% liquid content
- Onset is difficult to predict and prevent.
- Mitigations on topsides and subsea piping can reduce risk, but not eliminate it entirely.

Flexible Risers – Anti-FLIP designs

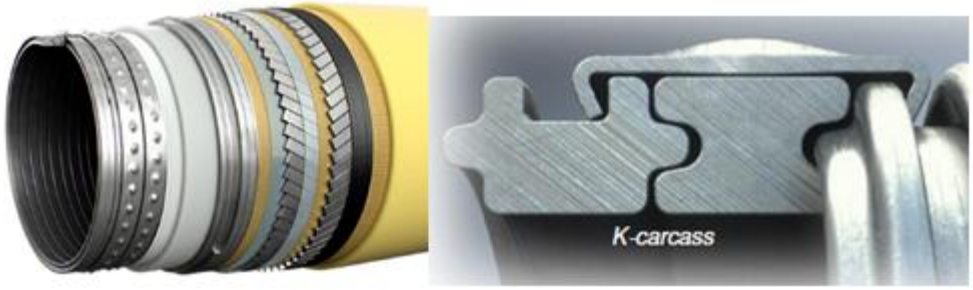


Figure 6-7 NOV K-Profile Carcass

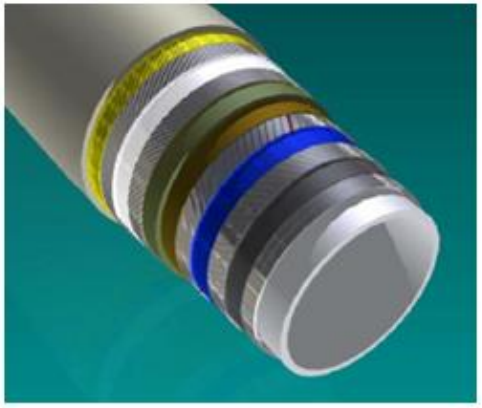


Figure 6-6 Smooth Bore Flexible Pipe Cross-section

Project/Facility Name	Year	ID [inch]	DP [Bar]	Water Depth [m]
Prototype	2015	11.5	426	1350
Prototype	2015	8.0	426	3500
Prototype	2015	7.5	426	3100
Equinor Johan Castberg	2021			370

Project/Facility Name	Installation Year	Size [inch]	DP [Bar]	Water Depth [m]
Statoil Åsgard B	2006	14	240	310
GDF Suez Gjøa Field	2011	12		360
Statoil Norne	2014	9.6		380
BP Schiehallion	2015			400
INPEX Ichthys	2016	10		280
ENI Jankriek	2017	12		400

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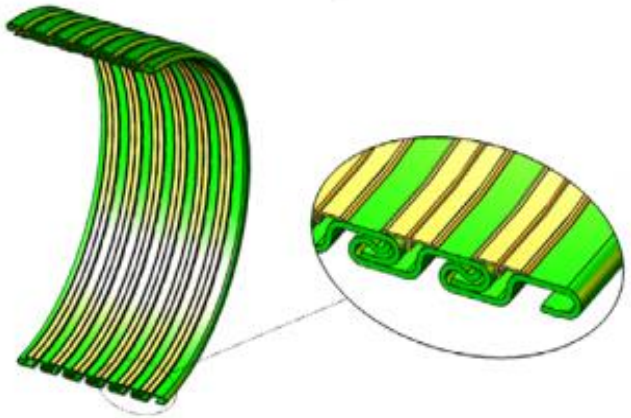
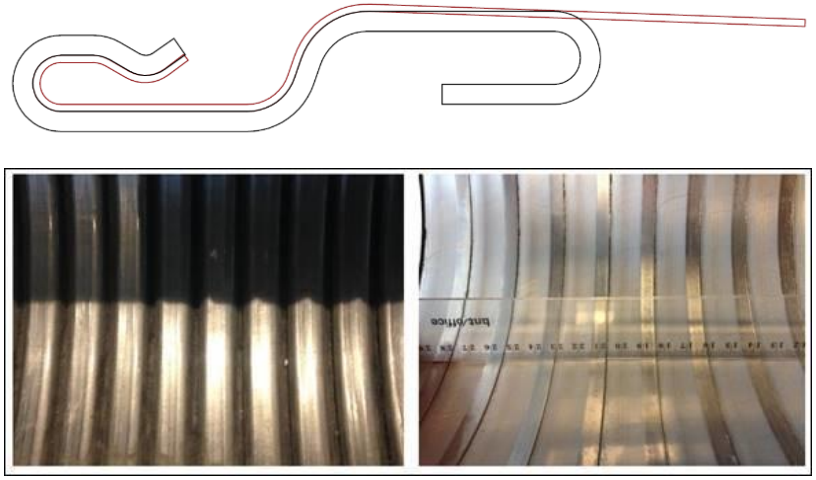
Flexible Risers – Anti-FLIP designs

- All three manufacturers are now offering or qualifying a variation on an insert.
- This means that the flexible structure is essentially the same, so provides greater confidence.
- Unlike the plastic smooth bore, it can be pigged and is not at risk of collapse due to gas build up.



Courtesy of BHGE



Courtesy of NOV

Flexible Pipe

Transportation

- Carousel – Long lengths, vessel availability limited Weigh ~2500Te
- Reels – Diameter ~ 9 - 12m, Weight ~ 250 - 350Te
- Crates/Baskets/Pallets – Short lengths only

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Flexible Pipe

Installation

- Directly off the reel – *(Limited applications)*
- Horizontally with Tensioners
- Vertically with Tensioners also known as VLS

Flexible Risers – Design Pressure

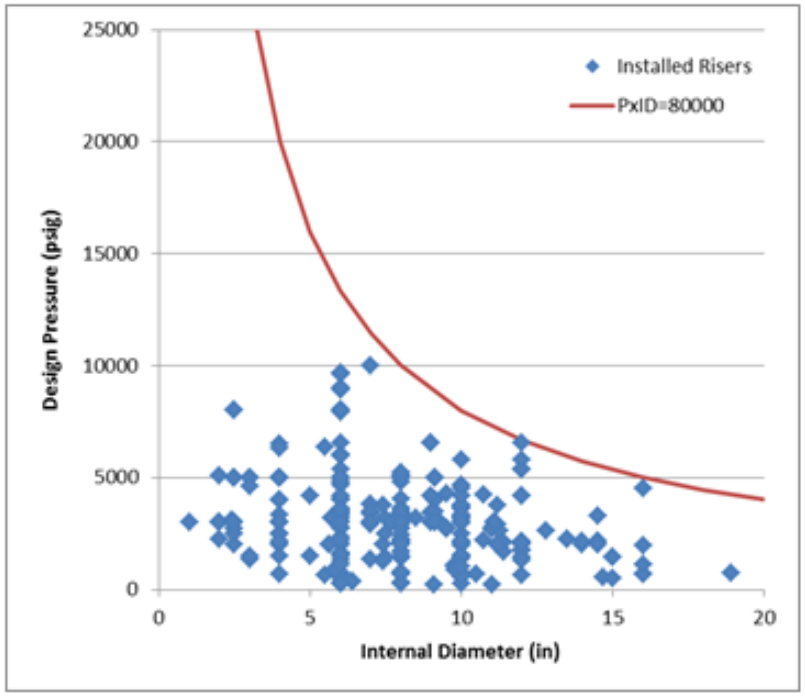


Figure 6-1 Installed Flexible Riser Systems – ID vs Design Pressure

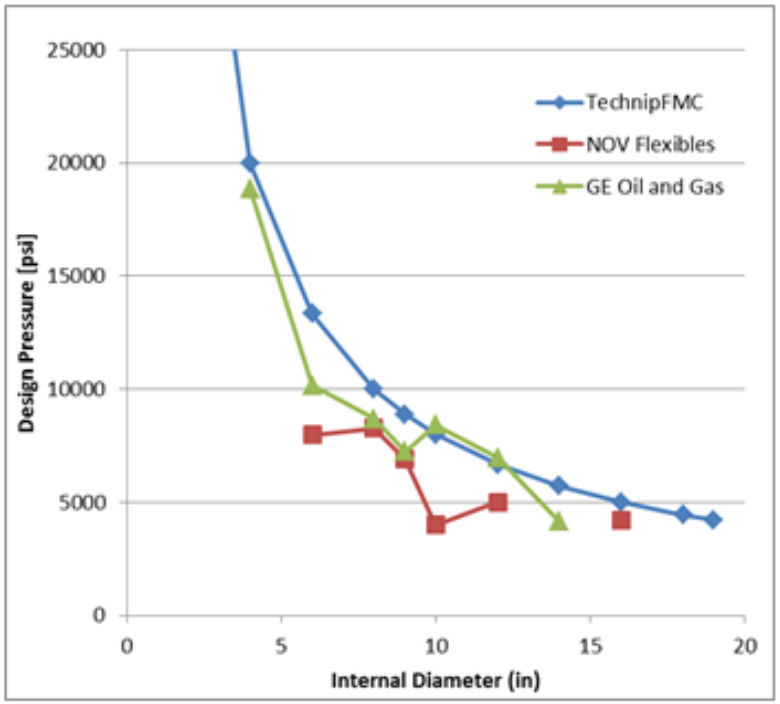


Figure 6-2 Qualification Limits – ID vs Design Pressure (Sweet Service)

Flexible Risers – Water Depth

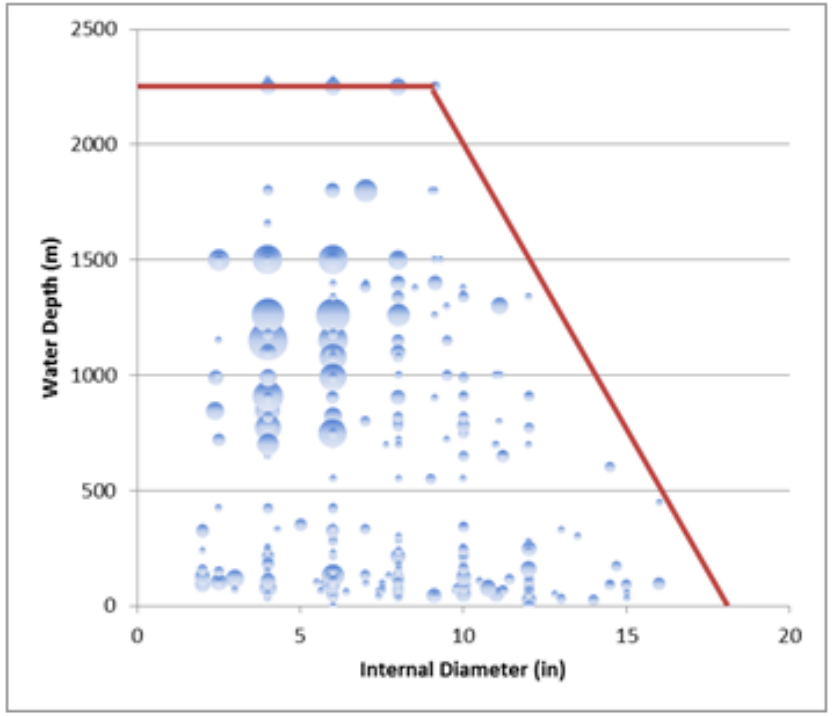
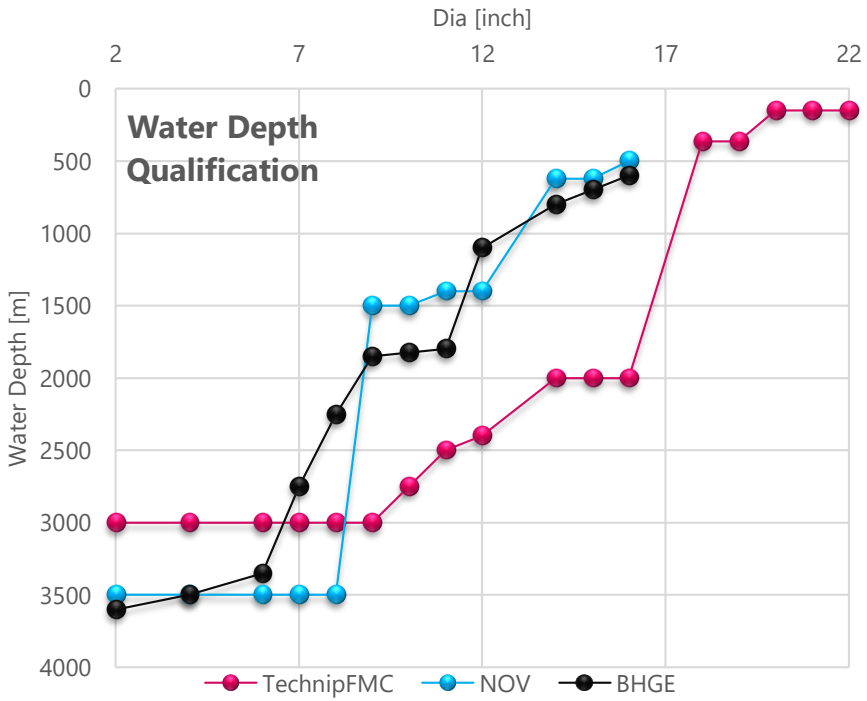


