USP

Course on Flexible Pipes

Introduction to Unbonded Flexible Pipe Design & Manufacturing

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Course Outline

1.What are Flexible Pipes Used For? What is a Flexible Pipe?

- I. Flexible Pipe Layers & Construction
- II. Key Design Considerations
- III. Main Ancillaries
- IV. Main Flexible Pipe Standards and Documentation

2.Flexible Pipes Layer Function and Materials

3.Flexible Pipes Design

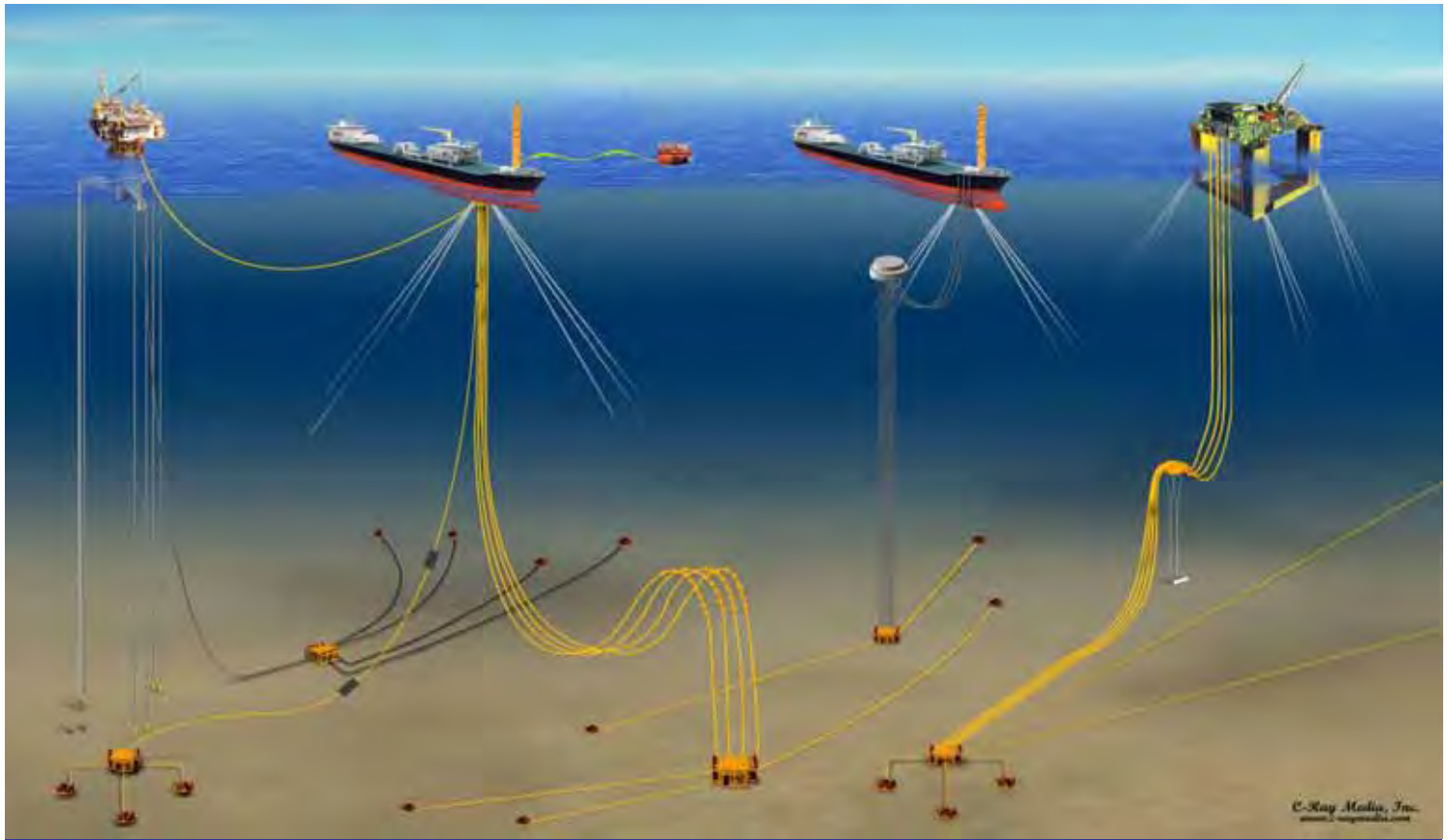
- I. Design Verification Flowcharts (*)
- II. Preliminary Design, Fluid Compatibility & Collapse & Local Stress
- III. Global FEA analysis
- IV. Bird Cage Local Analysis
- V. Bending Stiffener and Pipe Fatigue Local Analysis
- VI. Pipe and End Fitting Final Local Analysis

4.Flexible Pipes Layers Raw Material Qualification

5.Flexible Pipes Layers Manufacturing Process & Pipe Completion & FAT & Load Out

6.Flexible Pipes Prototype Tests

What are Flexible Pipes Used For?



Designed to have the strength and durability associated with rigid steel pipes, flexible systems are often the only solution for risers in dynamic environments

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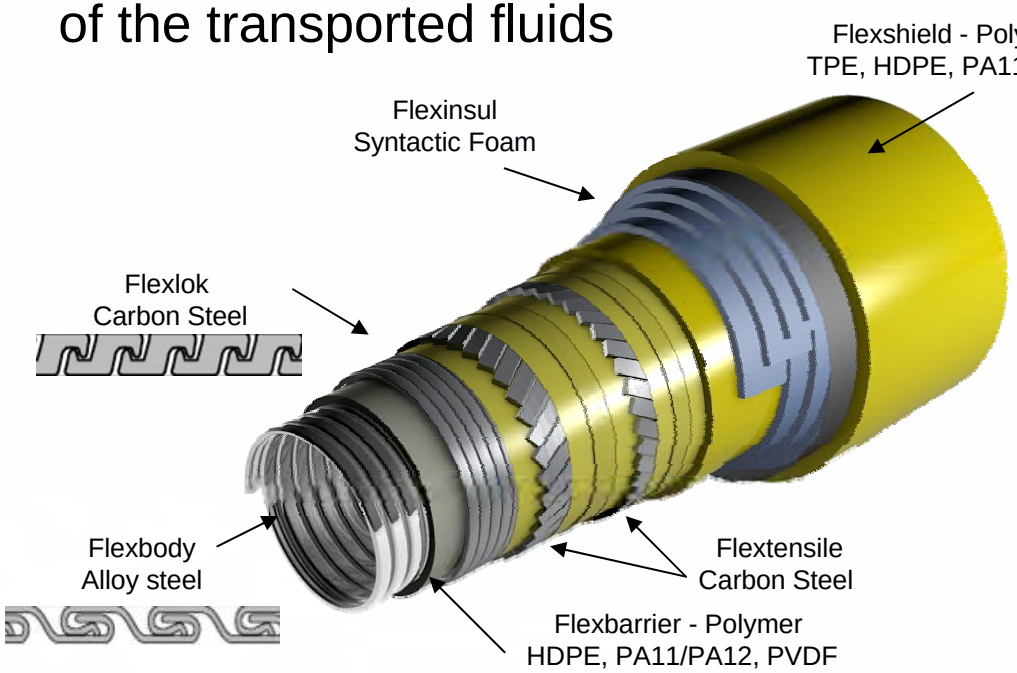
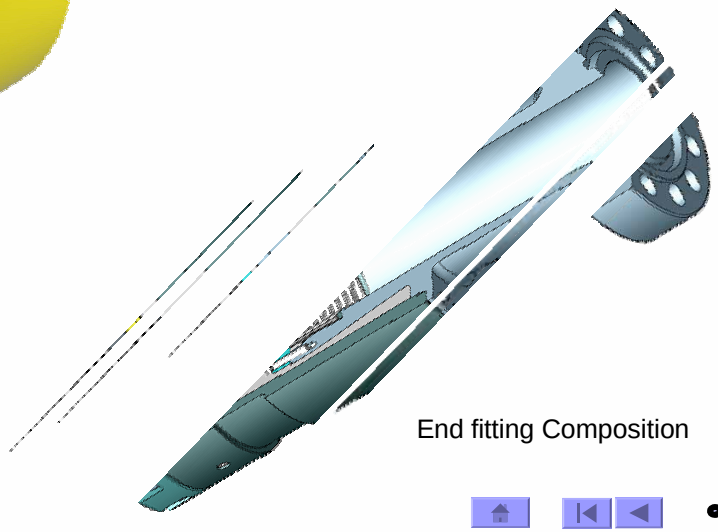
What is a Flexible Pipe?

- Unbonded flexible pipes consist of concentric layers of metallic wires, tapes and extruded polymers designed to form a structure that addresses the specific environmental requirements and characteristics of the transported fluids

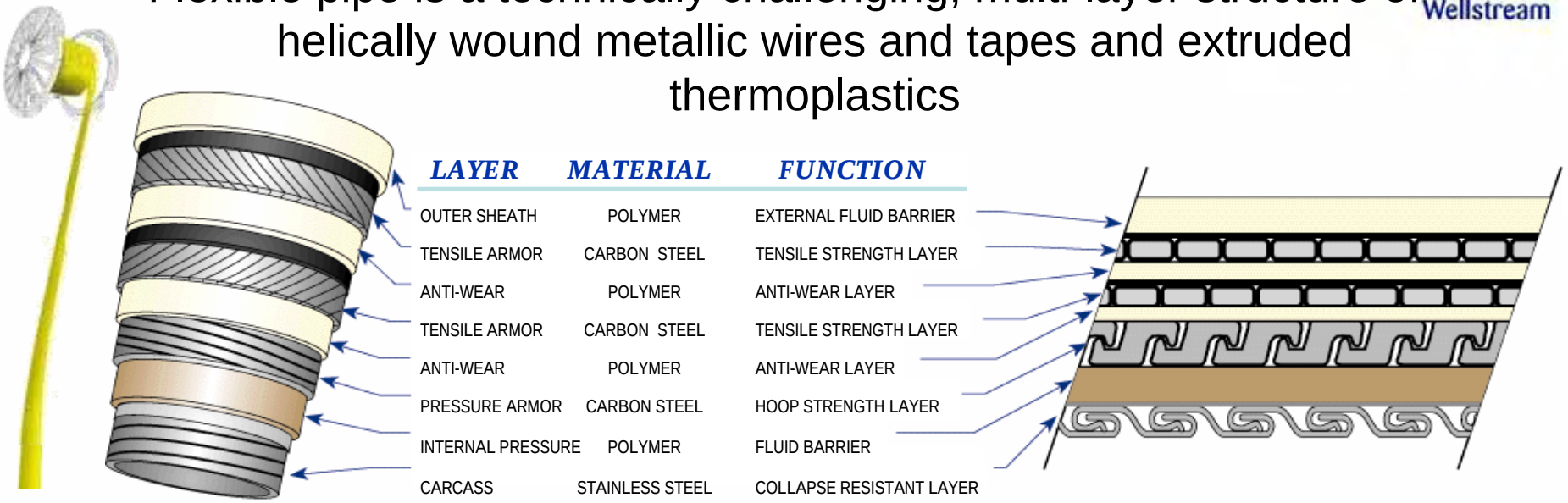




End fitting Composition

Flexible Pipe Construction

Flexible pipe is a technically challenging, multi-layer structure of helically wound metallic wires and tapes and extruded thermoplastics



LAYER	MATERIAL	FUNCTION
OUTER SHEATH	POLYMER	EXTERNAL FLUID BARRIER
TENSILE ARMOR	CARBON STEEL	TENSILE STRENGTH LAYER
ANTI-WEAR	POLYMER	ANTI-WEAR LAYER
TENSILE ARMOR	CARBON STEEL	TENSILE STRENGTH LAYER
ANTI-WEAR	POLYMER	ANTI-WEAR LAYER
PRESSURE ARMOR	CARBON STEEL	HOOP STRENGTH LAYER
INTERNAL PRESSURE	POLYMER	FLUID BARRIER
CARCASS	STAINLESS STEEL	COLLAPSE RESISTANT LAYER

- **Regarding Aplication**
  - Risers : Static or Dynamic Application
  - Flowlines : Static Application
- **Regarding the Internal Fluid**
  - Smooth bore : Water Injection
  - Rough Bore : Oil and Gas
- **Regarding H2S presence**
  - Sweet service : with H2S
  - Sour service : without H2S