Figure 6-3 Installed Flexible Riser Systems – ID vs Water Depth



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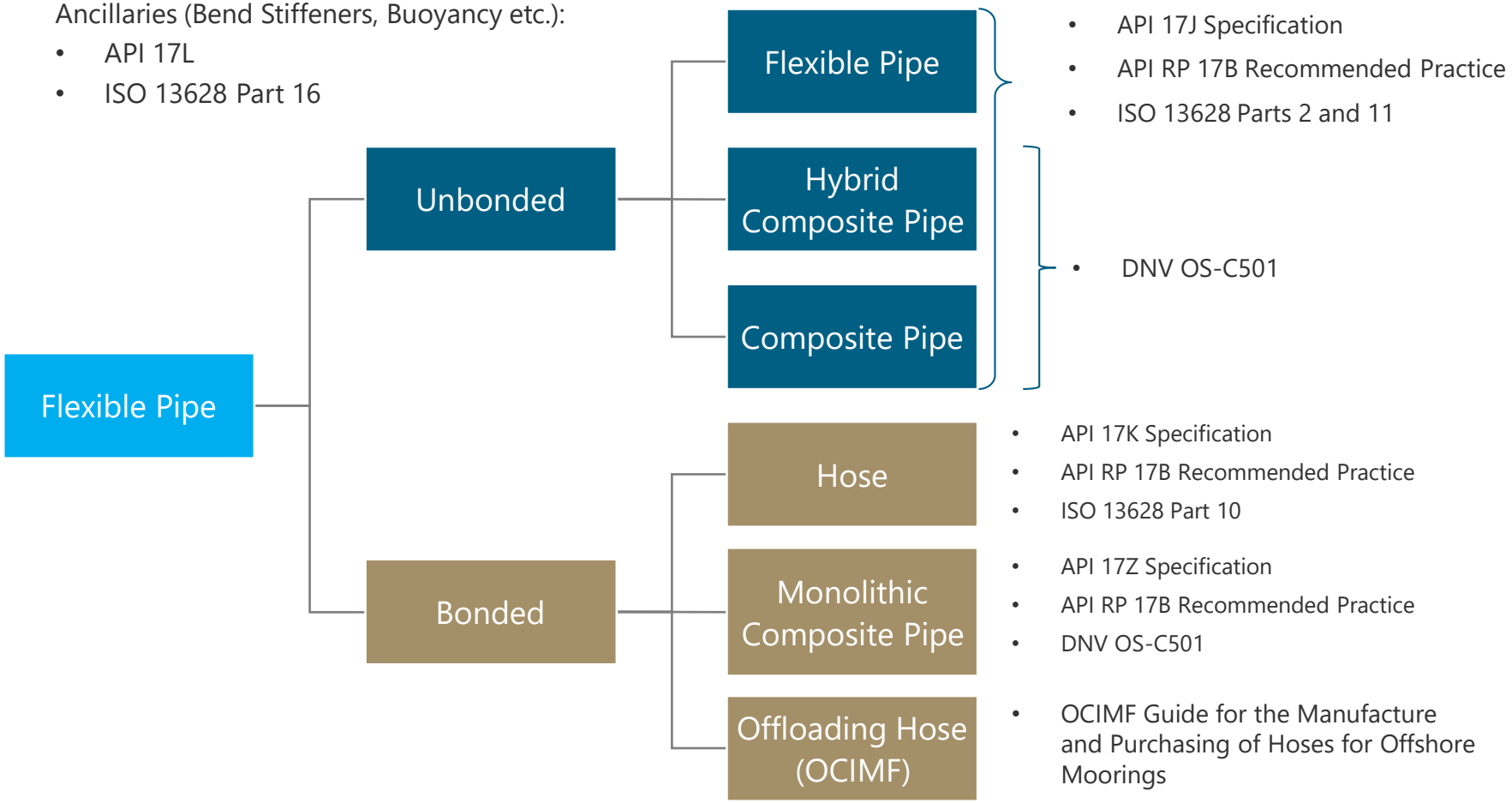

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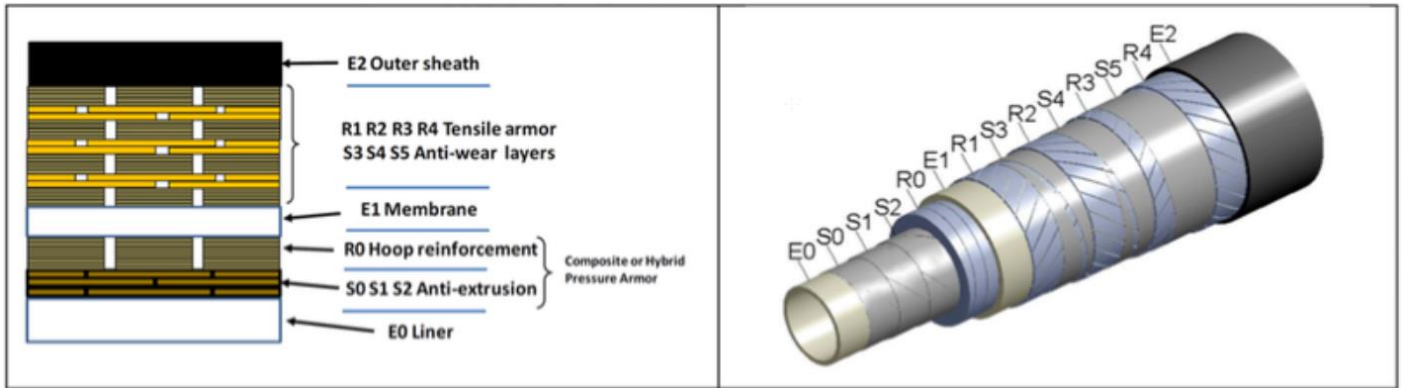
Composite Pipe

- Developed by DeepFlex
- Similar to Un-bonded Flexible Pipe
- All parts of made from Composites or Plastic instead of Steel

POSITIVES:

- No corrosion
- Improved Flow
- Great Fatigue Resistance
- Lightweight – Low H/O Weight
- Lightweight – Low Installation Weight



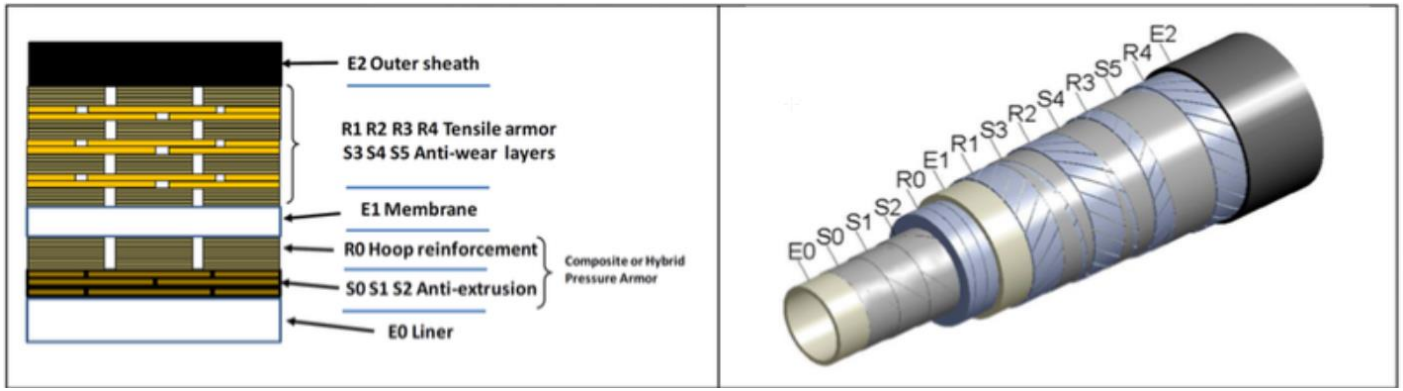
Deepflex Flexible Fiber Reinforced pipe for downline (Kalman, Yu, & Durr, 2014)

Composite Pipe

- Developed by DeepFlex
- Similar to Un-bonded Flexible Pipe
- All parts of made from Composites or Plastic instead of Steel

NEGATIVES:

- Very expensive materials
- Too Light – Unstable
- Difficult to inspect
- Limited Experience & track record in O & G



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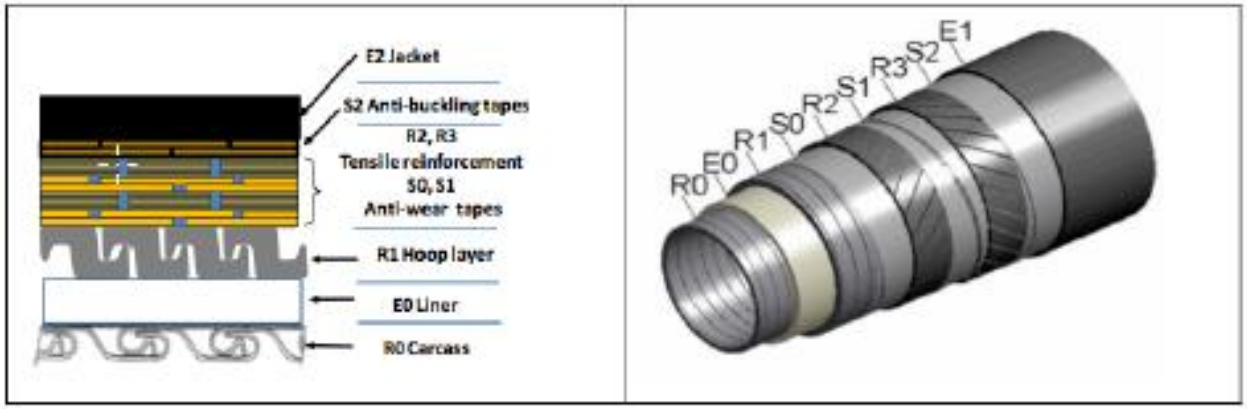
Hybrid Composite Pipe

- Pressure Containing Layers made from Stainless Steel
- Tensile Armour made from Fibre (Glass / Kevlar)
- Produced by DeepFlex & Technip

POSITIVES:

- Less novel components
- Good fatigue resistance
- 50% Reduction in hang-off weight, but still stable.
- Lightweight – low installation weight



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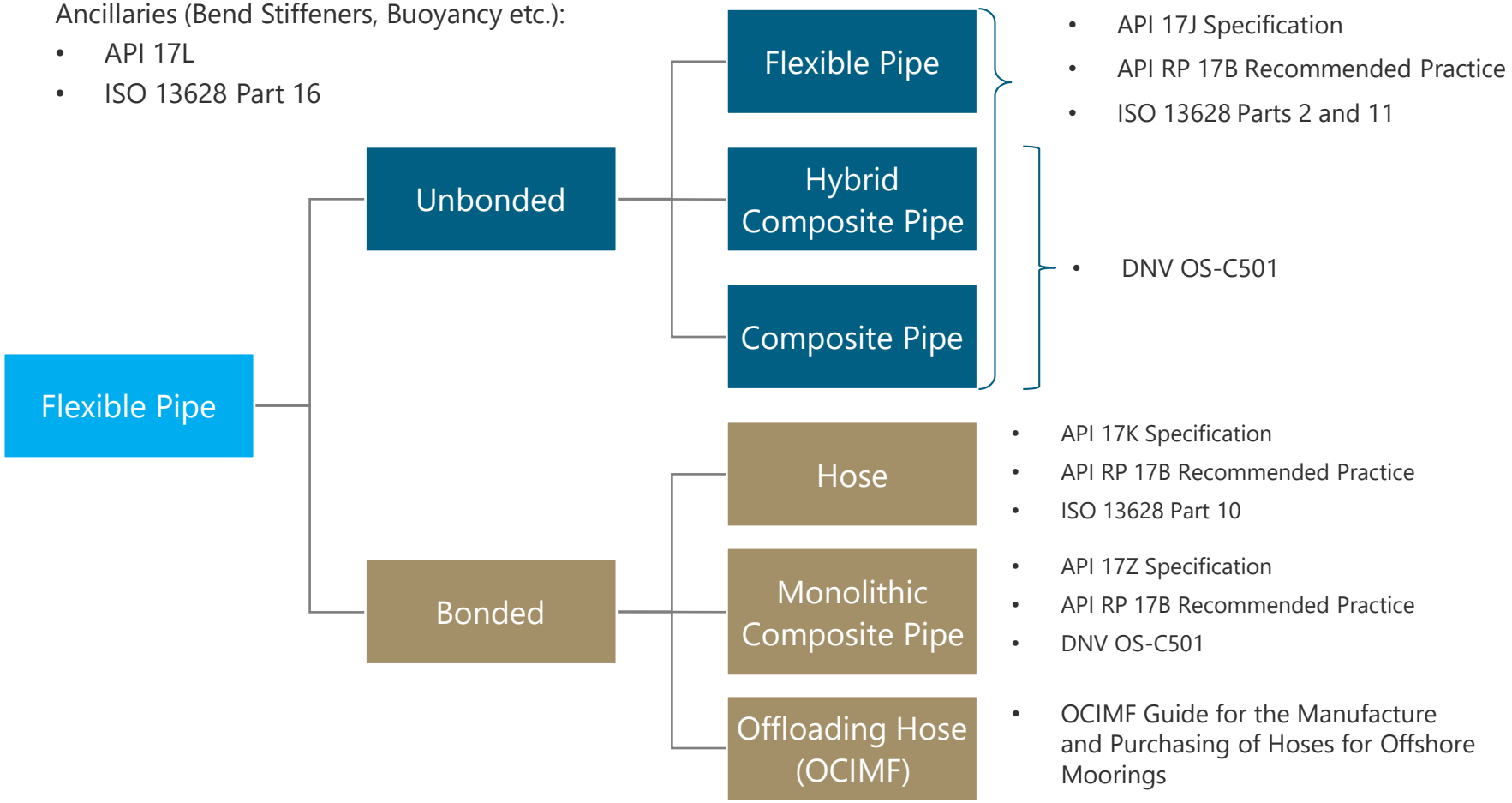

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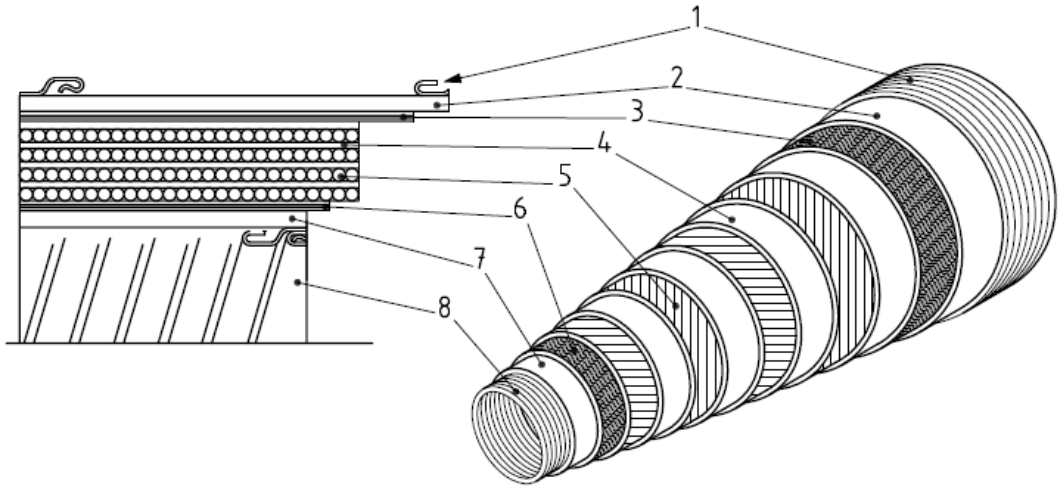
High Pressure Hose

- Steel and Rubber Layers Vulcanically Bonded
- Contain Pressure above 15 Bar
- Smaller Bore Applications than Flexible Pipe
- Produced by many manufacturers incl. Pirelli, Bridgestone, Manuli and Pirtek

POSITIVES:

- Cheaper than Unbonded pipe
- Standard Design



Key

1	outer wrap	5	reinforcement layer
2	cover	6	breaker layer
3	breaker layer	7	liner
4	cushion layer	8	carcass

Figure 1 — Typical bonded flexible pipe

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NEGATIVES:

- Limited Sizes and Pressures
- Limited collapse pressure
- Limited Lengths <400m (4")
- Shorter service life 2 - 5yrs

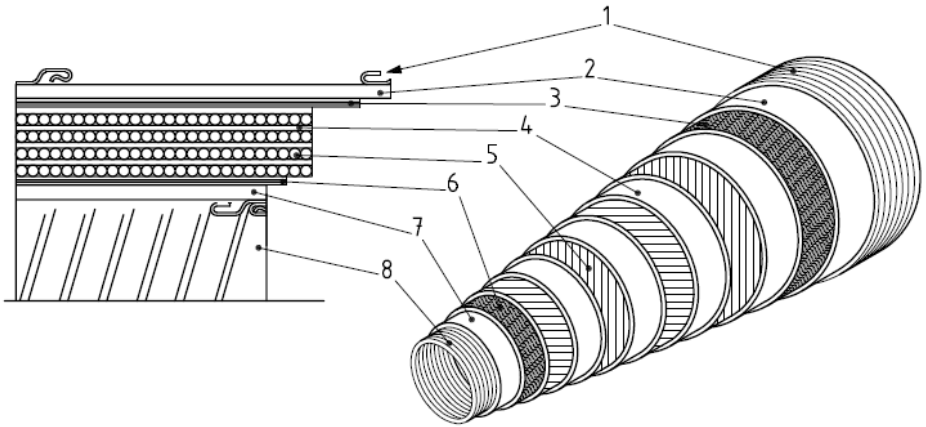

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Figure 1 — Typical bonded flexible pipe

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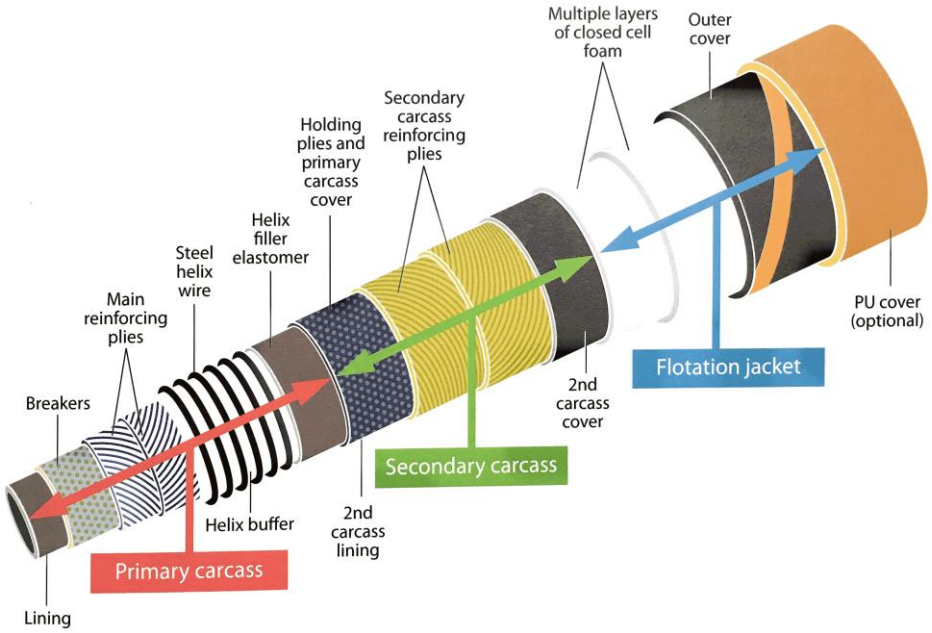
Offloading Hose (OCIMF)

- Steel and Rubber Layers Vulcanically Bonded
- Contain Pressure below 21 Bar
- Produced by manufacturers incl. Pirelli, Bridgestone, Yokohama
- Built up from multiple standard length of pipe

POSITIVES:

- Cheaper than Unbonded pipe
- Standard Design
- Extensive Track Record



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- Contain Pressure below 21 Bar
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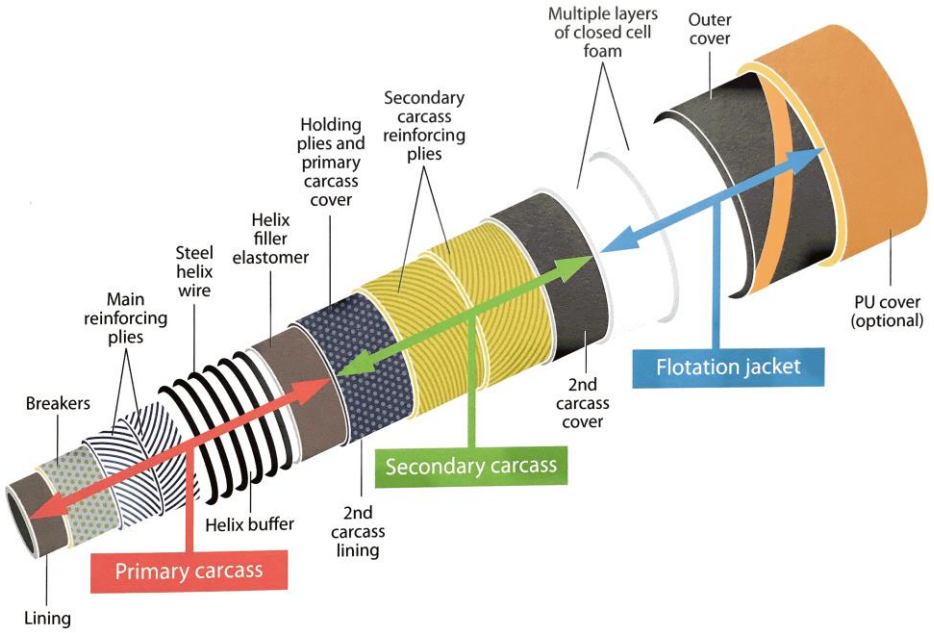
- Built up from multiple standard lengths of pipe

NEGATIVES:

- Limited to 21 Bar
- Bulky – Large OD / ID Ratio



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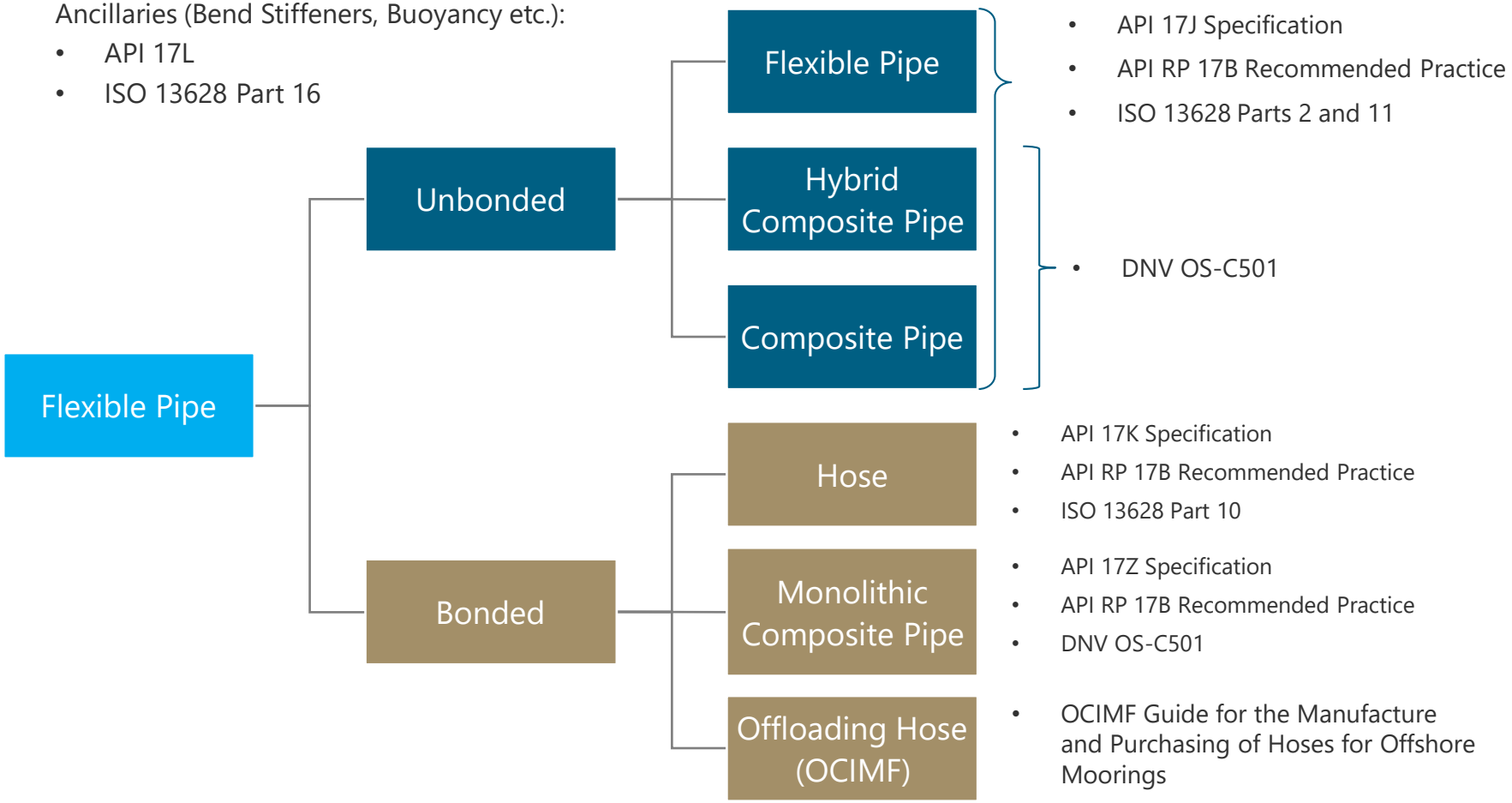

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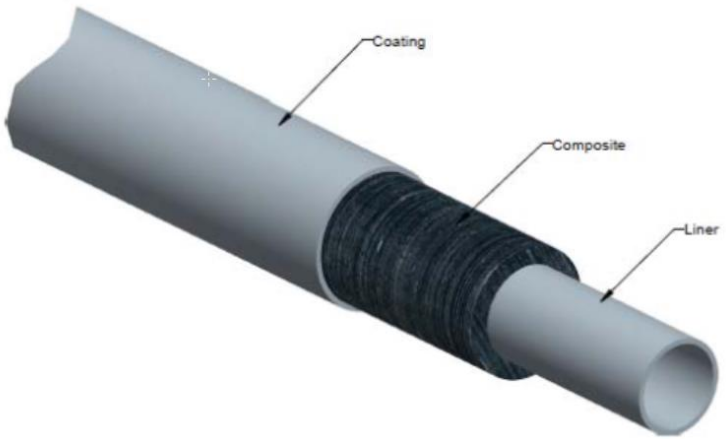
Monolithic Composite Pipe

- Supplied by Airborne, Magma or Longpipes
- 2 or 3 layers cooked together:
  - Thermoplastic Liner
  - Composite of Fibers
  - Coating (Airborne)

POSITIVES:

- No corrosion
- Improved Flow
- Superior Mechanical Properties
- Lightweight – Low H/O Weight
- Fast Manufacture



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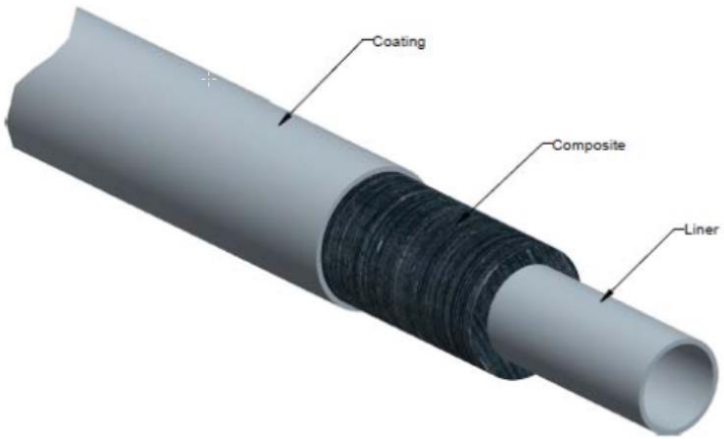
NEGATIVES:

- Very expensive materials
- Unstable due to light weight
- Limited experience and track record in O & G



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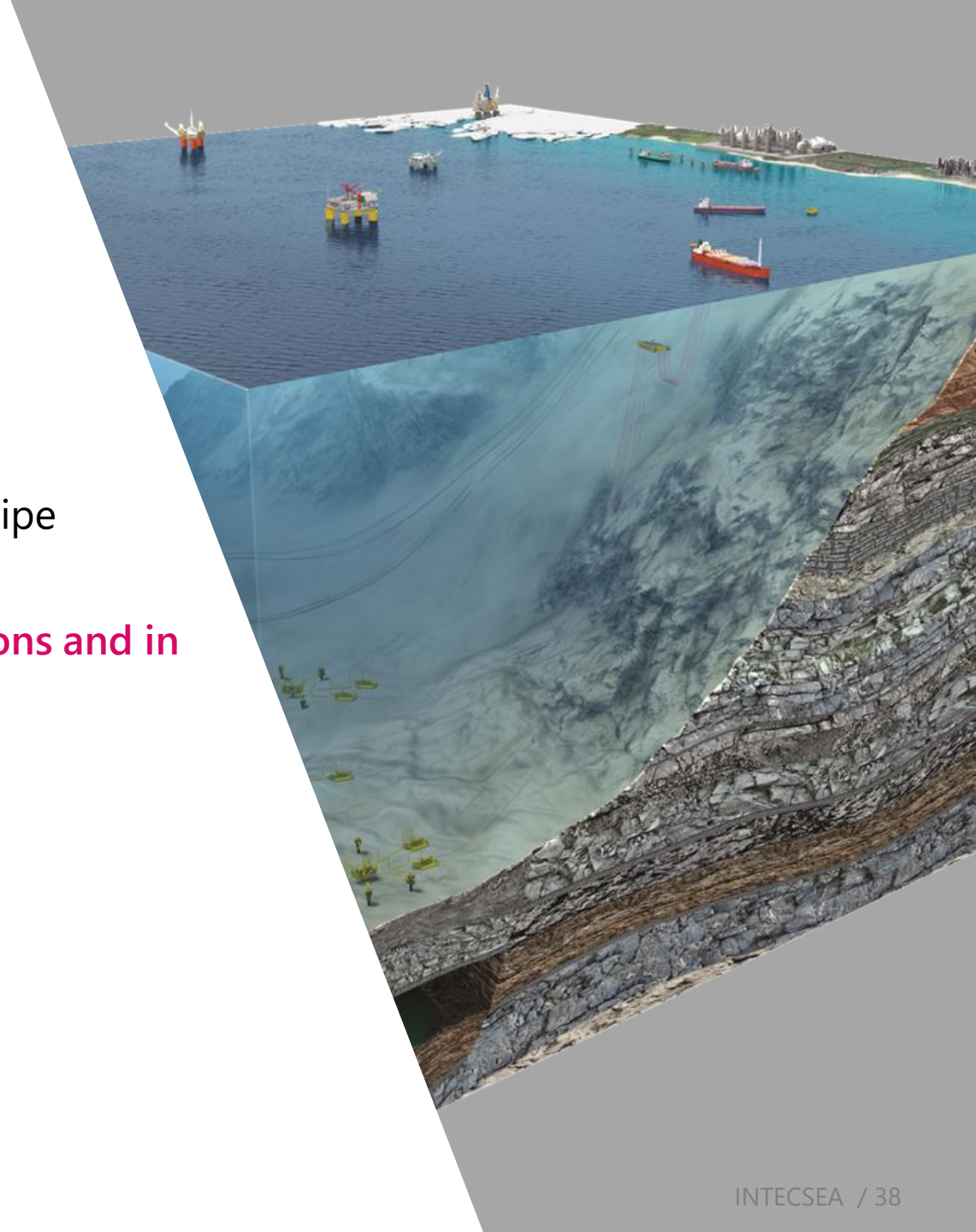
Agenda

- Rigid vs. Flexible Pipe
- Different Types of Flexible Pipe
- **Flexible Risers Configurations and in Australian Conditions**
- Flexible Riser Design



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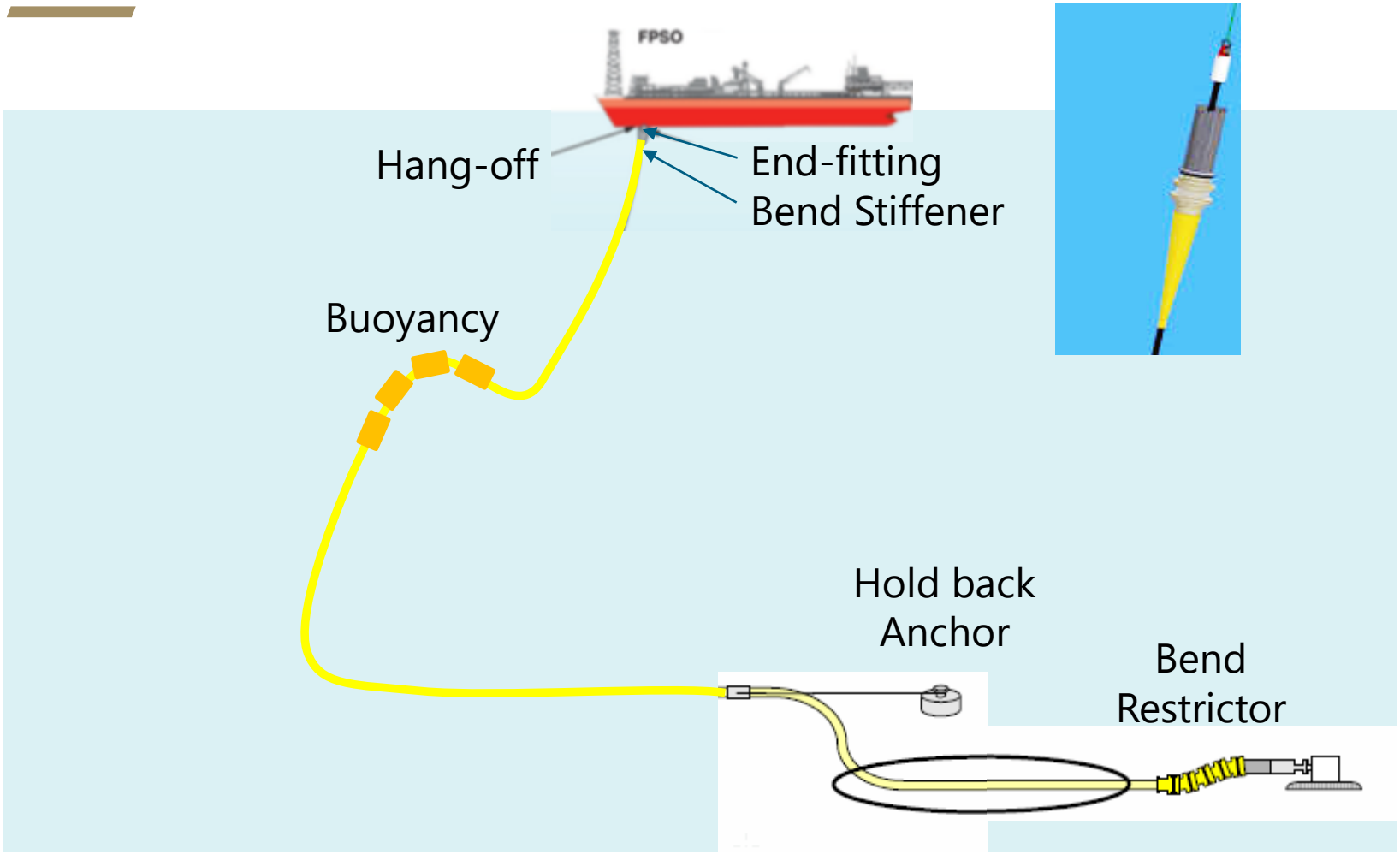
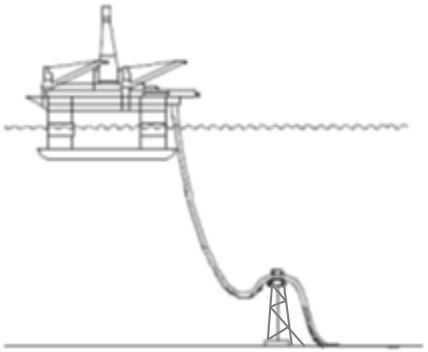
Typical Flexible Riser Components