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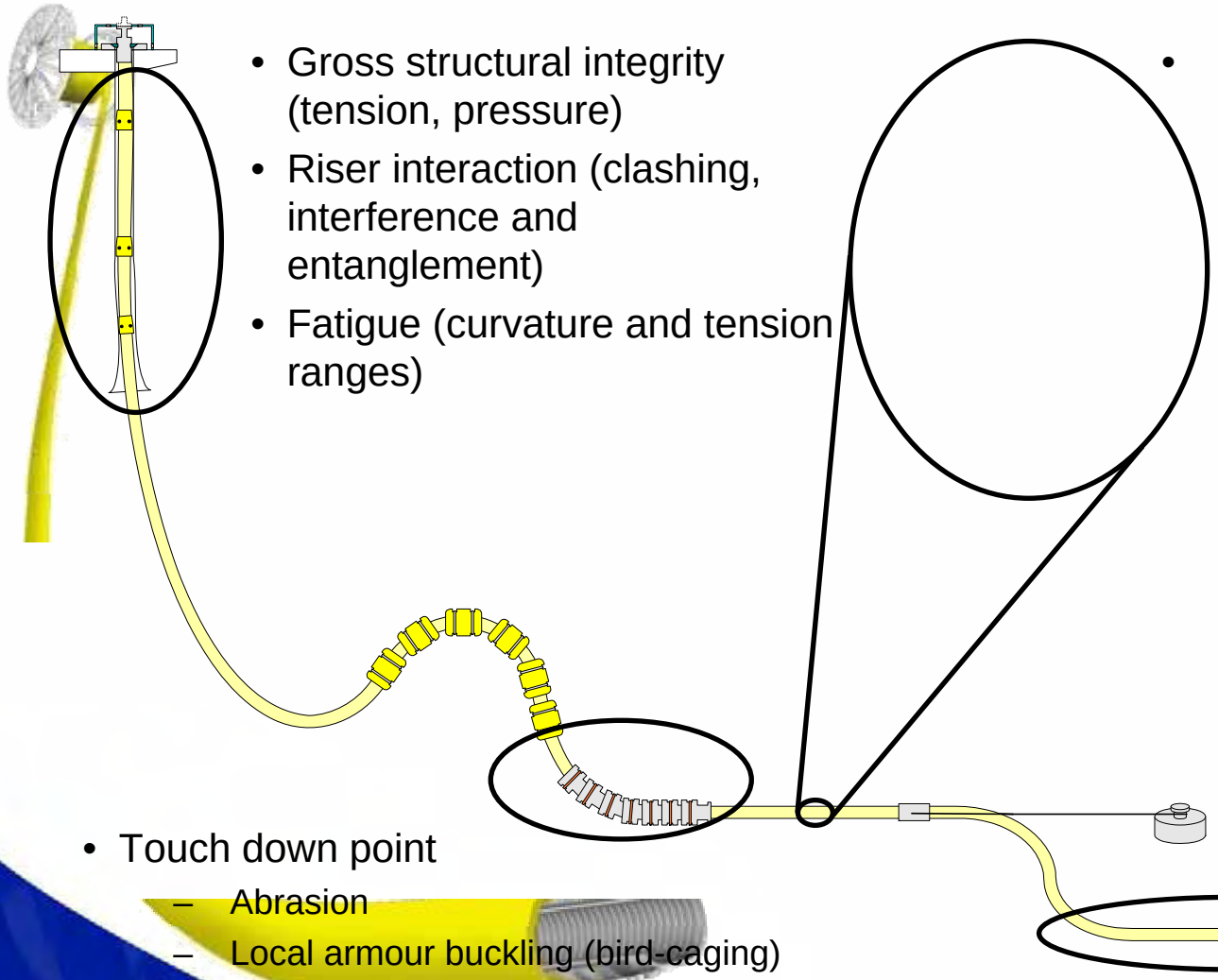
Key Design Considerations



- Gross structural integrity (tension, pressure)
- Riser interaction (clashing, interference and entanglement)
- Fatigue (curvature and tension ranges)

- Local analysis
  - Gap span
  - Flexlok stress analysis
  - Corrosion fatigue
  - Material compatibility

- Collapse
- On-Bottom Stability
- Upheaval Buckling

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

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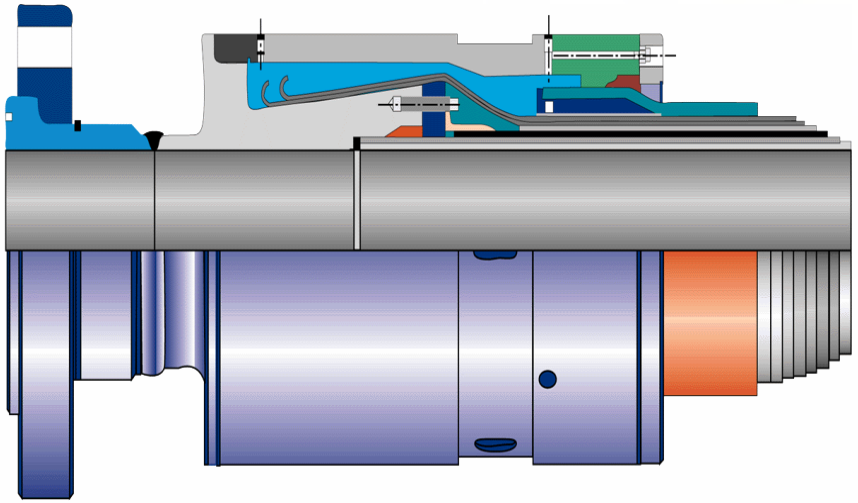
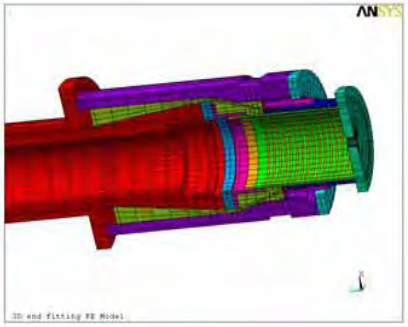
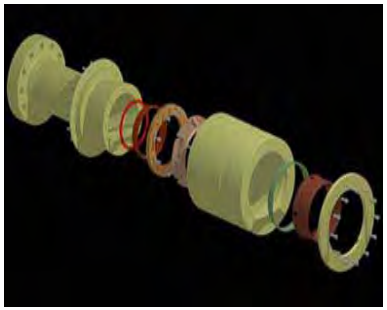
Main Ancillaries
End Fittings

- End fittings are custom designed for each flexible pipe structure
- Terminations can be any design – API/ANSI flanges, hubs, welded, or other
- Stronger than pipe in burst and failure tension
- Most common structural material is AISI 4130 low alloy steel
- Common coatings include electrolysis nickel plating, and various epoxies.
- Assembly is a manual process







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Main Ancillaries
IP - Anode Clamp Design

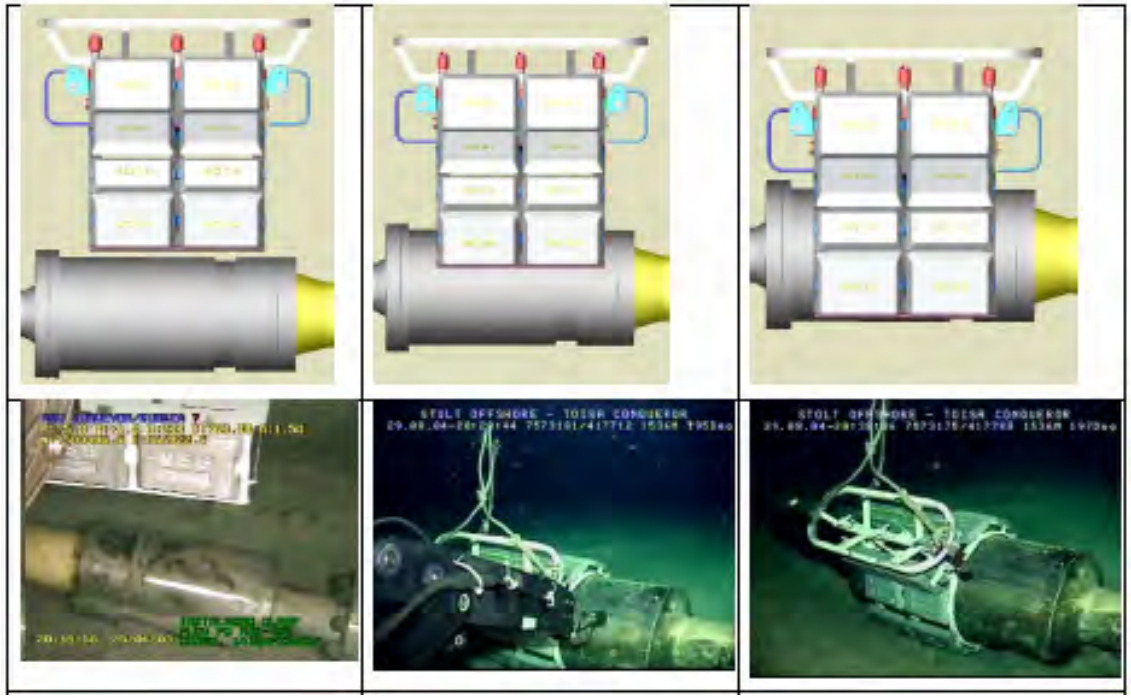
Anode Clamp Design

Used to protect flexible pipe end fittings against corrosion

Installation Sequence

Before the installation, the ROV clean the Endfitting surface using a steel brush to guarantee a better electrical contact of the Anode Clamp.

After that, the installation process is illustrated in the figure aside.



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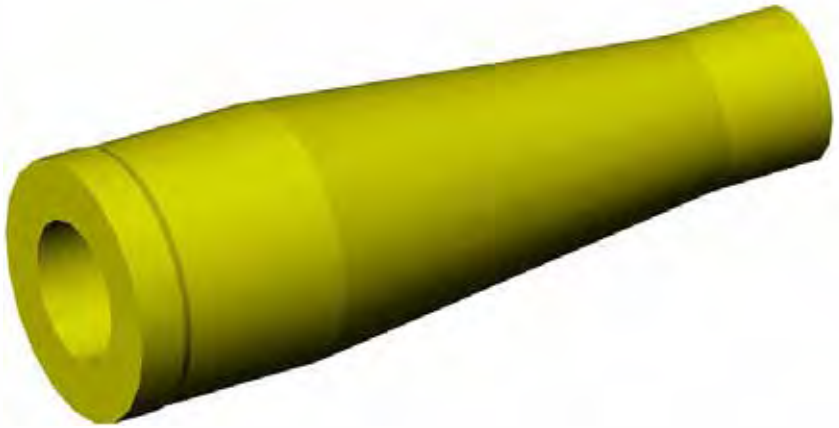
Main Ancillaries
Bend Stiffener

- Required for dynamic risers
- Polyurethane cone that moves bending moment from base of end fitting
- Installed remotely or diver assisted.



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Main Ancillaries
Bend Restrictor

- Used at connections to wellhead, PLEM, manifold, etc.
- Prevents overbending. Installation aid when pipe deployed with subsea hardware
- Polyurethane units which can be installed offshore
- Steel solutions also available at lower cost but must be packaged in plant

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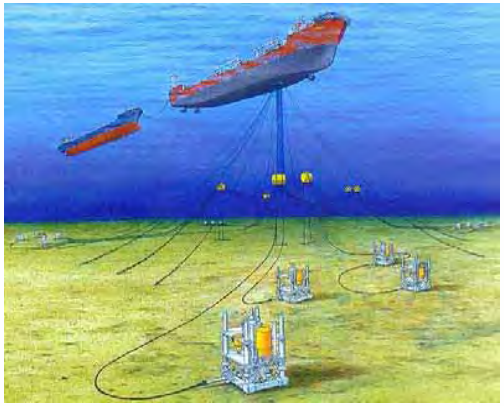
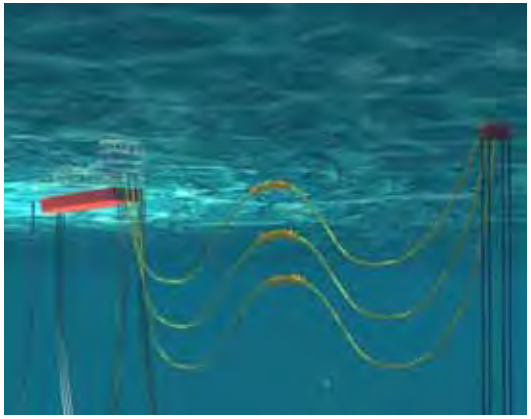
Main Ancillaries
Buoyancy Modules

- Floatation attached to result in desired riser configuration
- Both concentrated and distributed
- Clamps required for concentrated buoy to make connection to arch





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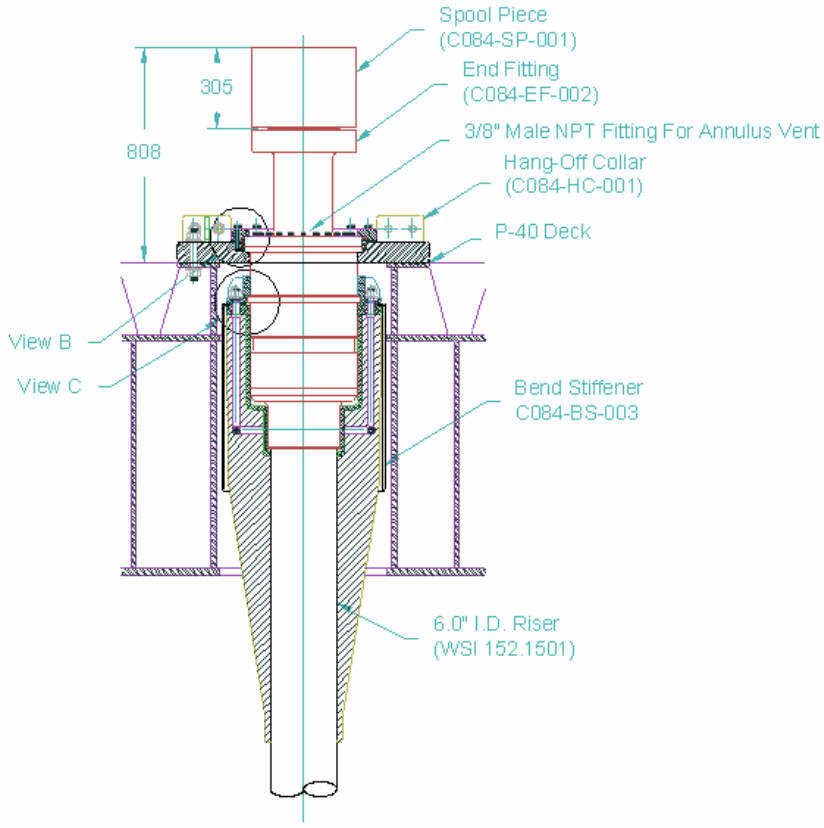
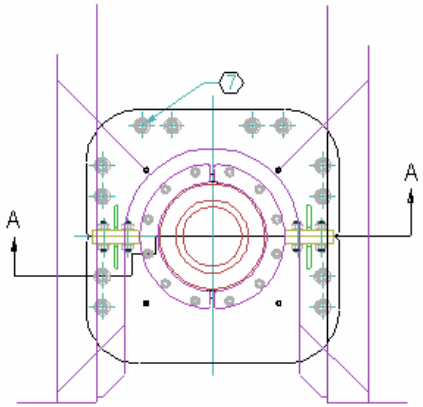
Main Ancillaries
Hang Off Clamp



SECTION A-A

(Riser, End Fitting, and Spool Piece Not Sectioned For Clarity)



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Flexible Pipe Standards

- **API 17J - Specification for Unbonded Flexible Pipe**
- **Petrobras NI-2409-A - Flexible Pipe Specification - 2003**
  - **Must be in compliance on all Petrobras Projects.**
- **ISO 13628 - Petroleum natural gas industries - Drilling and production equipment - Design and operation of subsea system- Part 2: Flexible pipe systems for subsea and marine applications.**
- **Bureau Veritas NI 364 DTO ROO E - Non-bonded Flexible Steel Pipes used as Flowlines**
- **DNV Rules for Flexible Pipe**
- **Other oil company specifications**
  - **ALL SUPERSEDED BY API 17J**
- **RP17B - Recommended Practice for Unbonded Flexible Pipe (sister document to API 17J)**

Technical Documentation Requirements for Flexible Pipe

- **Design Premise**
- **Design Load Report**
- **Design Report (with Riser System / Service Life Analysis)**
- **Fabrication Specification**
- **Operation Manual**
- **Manufacturing Quality Plan**
- **Data Book**

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Petrobras - Marlim Sul
Pipe ID : 6 inches
Water Depth : 1500m
Pressure Rating : 20.68 Mpa
Design Temperature : 60 Deg. C
Function : Oil / Gas Insulated Flowline

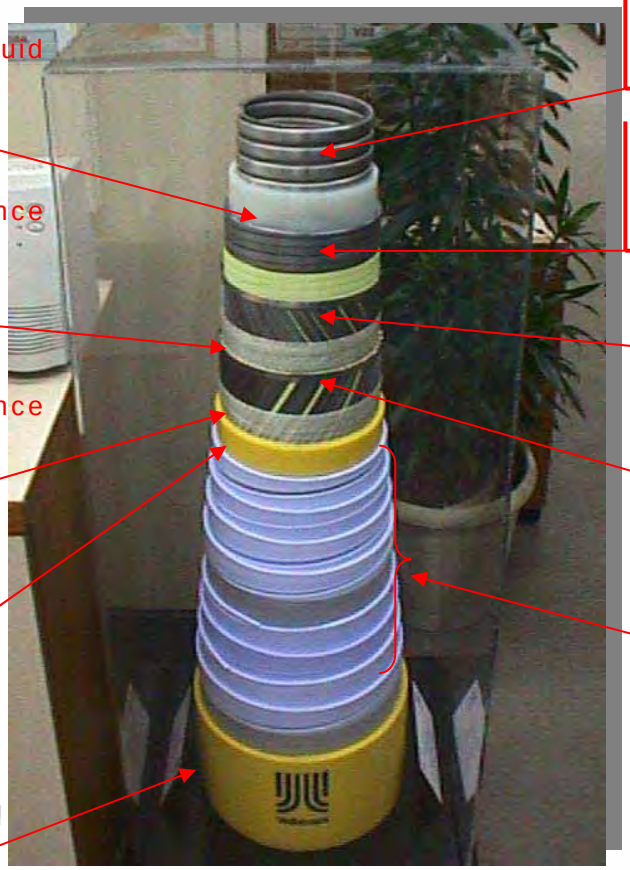
Layer: FLEXBARRIER ™
Function: Seal Internal Fluid
Material: Nylon PA-11
Thickness: 7,00 mm

Layer: FLEXTAPE ™
Function: Birdcaging Resistance
Material: High Strength Glass Filament
Thickness: 0,81 mm

Layer: FLEXTAPE ™
Function: Birdcaging Resistance
Material: High Strength Glass Filament
Thickness: 0,81 mm

Layer: FLEXWEAR ™
Function: Limit Steel Layer Wear, Constrain Flextensile Wires, Manufacturing Aid
Material: HPDE
Thickness: 5,00 mm

Layer: FLEXSHIELD ™
Function: Environmental Protection
Material: HPDE PT7000
Thickness: 10,00 mm



Layer: FLEXBODY ™
Function: Collapse Resistance
Material: Stainless Steel
Thickness: 8,40 mm

Layer: FLEXLOK ™
Function: Provides Hoop Strength
Material: Carbon Steel
Thickness: 6,35 mm

Layer: FLEXTENSILE 1 ™
Function: Provides Hoop and Axial Strength
Material: Carbon Steel
Thickness: 3,00 mm

Layer: FLEXTENSILE 2 ™
Function: Provides Hoop and Axial Strength
Material: Carbon Steel
Thickness: 3,00 mm

Layer: FLEXINSUL ™
Function: Decrease Heat Loss
Material: Syntetic Foam PT7000
Thickness: 40,00 mm (total)

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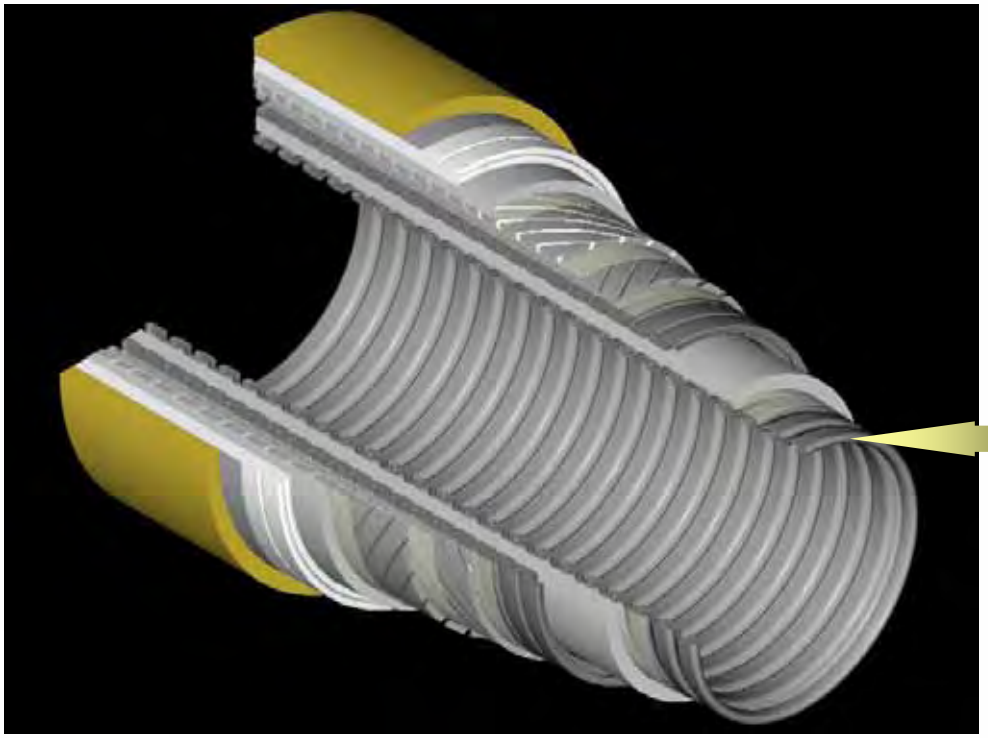
Flexible Pipe Design Make-up

•Provides collapse resistance by forming into an interlocking spiral



Flexbody™ - (Internal Carcass)

The Flexbody is a corrugated metallic tube with a specified internal diameter. The Flexbody supports the extruded fluid barrier and prevents collapse from hydrostatic pressure or crushing loads applied during pipe operation.

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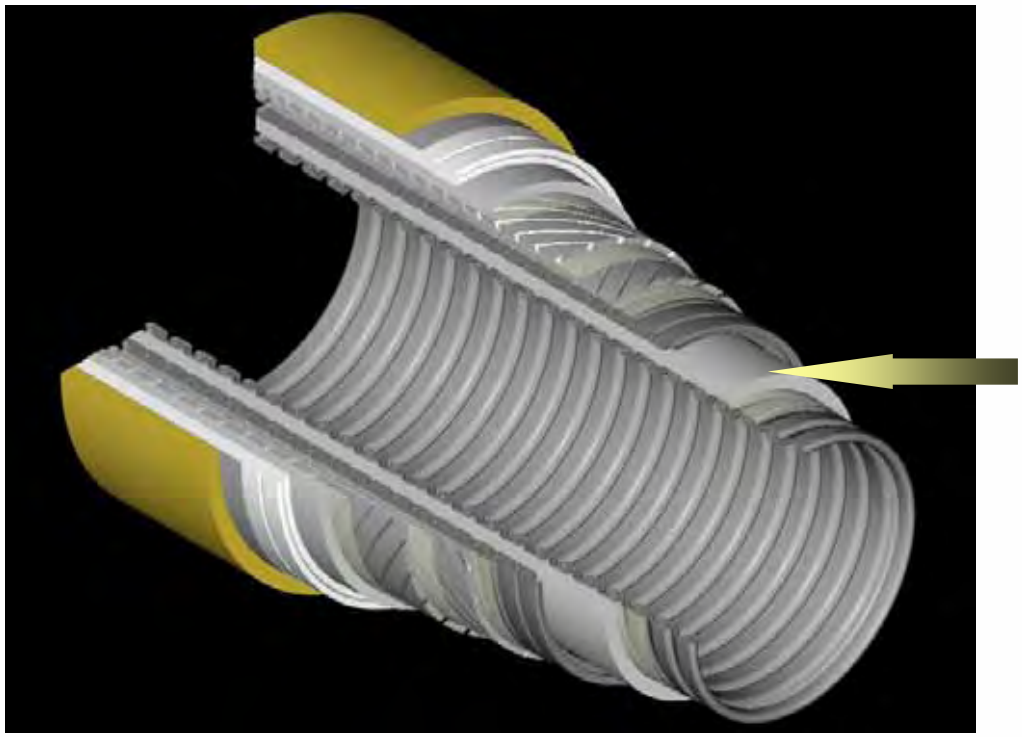
Flexible Pipe Design Make-up



Flexbarrier™ - (Internal Pressure Sheath)

The Flexbarrier is a polymer layer extruded over the Flexbody to form a boundary for the conveyed fluid. The Flexbarrier material is selected to be chemically resistant to the conveyed fluid and unaffected by its service conditions.