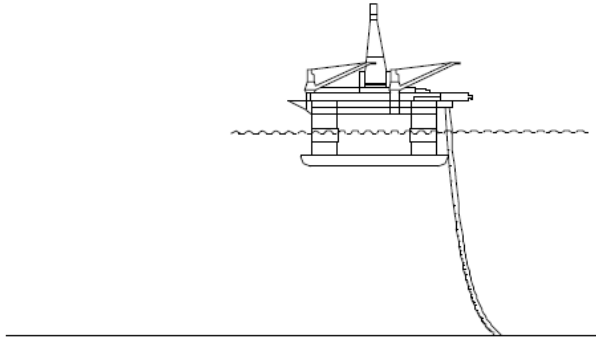


Flexible Riser Concepts

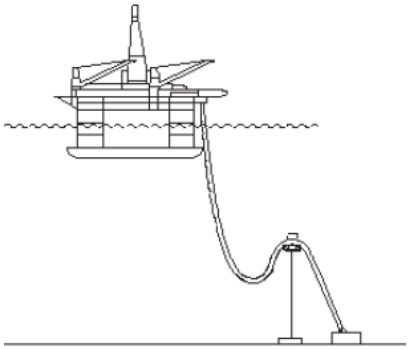
Standard Riser Configuration Options:

- Free Hanging Catenary
- Steep S
- Steep Wave
- Lazy Wave
- Lazy S
- Fixed S

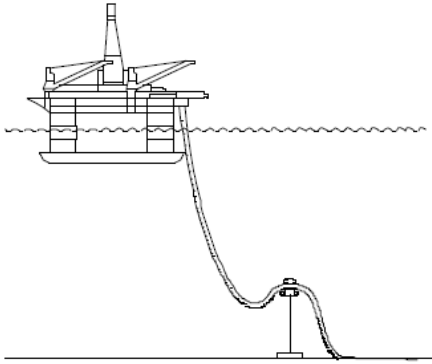




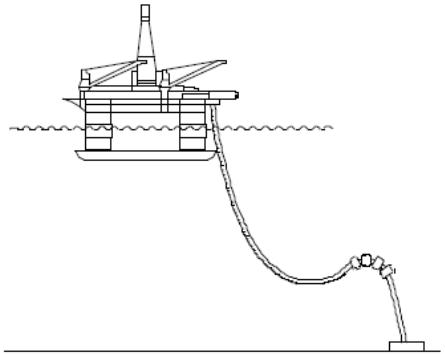
a) Free-hanging Catenary



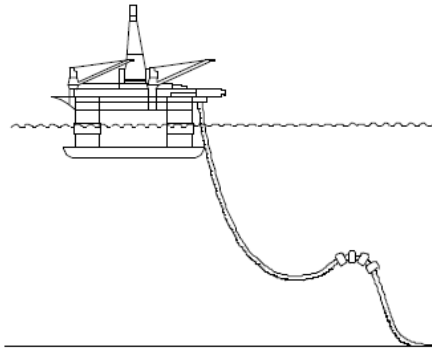
b) Steep-S



c) Lazy-S



d) Steep Wave



e) Lazy Wave

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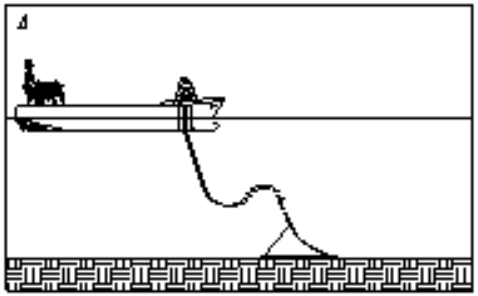
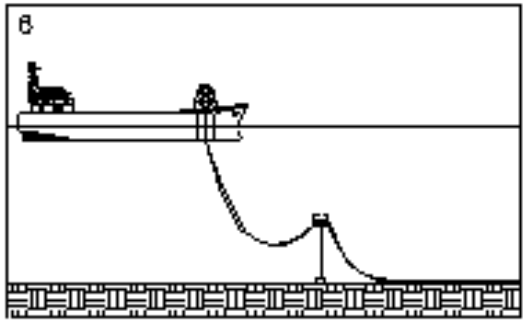
Flexible Riser Concepts

Options for big density variations or currents:

- Pliant Wave
- Lazy S Pliant
- Fixed S



PLIANT WAVE



LAZY S PLIANT ®

Flexible Risers – Configuration

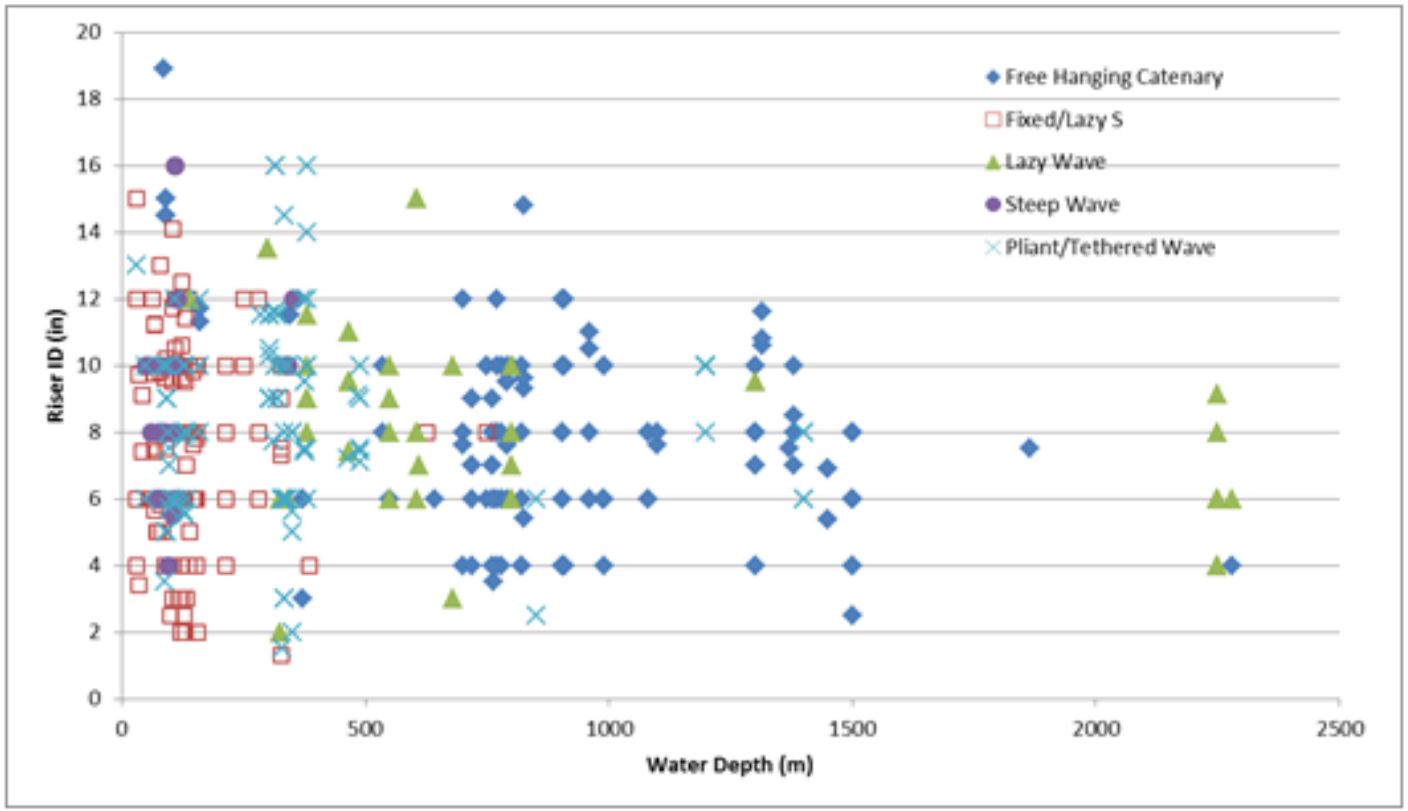


Figure 6-9 Configuration Type – Installed Systems (All Regions)

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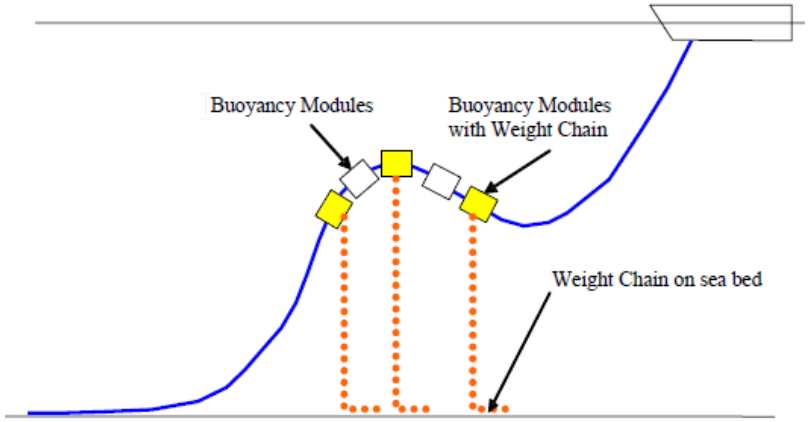
Risers in Australian Waters

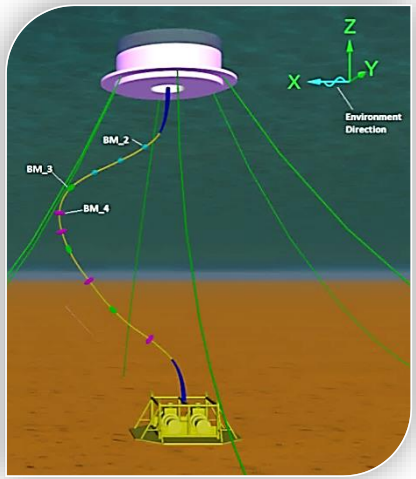
Vessel	Field	WD	NO	Configuration
FPSO Front Puffin	Puffin	70	3	Steep Wave
FPSO Cossack Pioneer	CWLH	76	6	Steep Wave
FPSO Montara Venture	Montara	83	6	Lazy or Pliant Wave
FPSO Four Rainbow	Woollybutt	100	12	Lazy S
FPSO Challis	Challis	106		Rigid SALRAM
FPSO Crystal Ocean	BMG	155	3	Lazy Wave
FPSO MODEC Venture	Mutineer Exeter	156	8	Lazy S
FPSO Pyrenees Venture	Pyrenees	250	15	Lazy S
FPSO Buffalo Venture	Buffalo	255	3	Pliant Wave
FPSO Ngujima-Yin	Vincent	340	4	Lazy Wave with Hold Back Clamp
Semi-submersible	Ichthys	340	27	Fixed S (Risers) Lazy Wave (Umbilical)
FPSO Ichthys	Ichthys	340	15	Lazy S (Risers)
FPSO Glas Dowr	Kitan	344	7	Pliant Wave
FPSO Ningaloo Vision	Van Gogh	380	5	Steep Wave (Risers) Lazy Wave (Umbilicals)
FPSO Northern Endeavour	Laminaria	380	6	Pliant Wave
FPSO Nganhurra	Enfield	550	6	Lazy Wave with Hold Back Clamp
FPSO Stybarrow Venture	Stybarrow	825	9	Lazy Wave with Hold Back Clamp