Material types

HDPE PA11/PA12 PVDF

Increasing temperature resistance

Increasing chemical compatibility

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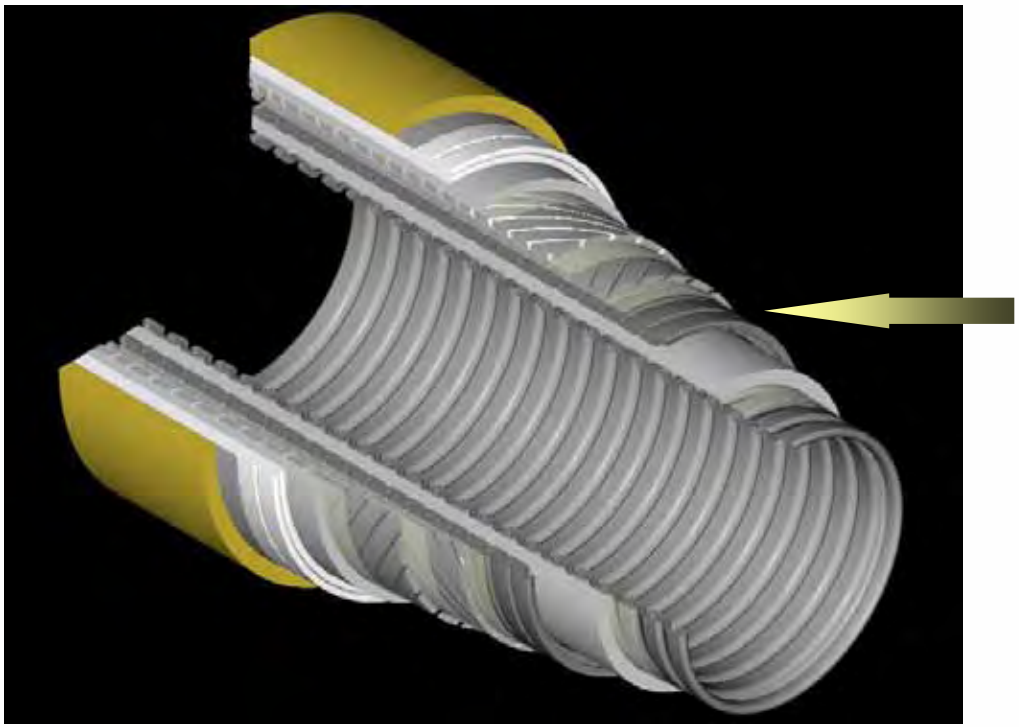
Flexible Pipe Design Make-up



Flexlok™ - (Pressure Armour)

The Flexlok is a steel hoop strength layer consisting of circumferentially wound profiled wire to resist to internal pressure and bending.

The Z-shaped wire is profiled to allow interlocking of the edges as they are formed around the pipe.

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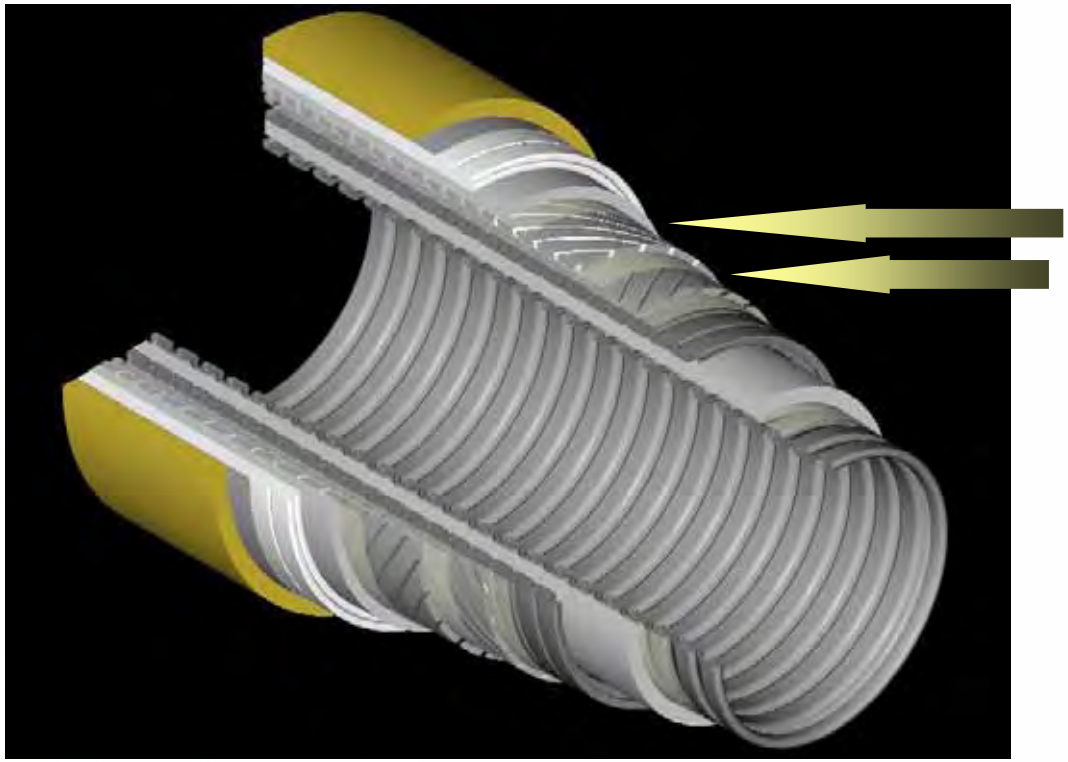
Flexible Pipe Design Make-up



Flextensile™ - (Tensile Armour)

The Tensile Armor layer is a helical steel armor layer that resists internal pressure and axial tension.

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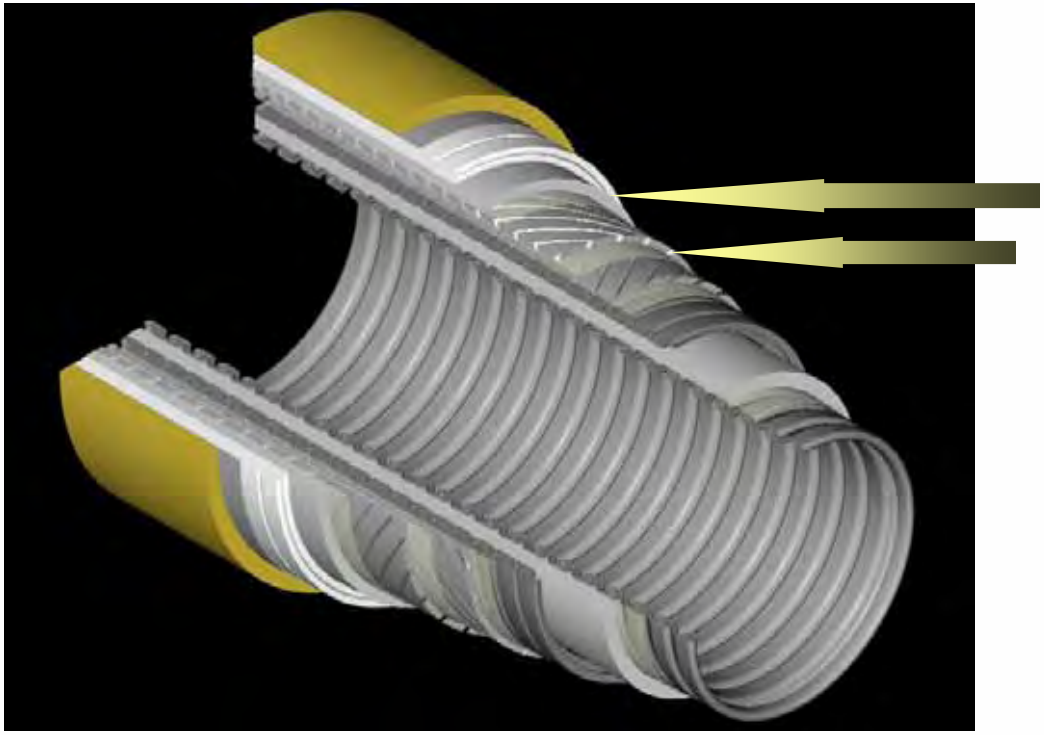
Flexible Pipe Design Make-up



Flexwear™ - (Anti-wear Layer)

The Flexwear is a thin polymer tape layer applied between any two adjacent metallic layers, and such prevents metal-to-metal contact between the layers to prevent wear.

Flextape™ -

Tape layers are applied over the tensile armors as a manufacturing aid to prevent “birdcaging”.

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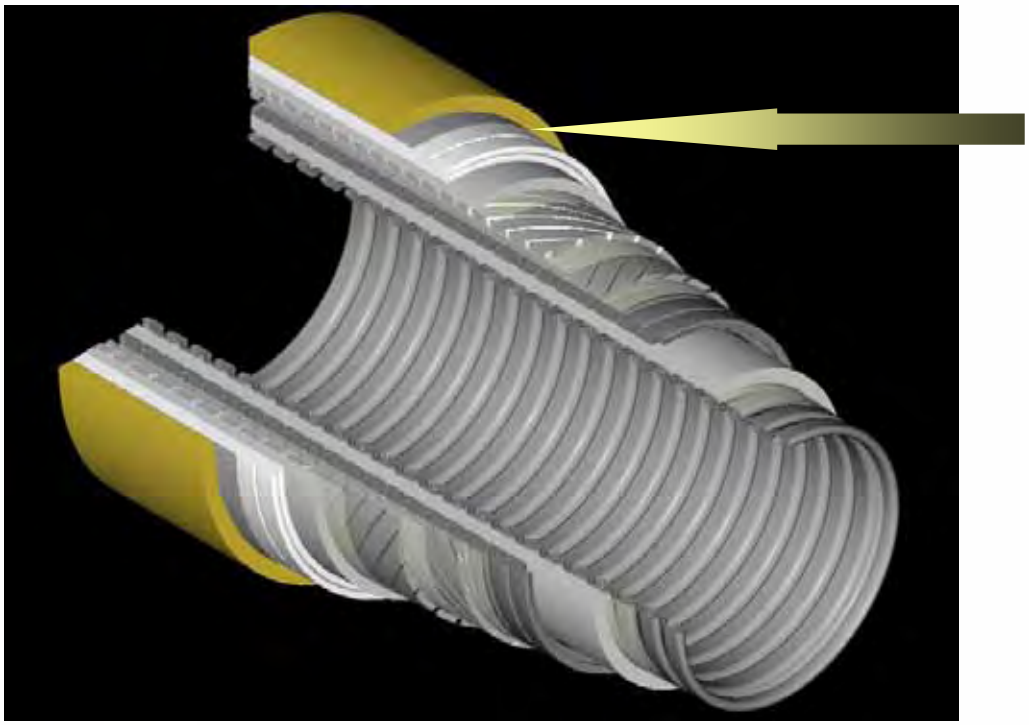
Flexible Pipe Design Make-up



Flexinsul™ - (Insulation)

Flexinsul is a thermal insulation layer used to limit heat loss through the pipe wall to the surrounding environment.

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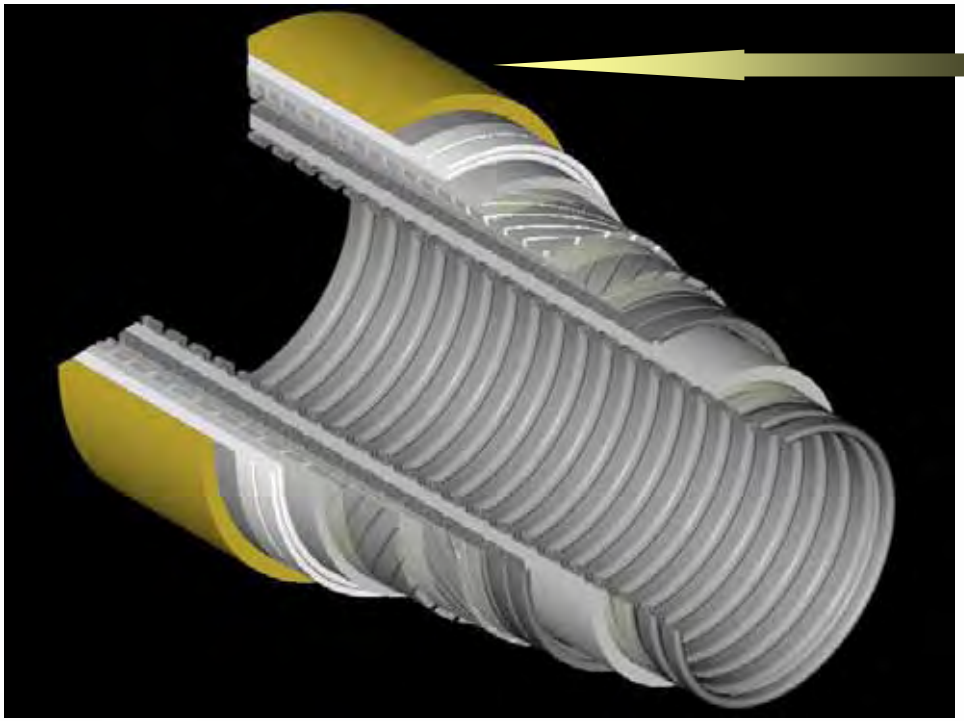
Flexible Pipe Design Make-up



Flexshield™ - (External Sheath)

Flexshield is an external polymer barrier applied to resist mechanical damage and intrusion of seawater.

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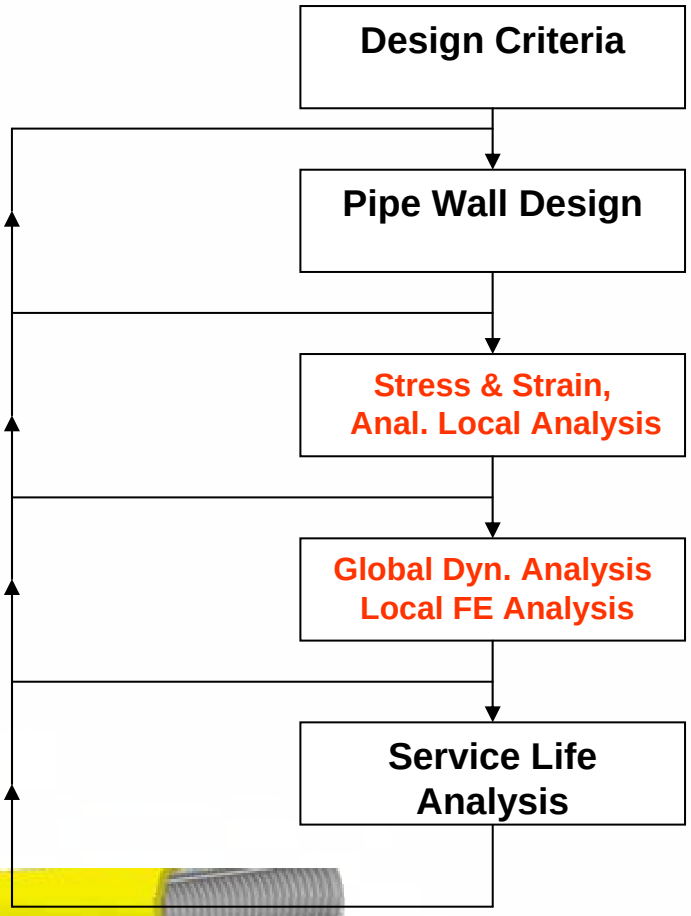
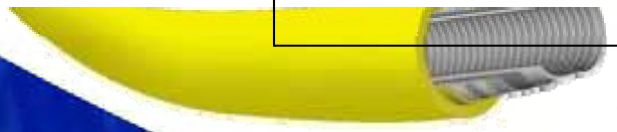
Pipe Structure Design Verification



See Figures
19, 20 API RP 17B
for more detailed
process charts for
static flowlines
and dynamic risers



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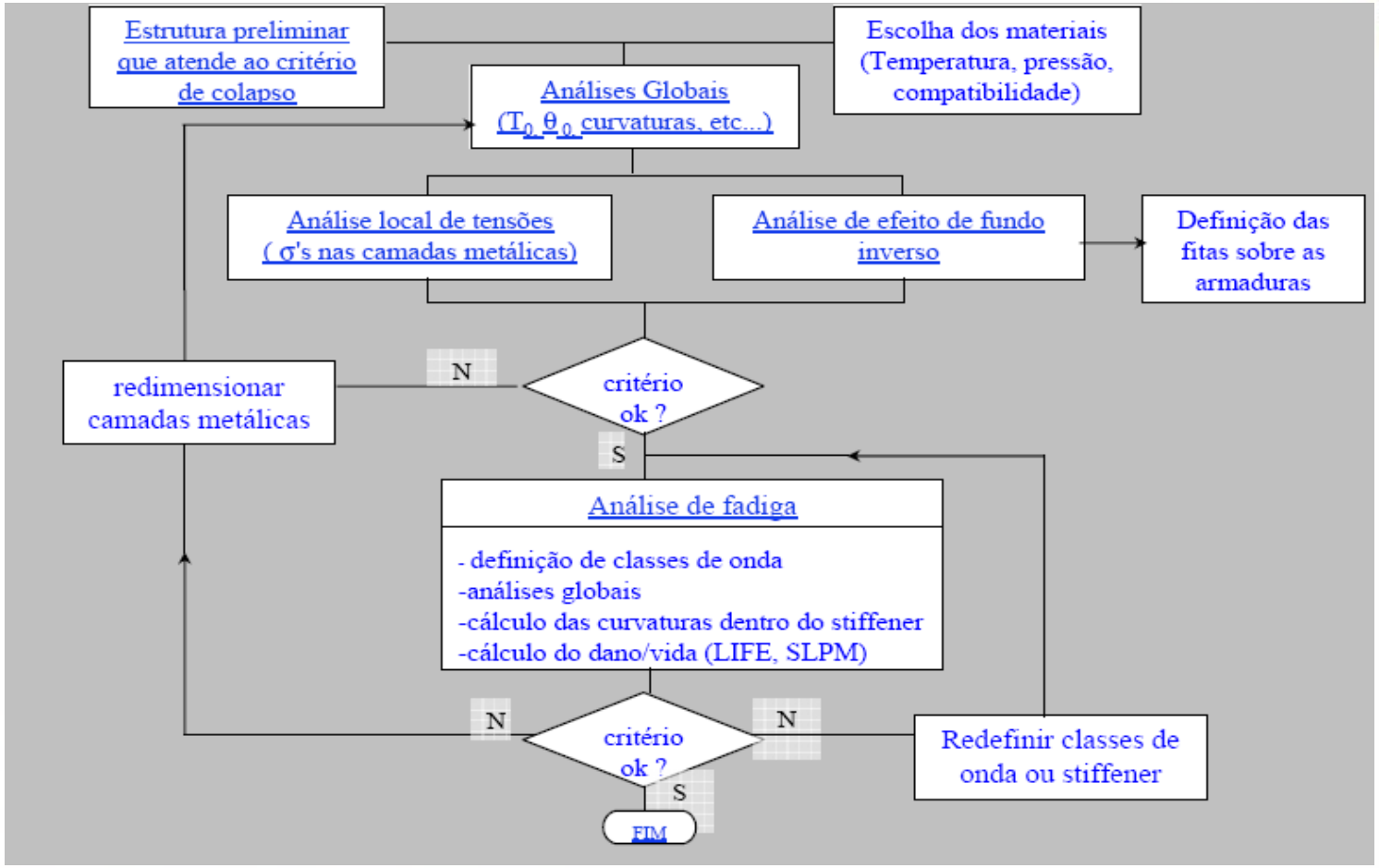
Flexible Pipe Design Flowchart



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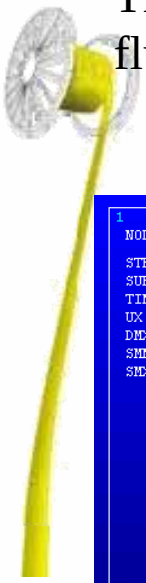
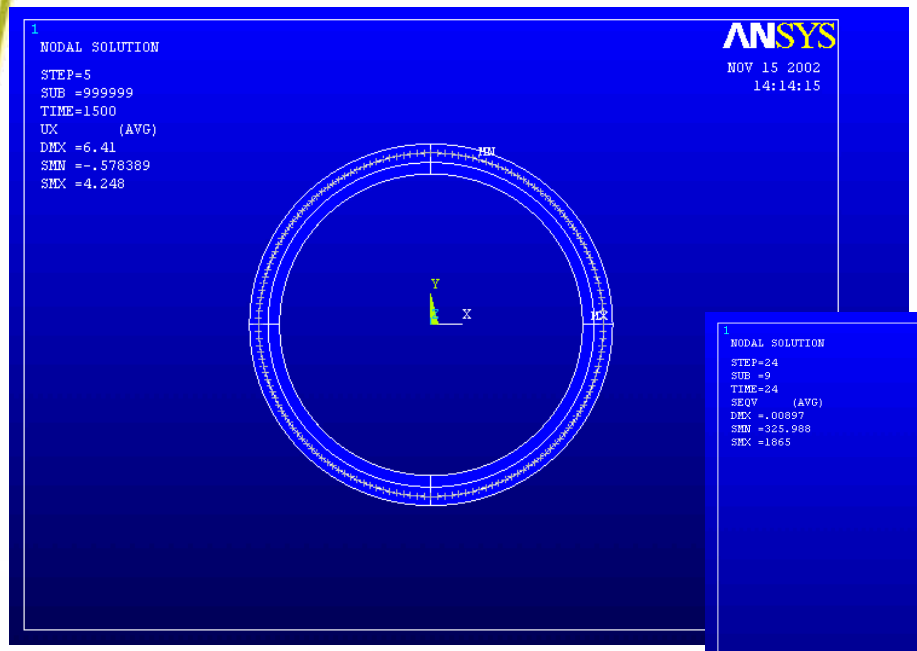
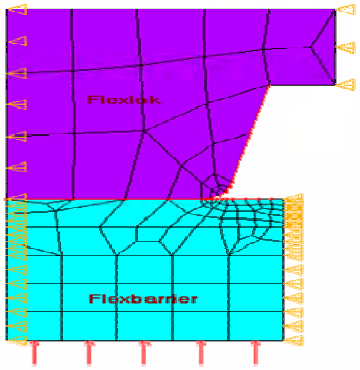
Preliminary Design, Fluid Compatibility & Collapse & Local Stress

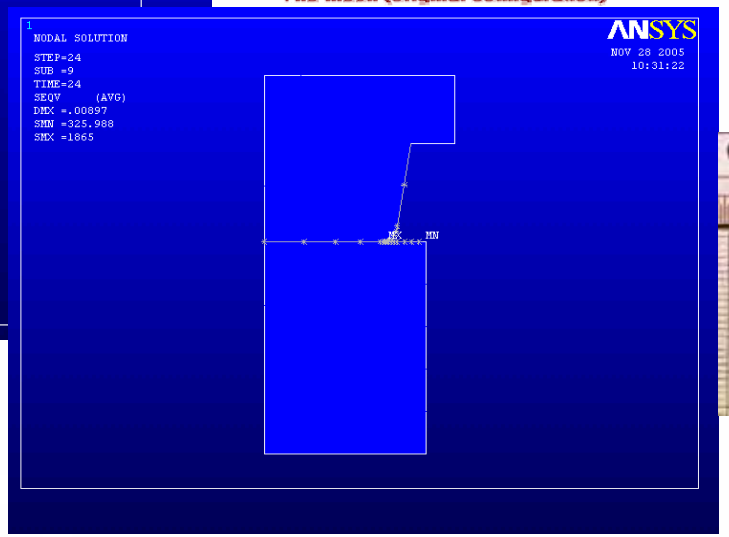
The first design step is execute preliminary collapase, gas permeation, creep and fluid compatibility to define the proposed pipe design

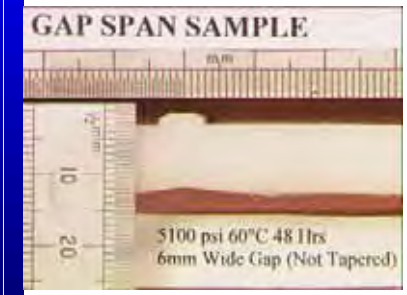






The mesh (original configuration) pressure





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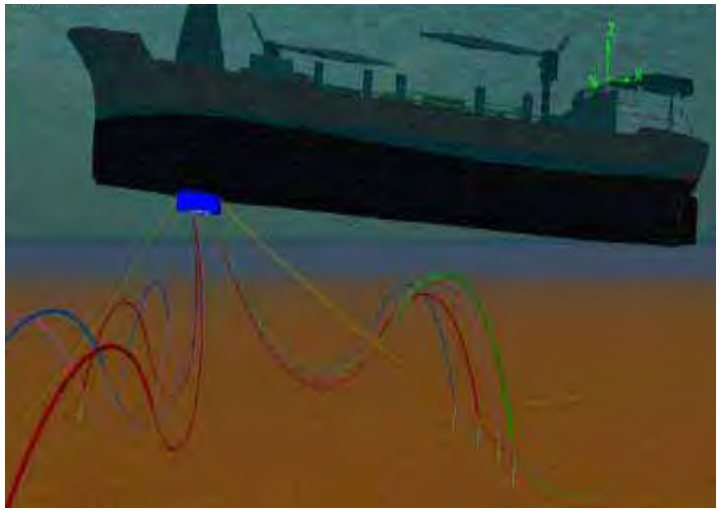
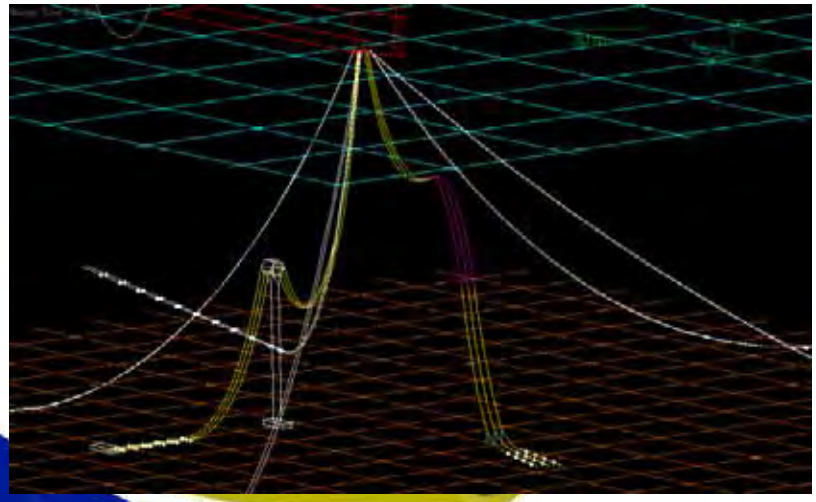
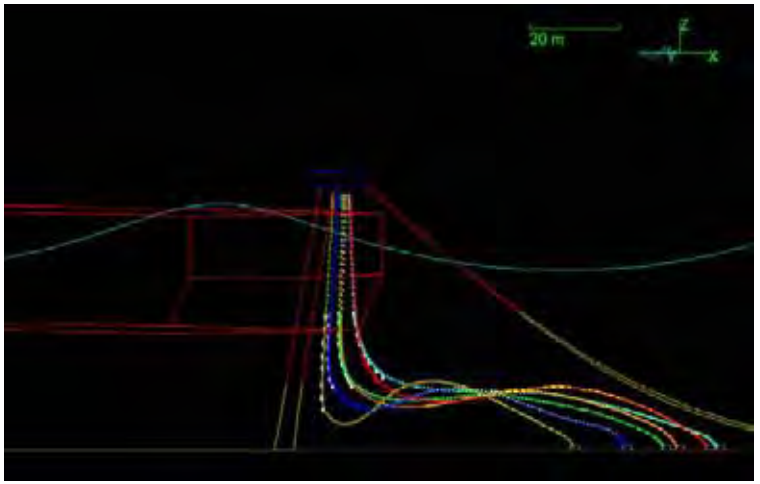
GLOBAL ANALYSIS - STRUCTURAL