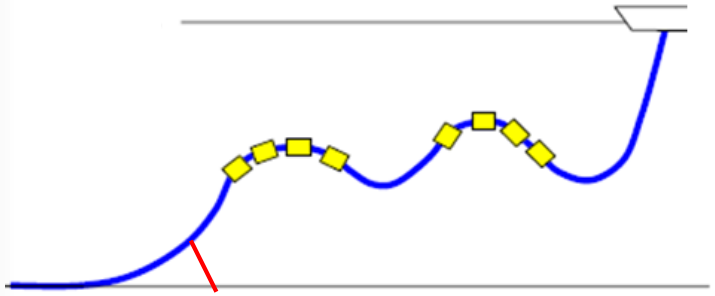
Shallow Water Riser Concept



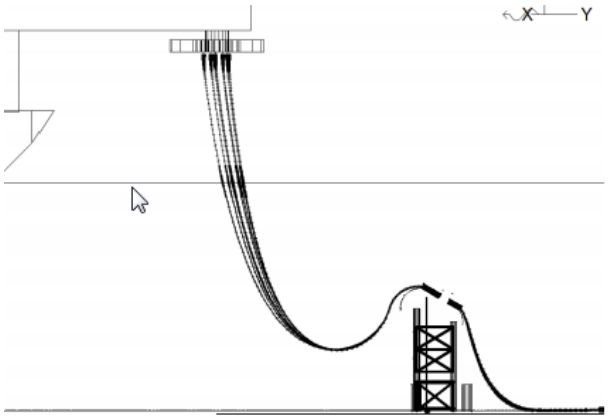
Shallow Water Options:

- Weight Added Wave
- Double Pliant Wave
- NOV's Fixed-S
- Chinese Lantern





Technip's Double Pliant Wave

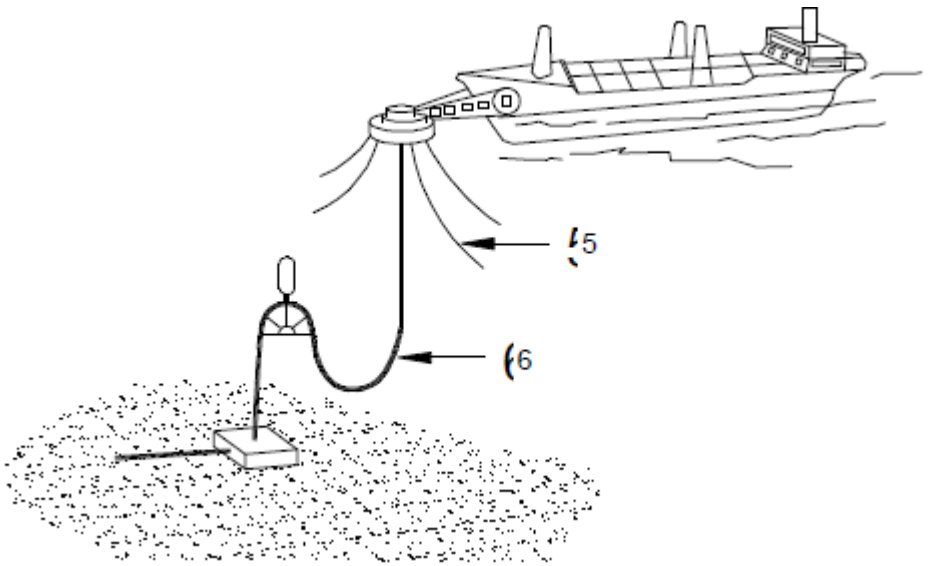


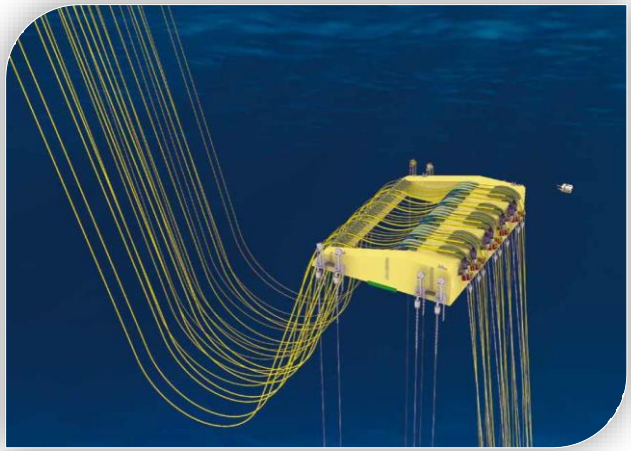
NOV's Fixed-S

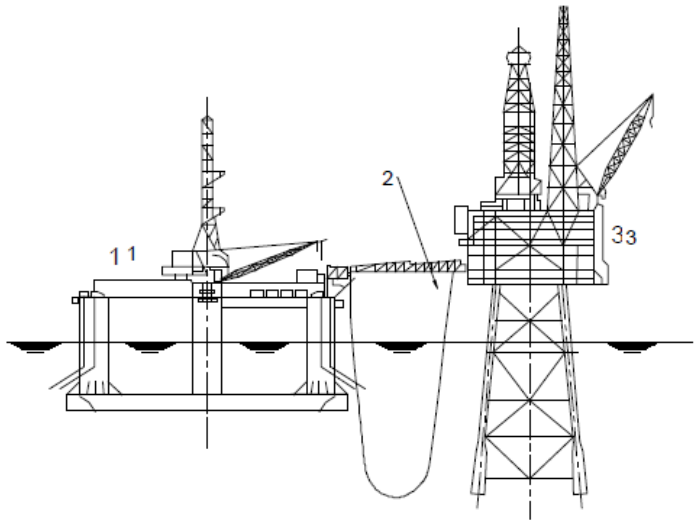
Other Dynamic Applications

Import/Export Facilities:

- CALM Buoys and other Terminal Buoys
- Offloading Buoys
- Fluid Transfer Lines
- Dynamic Jumpers at Topside Piping







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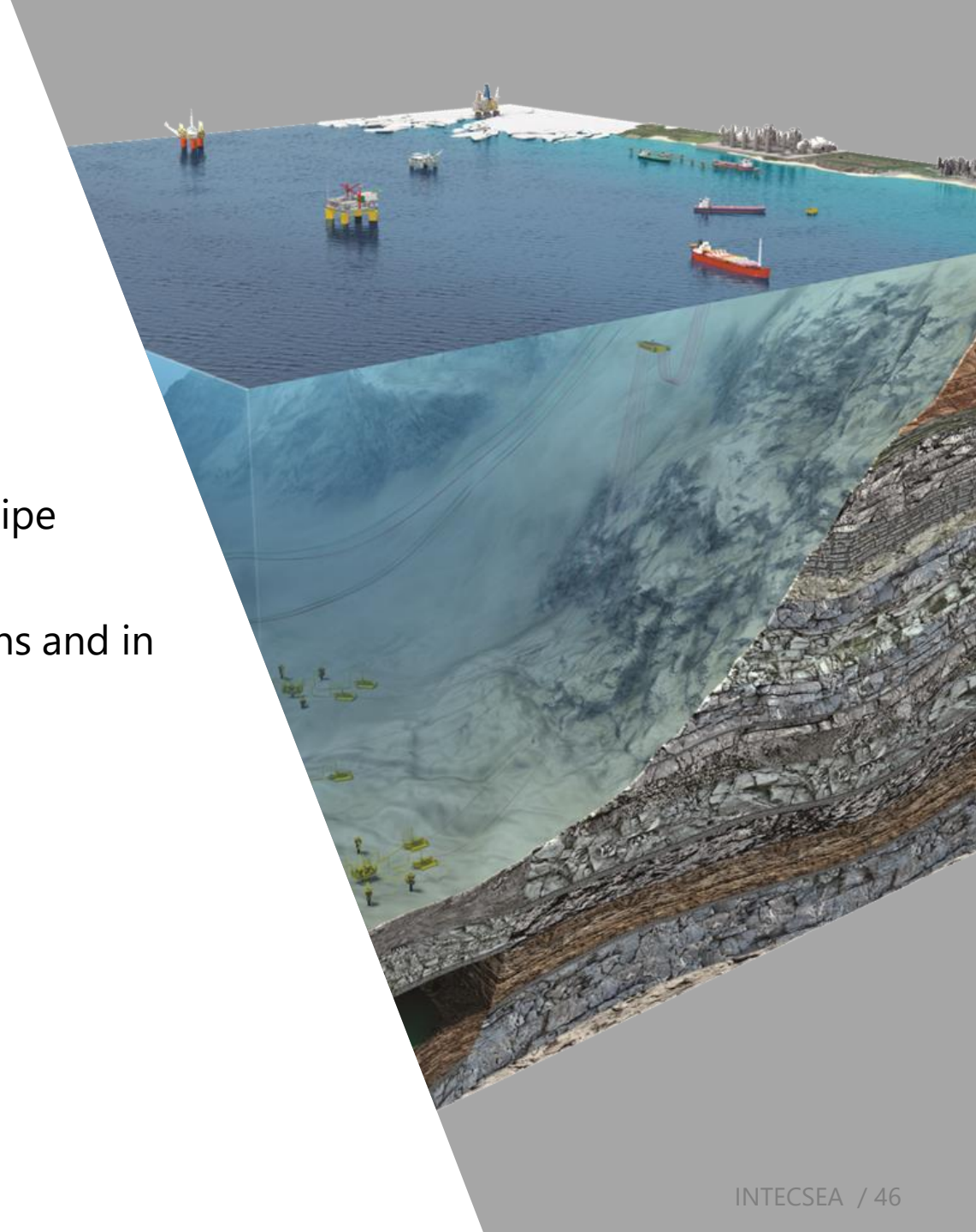
Agenda

- Rigid vs. Flexible Pipe
- Different Types of Flexible Pipe
- Flexible Risers Configurations and in Australian Conditions
- **Flexible Riser Design**