- First step is to define the riser configuration based on:
  - **Water Depth**
  - **Vessel Type**
  - **Environmental Conditions**
  - **Flexible ID**
  - **Minimum Service Life Specification**







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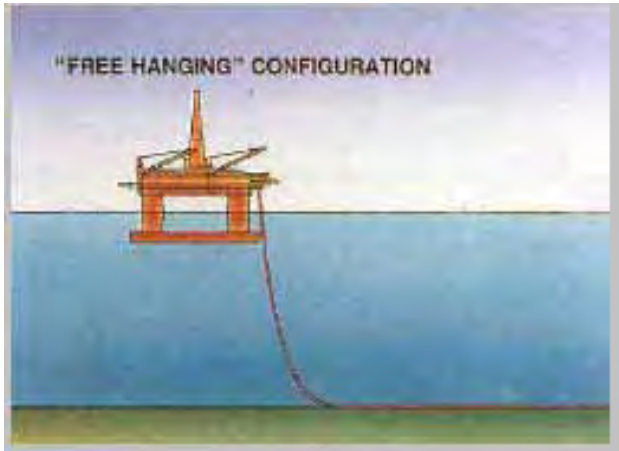
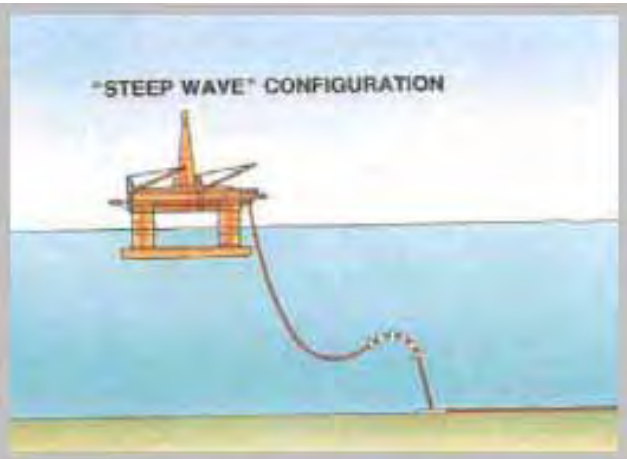
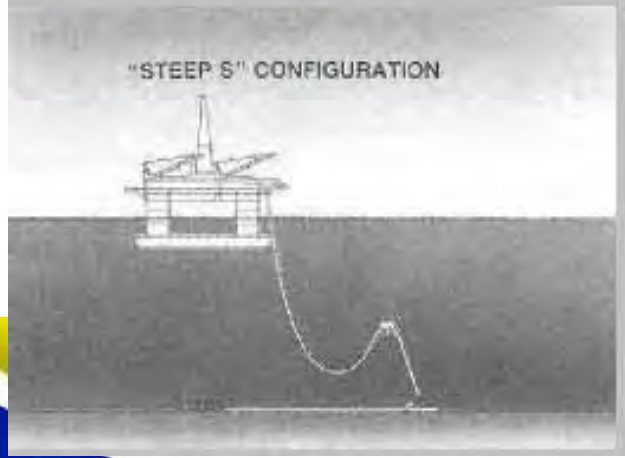
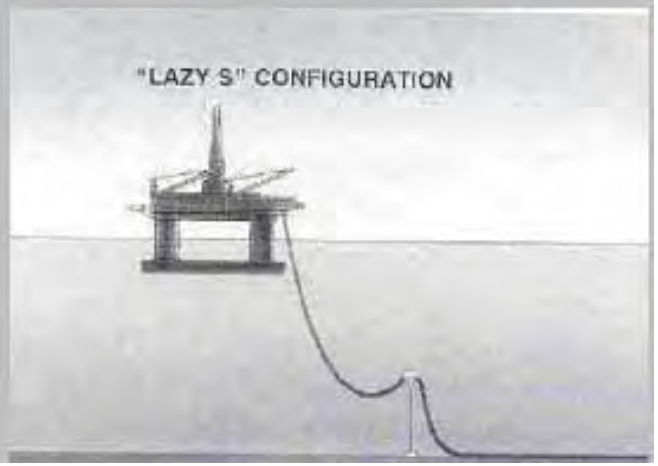
GLOBAL ANALYSIS – STRUCTURAL

RISER CONFIGURATION EXEMPLES









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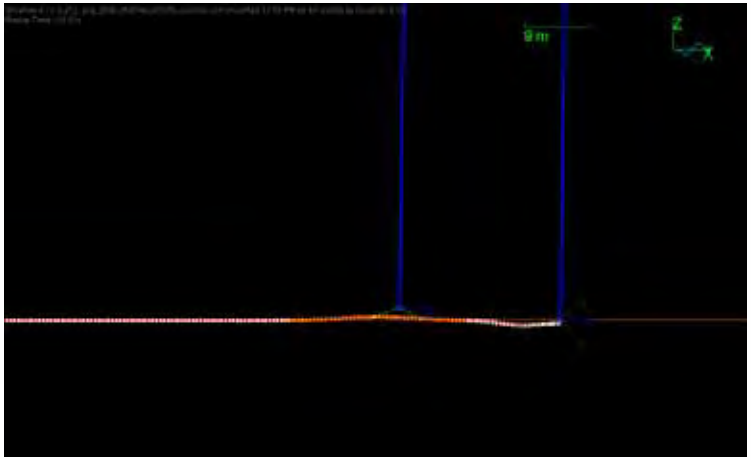
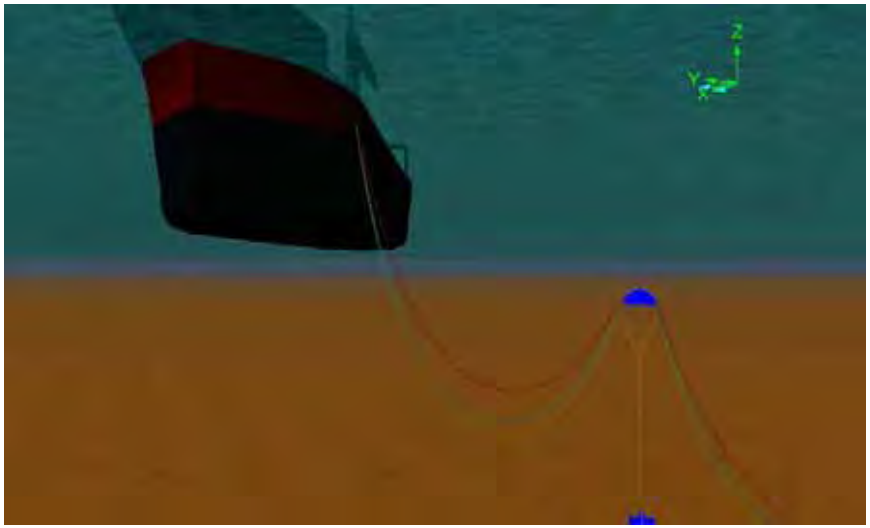
GLOBAL ANALYSIS - STRUCTURAL

- Once the configuration is defined, a non-linear dynamic structural analysis is performed in order to estimate typical loads experienced by the flexible pipe during:
  - **Installation**
  - **Recurrent Operation**
  - **Extreme Operation**
  - **Abnormal Conditions**





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- API 17B provides recommendations on how to perform the analysis
- Petrobras has its own specification with mandatory requirements

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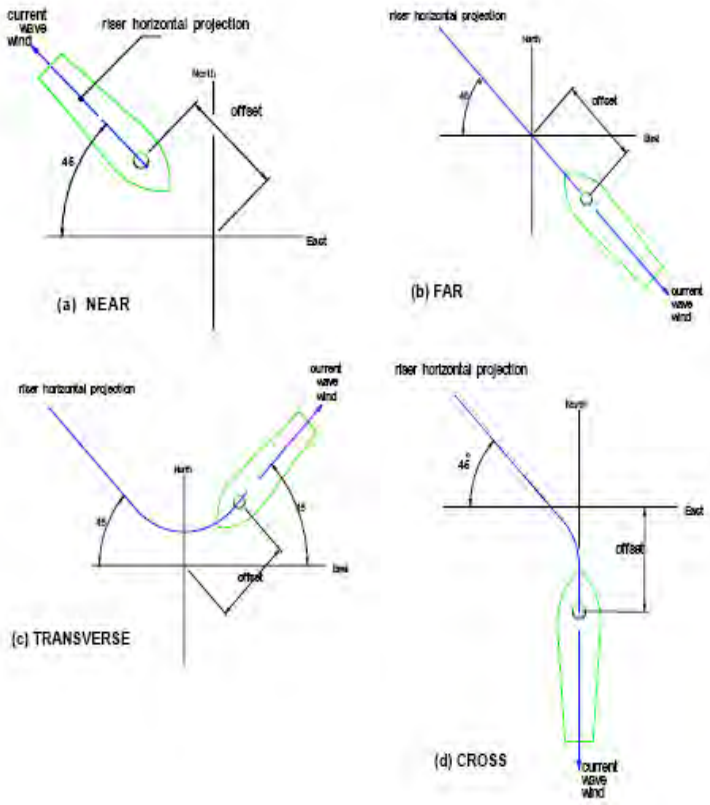
GLOBAL ANALYSIS - STRUCTURAL



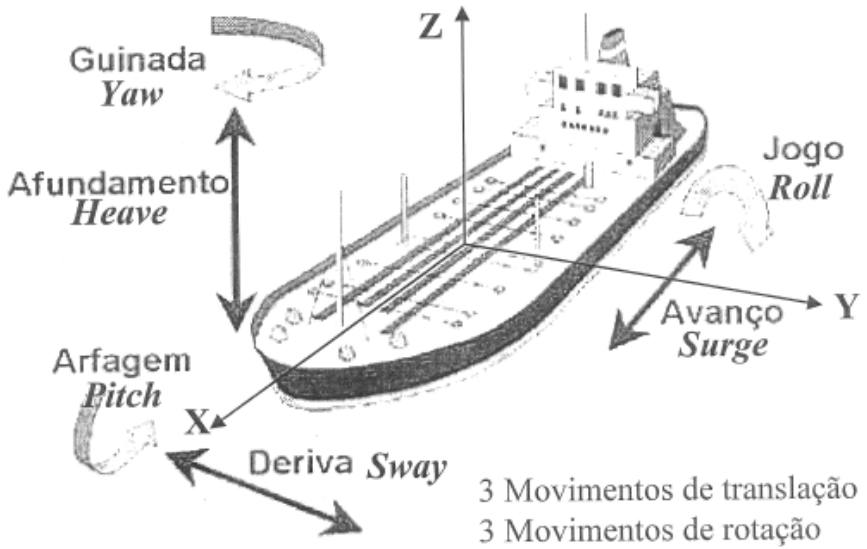
- General approach is to run several load cases (PB spec request aprox. 96 load cases) in order to determine the most severe combinations of:
  - **Wave (10yr or 100yr RP)**
  - **Current (10yr or 100yr RP)**
  - **Offsets (intact or broken mooring system)**

- The environmental conditions must be supplied by the client

- Petrobras have specific documents called METOCEANs that provide all necessary information to perform the analysis

GLOBAL ANALYSIS - STRUCTURAL

- Vessel behavior are simulated by a matrix loaded into the commercial software (Orcaflex/Flexcom)
- This table specify the vessel displacement/rotations for all vessel degrees of freedom in terms of wave height and period.
- On this way, the environmental condition influence can be translated in vessel movements and rotation that will impose loads on the riser.