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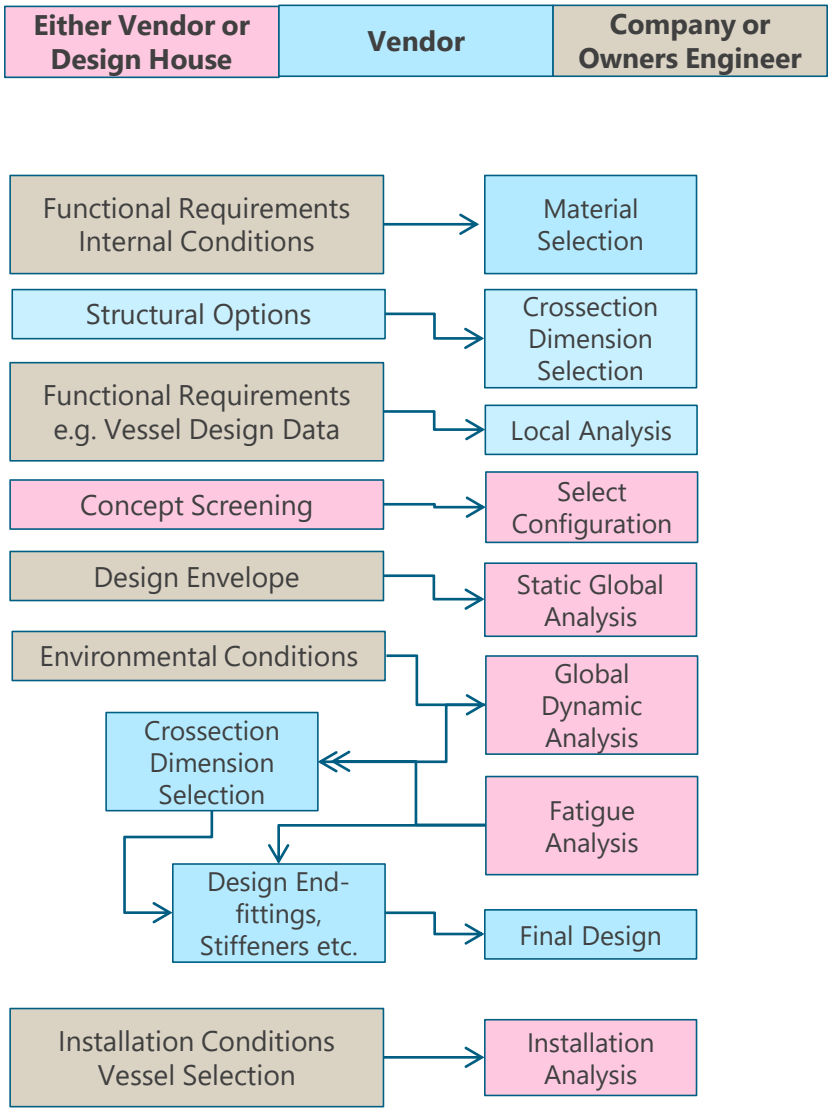
Riser Design Activities

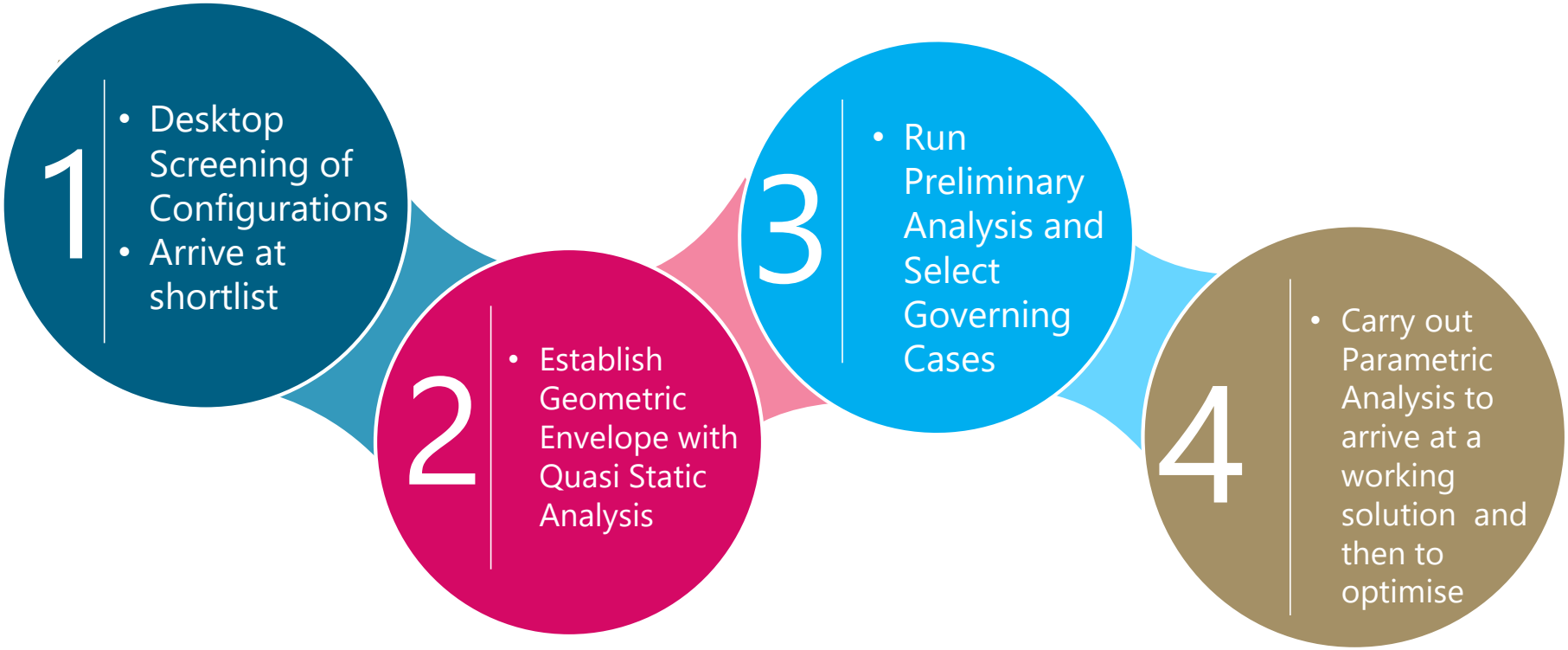
1. Diameter and contents conditions are based on flow assurance studies, which determine construction and material selection
2. The feasibility, concepts and specifications are developed.
3. Pipe Local Cross-Section Analysis, detailed configurations design performed by Flexible Vendors

Other design tasks include:

- Design of Ancillary components (e.g. buoyancy, bend stiffeners, bend restrictors)
- Design of End Terminations and Connections



Typical Configuration Design Sequence



Concept Screening

Weight	Configurations	Free Hanging Catenary	Lazy – S	Steep – S	Lazy Wave	Steep Wave	Fixed – S	Chinese Lantern
	Assessment Criteria:							
	Working Ranges:							
3	Feasibility	-1	0	0	1	2	-2	-3
3	Distance to Touchdown	2	0	1	-2	-1	1	
1	Clashing	2	1	1	-1	-2	2	
3	Offset Range	-2	1	1	2	2	-1	
1	Spacing Requirements at H/O	1	1	1	-2	-2	2	
1	Seabed Spread	0	-1	-1	-2	-2	2	
0.5	Riser Weight	0	0	0	-2	-1	2	
0.5	Riser Bend Stiffness	-1	-1	-1	0	-1	0	
1	Geometric Tolerances	1	-2	-2	2	1	-1	
	Sub Total	2	-1	0	-4	-4	5	-3
	Sub Total inc. Weight	0.5	1.5	4.5	-1	3	0	-9
	Global Considerations:							
3	Safety (Installation, Inspection)	0	-1	-1	-1	-1	-1	
3	Dropped Object Vulnerability	1	-1	-1	0	0	0	
3	Reliability (Leak Paths, Corrosion etc.)	1	-1	0	-1	-1	1	
1	Cost	2	-2	-1	-2	-1	-1	
2	Installability	2	-1	-1	0	0	-2	
2	Schedule (Lead Time & Installation Time)	1	-1	-1	0	0	-2	
3	Proven Technology	-1	1	-1	2	2	1	
2	Flow Assurance & Operability	1	0	0	0	0	0	
1	Expandability	0	-1	-1	0	0	-1	
2	Ease of Riser Replacement	1	-1	-1	0	0	1	
1	Foundations (Size and Complexity)	1	-2	-2	0	-1	-2	
2	Simplicity	2	-2	-2	-1	-1	-2	
1	Commonality (Interchangeable Parts)	1	0	0	-1	-1	1	
0.5	Ease of Inspection	1	-2	-2	0	-1	-2	
0.5	Ease of Repair	0	-2	-2	-1	-1	0	
	Sub Total	13	-16	-16	-5	-6	-9	0
	Sub Total inc. Weight	21.5	-23	-25	-5.5	-6	-11	0
	Total inc. Weight	22	-21.5	-20.5	-6.5	-3	-11	-9

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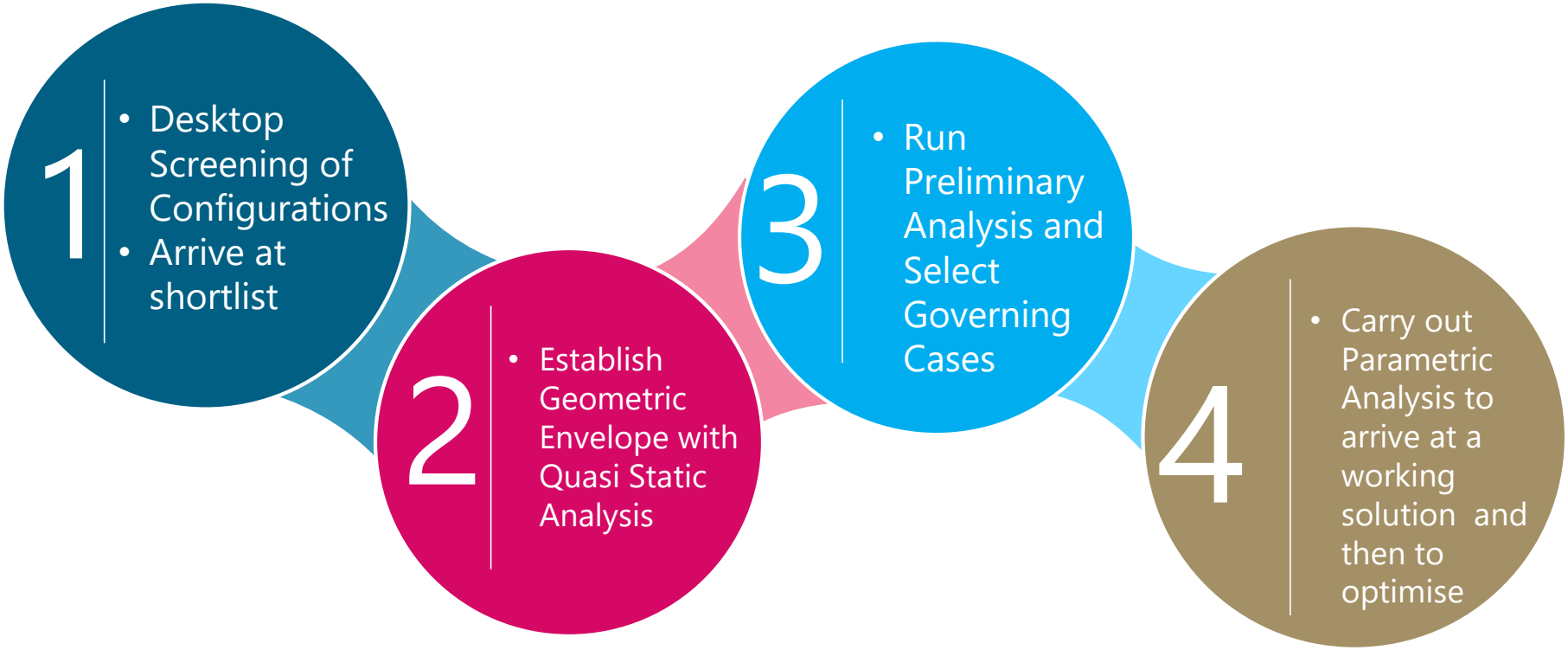
Typical Configuration Design Sequence