T	Surge		Sway		Heave		Roll		Pitch		Yaw	
	H	FAS	H	FAS	H	FAS	H	FAS	H	FAS	H	FAS
12,5	0.2	90	0.5	0.5	0.5	80	0.9	160	0.3	100	0.5	120

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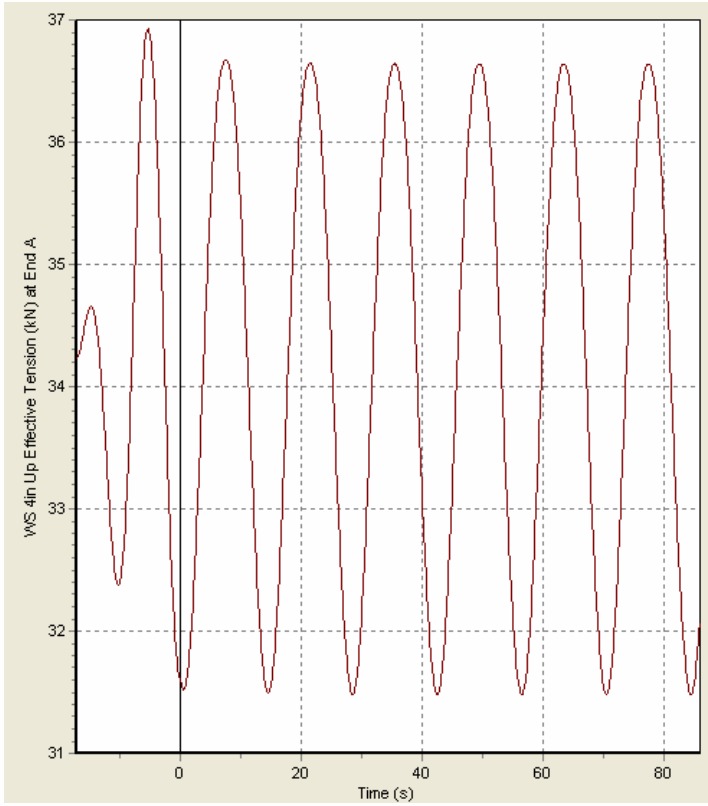
GLOBAL ANALYSIS - STRUCTURAL

- The relevant results often depend on riser configuration.
- For a free hanging catenary systems (most common configuration in Brazil), the most important results are:
  - **Top Tension**
  - **Tension@Angle Envelop**
  - **Curvature on TDP**
  - **Minimum Tension on TDP (Birdcaging)**
  - **Suspended length**
  - **Anchoring Loads**



GLOBAL ANALYSIS – Service Life

- Once the riser is proven to resist to the most severe environmental conditions, a service life analysis is performed in order to verify the suitability of the riser against a specified service life
- Petrobras has its own specification that drives the fatigue analysis. On this specification, the global analysis load cases are related with a number of incidences
- This way, the tension extracted from the load cases can be associated to a number of cycles and an accumulated fatigue damage and life can be calculated based on Palmgreen-Miner rule
- The load cases are based on annual environmental conditions
- Petrobras normally specify **20 years** of service life with a safety factor of **10**

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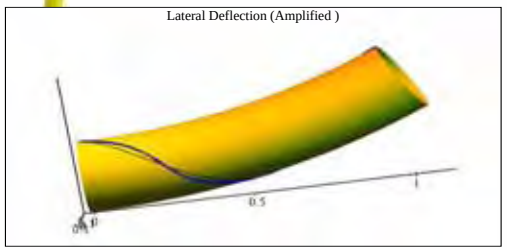
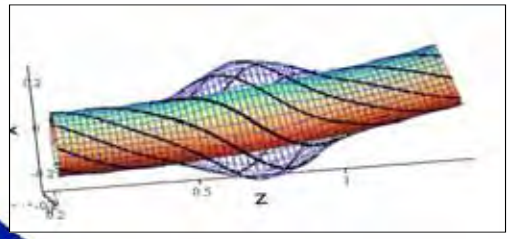
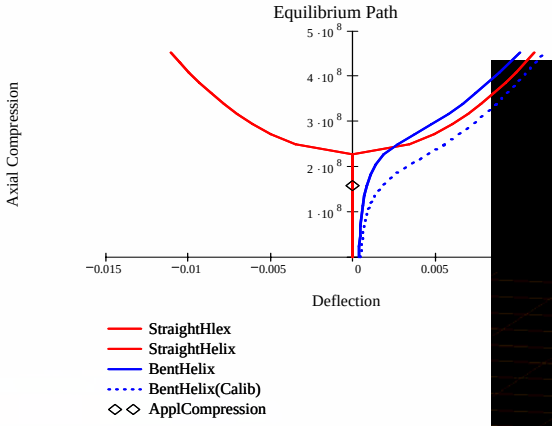
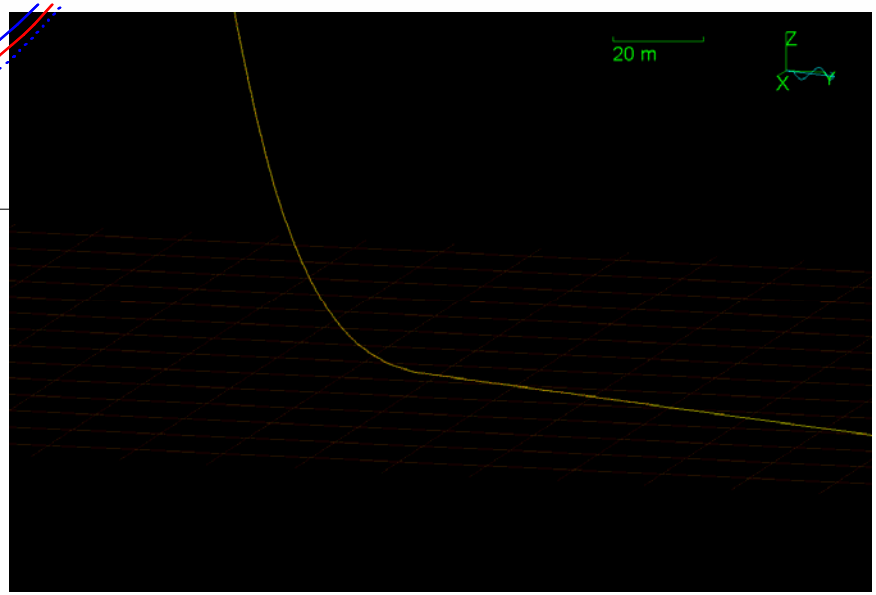
LOCAL ANALYSIS BIRD CAGE

Local BirdCage Analysis FEA & STRAIN ENERGY









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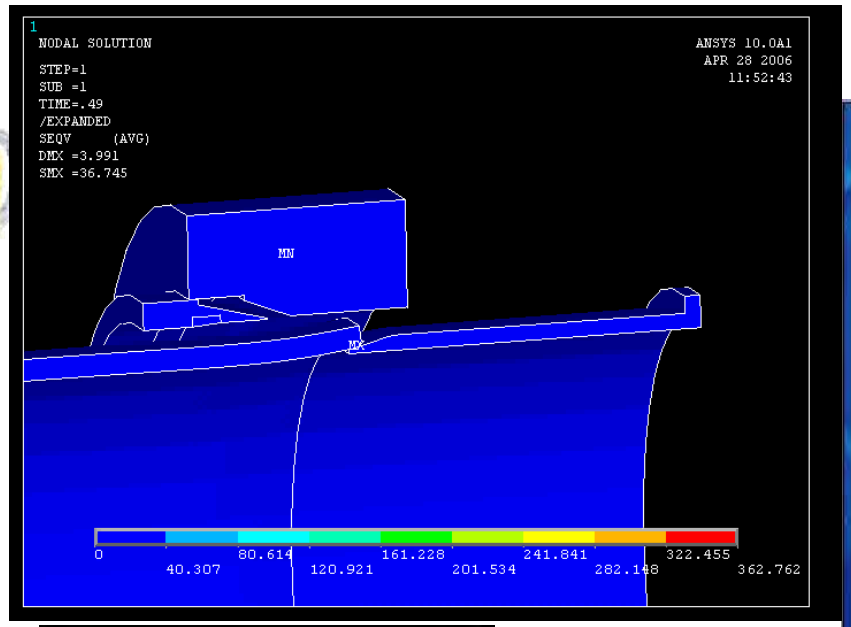
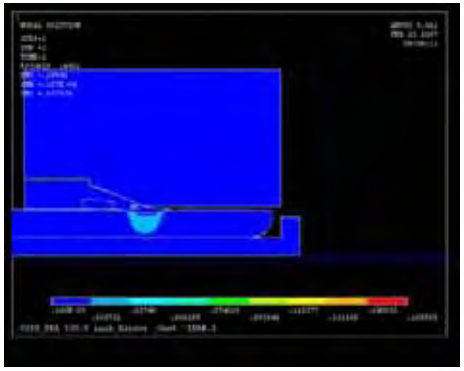
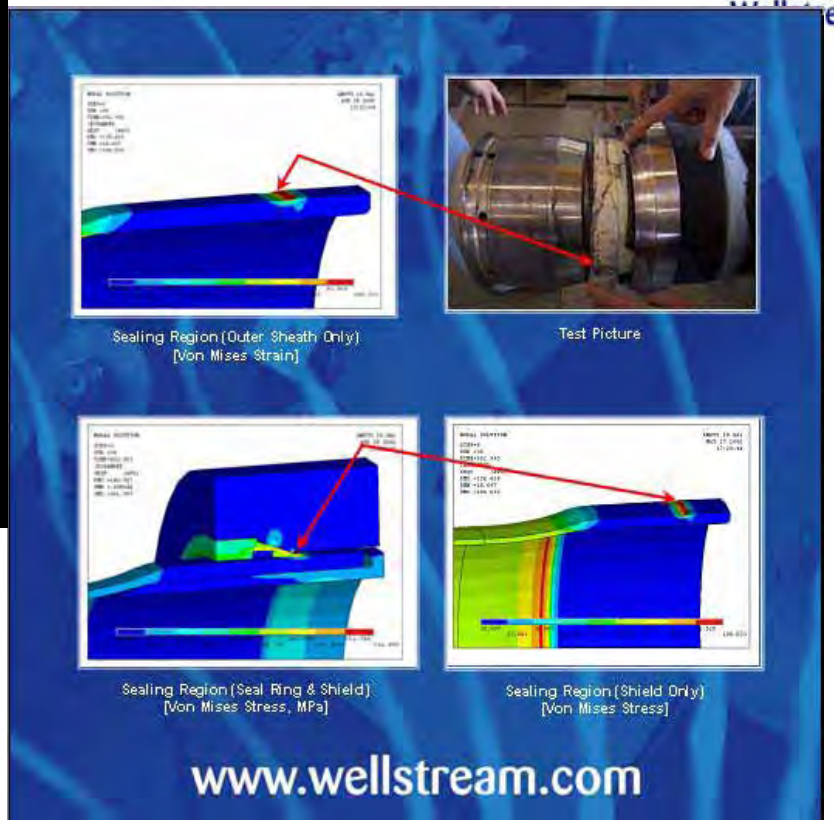
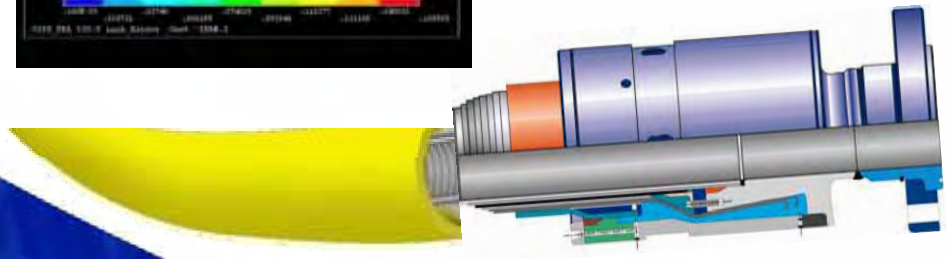
End Fitting Outer Sheath Holding System FEA Model