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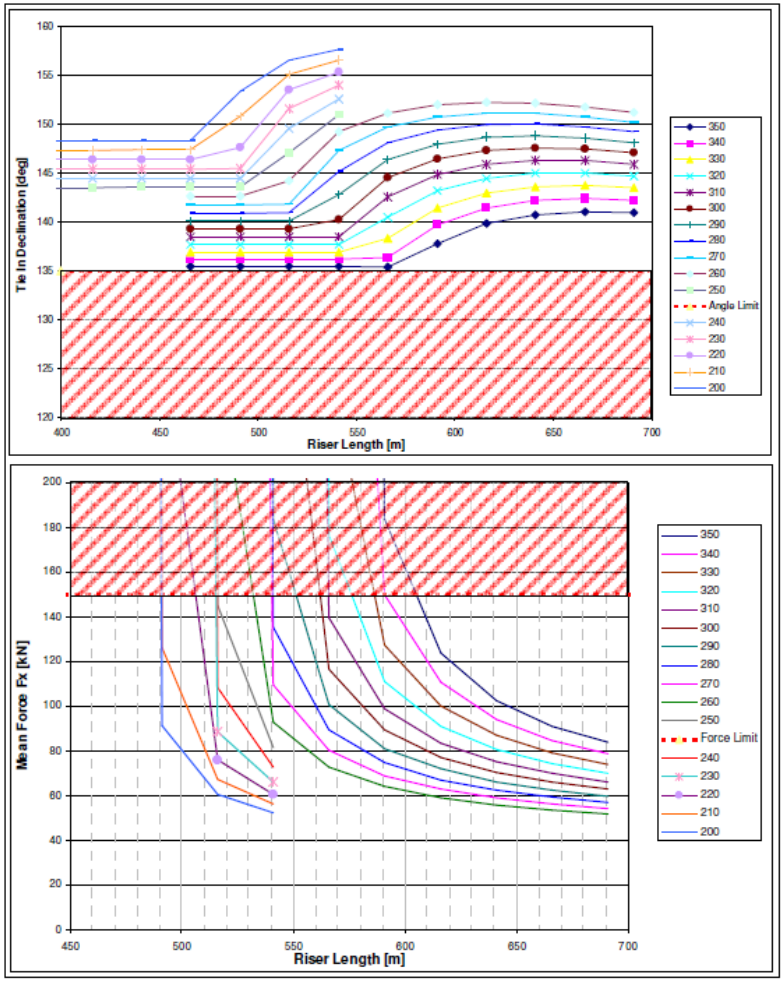
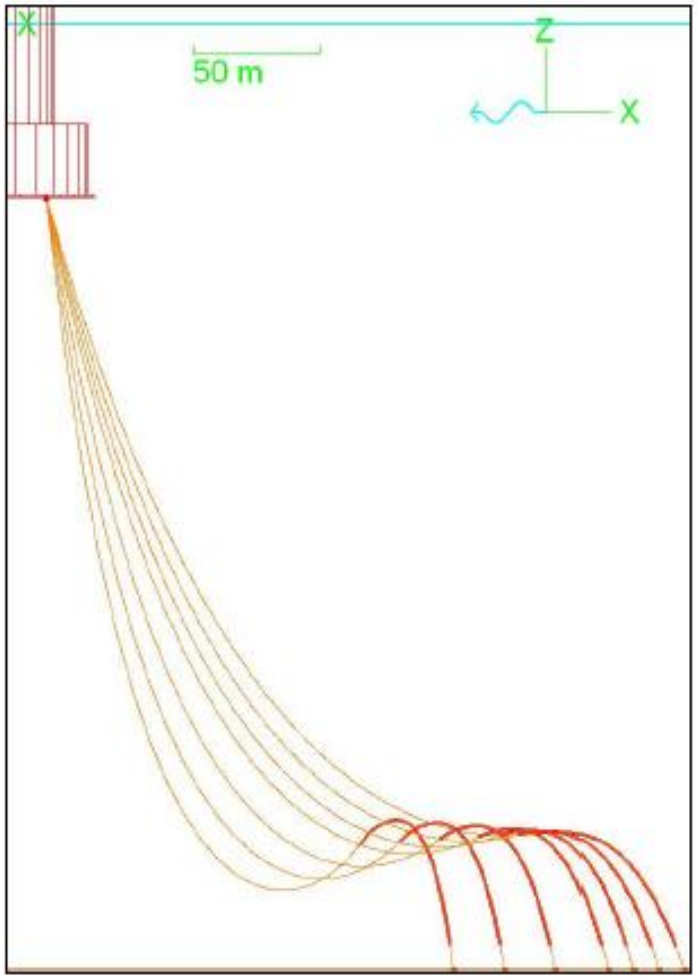
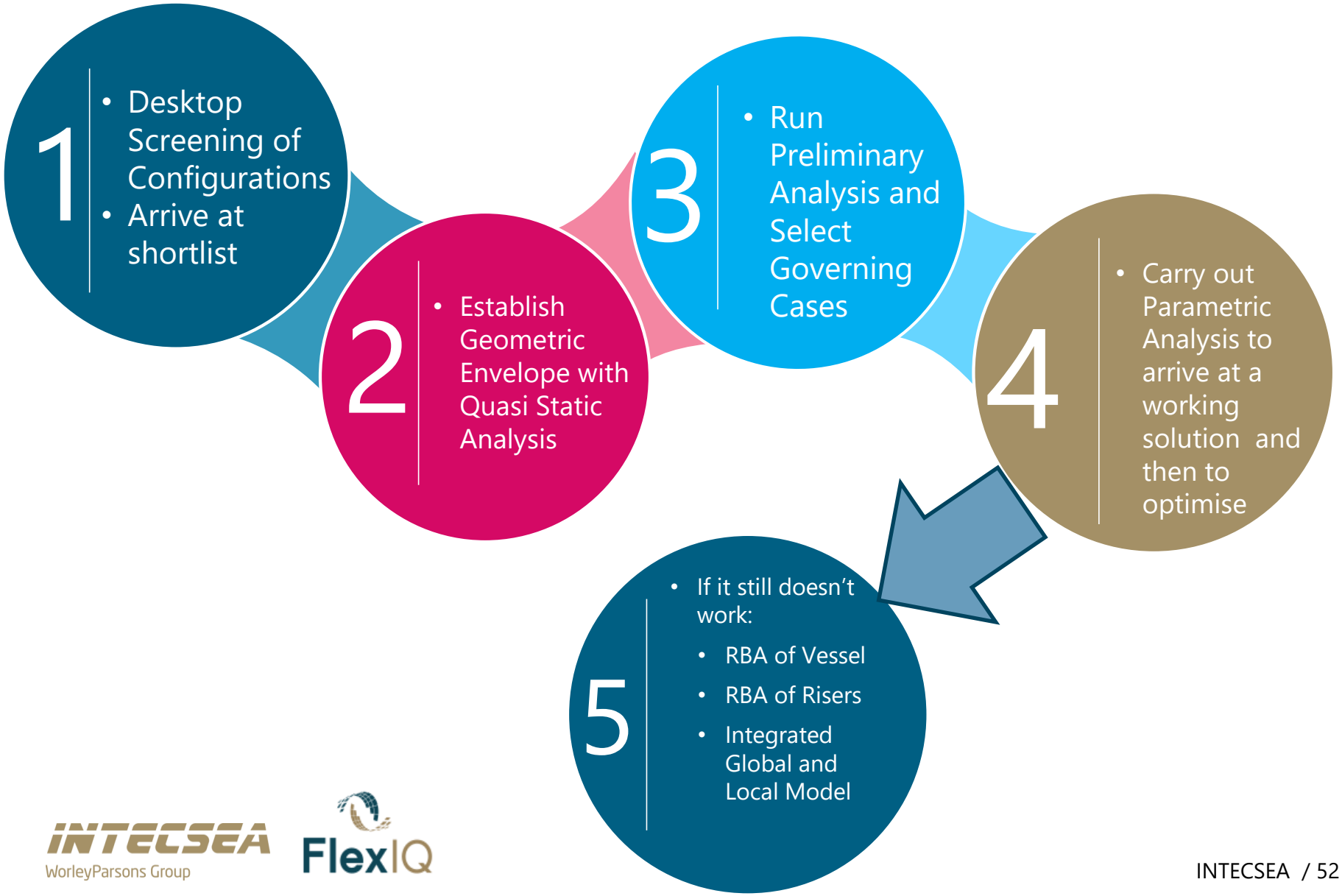
Parametric Analysis





Typical Configuration Design Sequence



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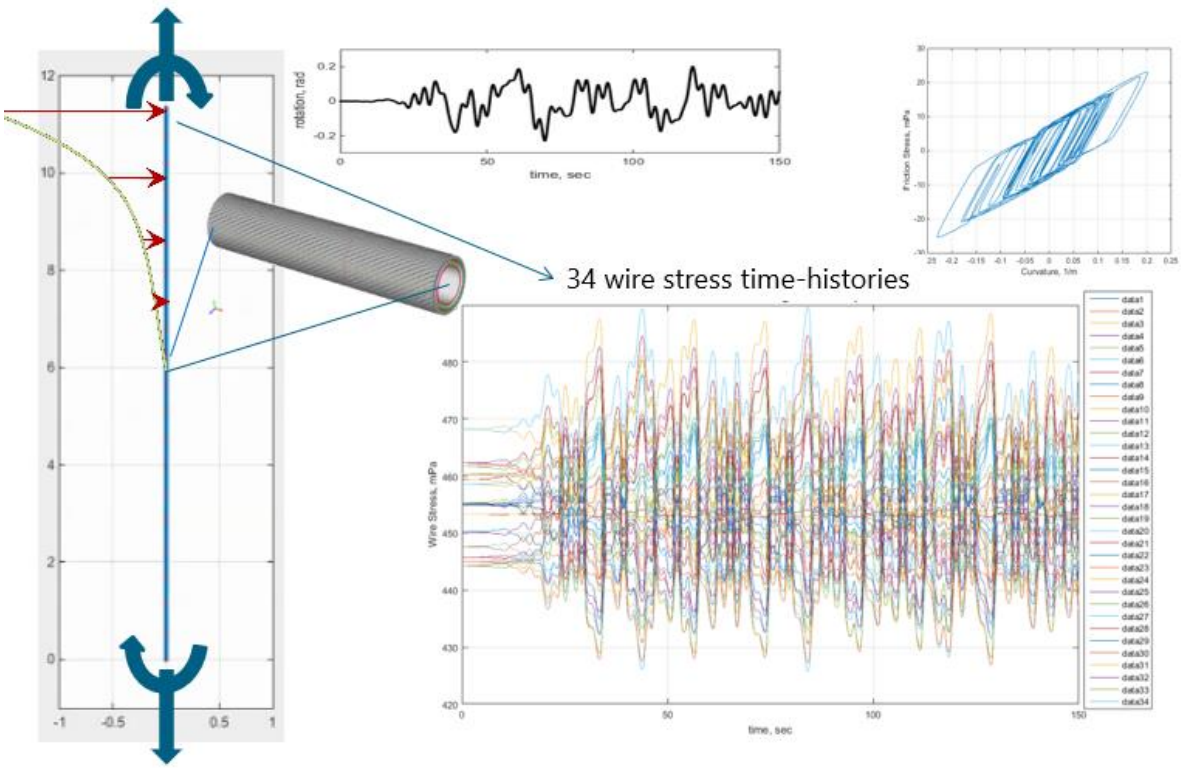
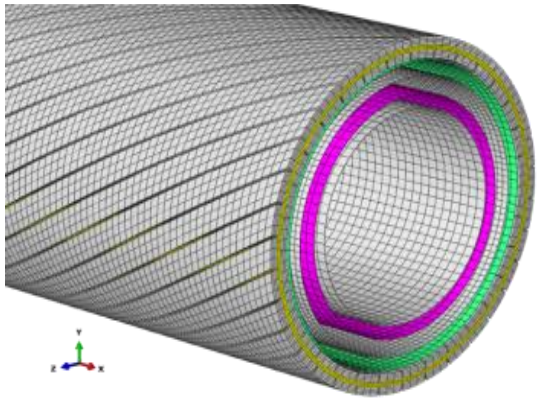
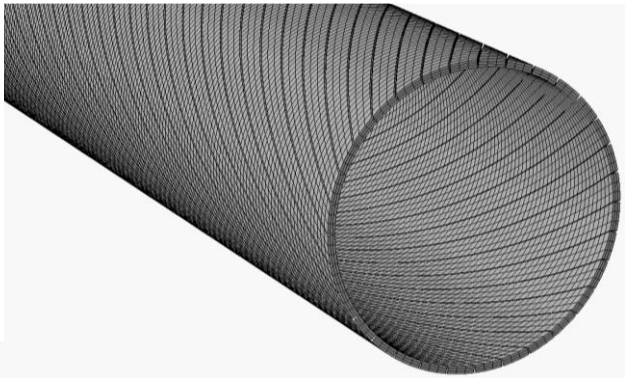
Global Local Model

20 pitch (12m) riser simulation with 80 million DoF using FLEXAS™





INTECSEA's high fidelity FEM
with 3D armour wires



armour wire kinematics
in axial extension

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