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Material Qualification

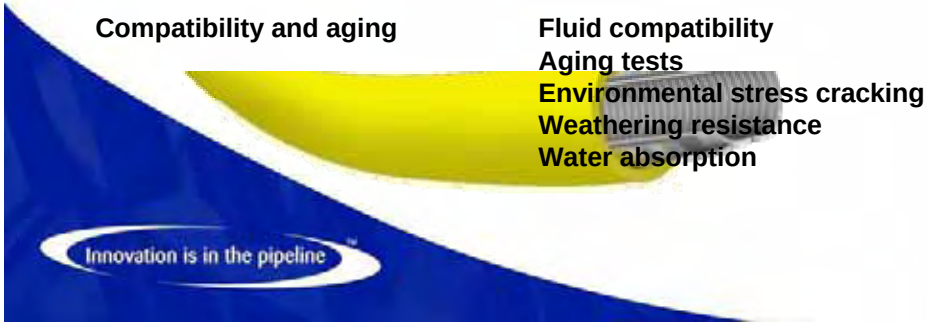
Test Procedures for Metallic Materials

Tests	Test Procedure	Comments
Chemical composition	ASTM A751	Or ISO 8457-2
Yield strength/elongation	ASTM A370	
Ultimate strength/elongation	ASTM A370	
Hardness	ASTM E92	Sour service applications only (Armor wires only)
SSC and HIC	API 17J Sect. 6.2.4.2	To specified environments (Armor wires only)
Corrosion resistance	API 17J Sect. 6.2.4.3	To specified environments (Armor wires only)
Erosion resistance	API 17J Sect. 6.2.4.4	Carcass only
Fatigue resistance	API 17J Sect. 6.2.4.5	Pressure and tensile armors in dynamic applications only
Hydrogen embrittlement	API 17J Sect. 6.2.4.6	only armor wires with yeild stress >= 700 Mpa and/or ultimate stress >= 900 Mpa and exposed to cathodic protection
Chemical resistance		To specified environments

Material Qualification

Test Procedures for Extruded Polymer Materials

Characteristic	Tests	Test Procedure	Comments
Mechanical/physical properties	Resistance to Creep	ASTM D2990	Due to temperature and pressure
	Yield strength/elongation	ASTM D638	
	Ultimate strength/elongation	ASTM D638	
	Stress relaxation properties	ASTM E328	
	Modulus of elasticity	ASTM D638	
	Hardness	ASTM D2240	Or ASTM D2583
	Compression strength	ASTM D695	
	Hydrostatic pressure resistance		
	Impact strength	ASTM D256	At design minimum temperature
	Abrasion resistance	ASTM D4060	Or ASTM D1044 or D1242
	Density	ASTM D792	Or ASTM D1505
	Fatigue	ASTM D671	Dynamic applications only
	Notch sensitivity	ASTM D256	
Thermal properties	Coefficient of thermal conductivity	ASTM C177	
	Coefficient of thermal expansion	ASTM E831	
	Heat distortion temperatures	ASTM D648	Method A
	Softening point	ASTM D1525	
	Heat capacity	ASTM E1269	
	Brittleness temperature	ASTM D746	Or glass transition temp (ASTM E1356)
Permeation characteristics	Fluid permeability	API 17J Sect. 6.2.3.1	As a minimum to CH4, CO2, H2O and methane, at design temp and press
	Blistering resistance	API 17J Sect. 6.2.3.2	At design conditions
Compatibility and aging	Fluid compatibility	API 17J Sect. 6.2.3.3	
	Aging tests	API 17J Sect. 6.2.3.4	
	Environmental stress cracking	ASTM D1693	Method C. PE only.
	Weathering resistance		Effectiveness to the UV stabilizer
	Water absorption	ASTM D570	Insulation material only



Offshore Facilities

- Newcastle, UK
  - Operational since 1997
  - Capability and experience to manufacture the full range of offshore products from 2” - 16” diameters
  - Annual production capacity of 260nkm
  - Proven track record of operating at highest standards required by industry
  - In 9 years of manufacturing there have been zero in-service failures

- Niterói, Brazil
  - Commenced manufacturing on schedule in May 2007
  - Annual production capacity of 150nkm
  - Expected product range: inside diameter of 2” to 12”
  - Facility designed to allow future expansion

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Manufacturing Process

- **The manufacturing of flexible pipes consists of 7 main stages, followed by assembly of end fittings, testing and packaging**
  - Work stations are laid out to optimize the sequential manufacturing process
  - Maximum flexibility in manufacturing to reel or carousel
  - Equipment parameters are computer monitored and controlled throughout the process ensuring consistency
  - Quality control teams operate at each work station, throughout the length of the production run
  - Continuous Improvement teams operate at each work station

Carcass Stage	Barrier Extrusion Stage	Flexlok™ Stage	Armour Stage	Insulation Stage	Flexwear™ Stage	Shield Extrusion Stage
Flexbody™	Flexbarrier™	Flexlok™	Flextensile™	Flexinsul™	Flexwear™	Flexshield™
R	E	R	R	T	T or E	E
▪ Provides collapse resistance	▪ Forms the fluid-conveying conduit	▪ Provides pressure retention capacity of pipe structure	▪ Provides axial tension strength	▪ Enhances thermal properties	▪ Reduces friction between metallic armour wires	▪ Protects structural layers from mechanical damage and ingress from sea water
▪ 2 machines maximise production output	▪ Flexliner™ may replace the carcass and Flexbarrier™ for smoothbore applications	▪ Flexpress™ used when Flexlok™ alone cannot provide sufficient strength	▪ Increases burst strength by enhancing hoop strength of Flexlok™	▪ Helical wrapping of single or multiple layers of insulation tape onto the pipe	▪ Supports tensile armour wires against buckling outwards	▪ Additional external protection can be given by a Flexgard™

R = Rotating equipment work centre | E = Extrusion work centre | T = Taping work centre

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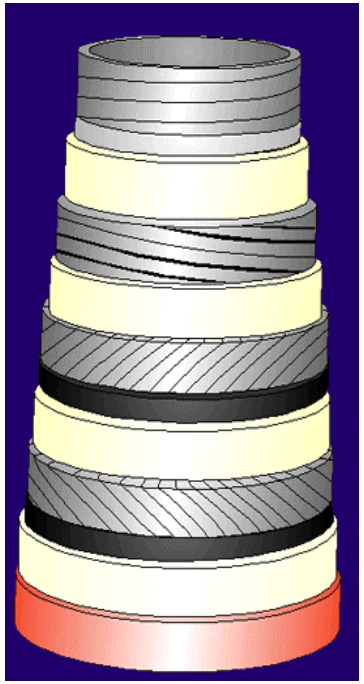
Flexible Pipe Construction Carcass



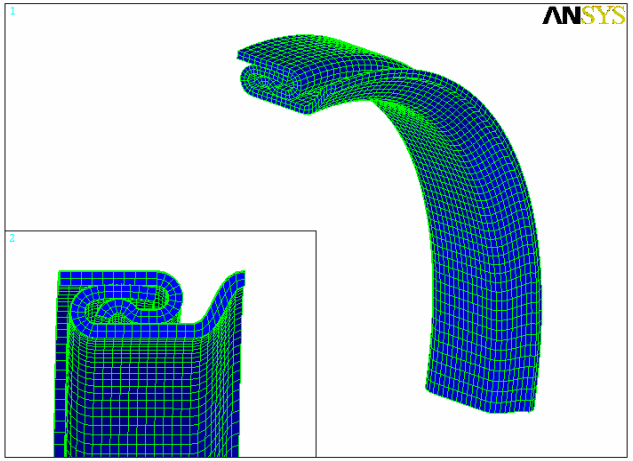
Carcass -

The Carcass is a corrugated metallic tube with a specified internal diameter. The Carcass supports the extruded fluid barrier and prevents collapse from pressure or crushing loads applied during pipe operation

Material Selection

Stainless 304L, 316 L

Duplex & AL6XN



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Carcass take up Reel

- The carcass is taken upon a reel, ready for the extrusion operation.

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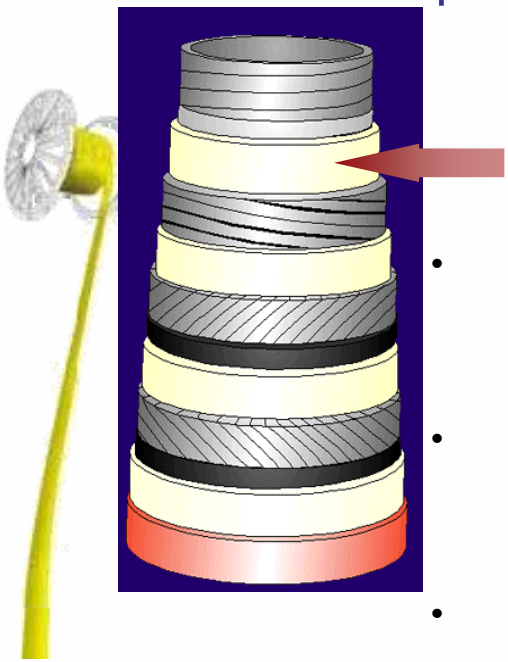
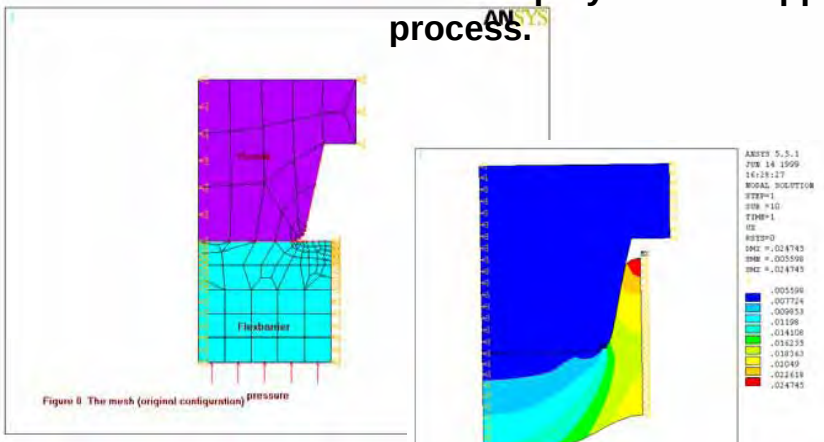
Flexible Pipe Construction Flexbarrier



Internal Pressure Sheath -

- **For Flexbarrier (polymer fluid barrier) the carcass is passed through the extruder cross-head, where the resin melt is applied over the carcass.**
- **Control of extruder volume and line speed, coupled with use of specially sized dies, determine the thickness of the wall around the carcass.**
- **High Density Polyethylene (HDPE), Nylon (PA11 or PA12), and polyvinylidene fluoride (PVDF) as well as other polymers are applied in this process.**



Material Selection

PVDF, HDPE & PA-11/PA-12

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Production Reels & Carousel

- The product is stored on reels or in a carousel as it is processed through each work centre.
- The reels are also used to transport the product to the customer.
- Carousels are used when the length of product exceeds the capacity of the production reels or where the SBR is large.
- Transportation to the customer takes place by loading the product on to the vessel either on reels or in to the vessels own carousel.

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Caterpullers

- There are two caterpullers on each extrusion line, one is used to pull the pipe from the pay-off Rim drive and feed it down the line at a constant speed.

- The other one is used to pull the product through the line at a constant speed dictated by UT the catenary setting. The catenary is a necessary function of the extrusion line.

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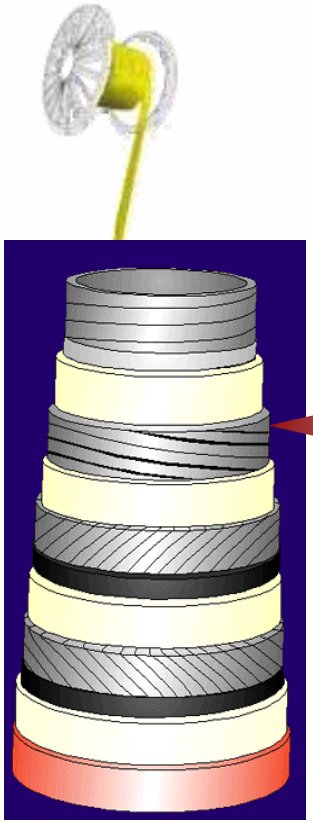
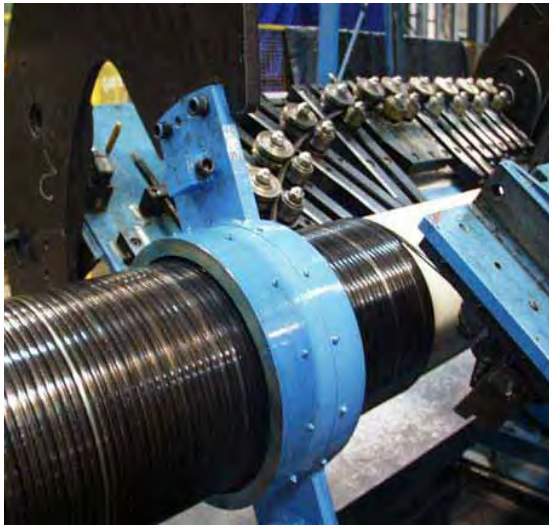
Pressure Armor



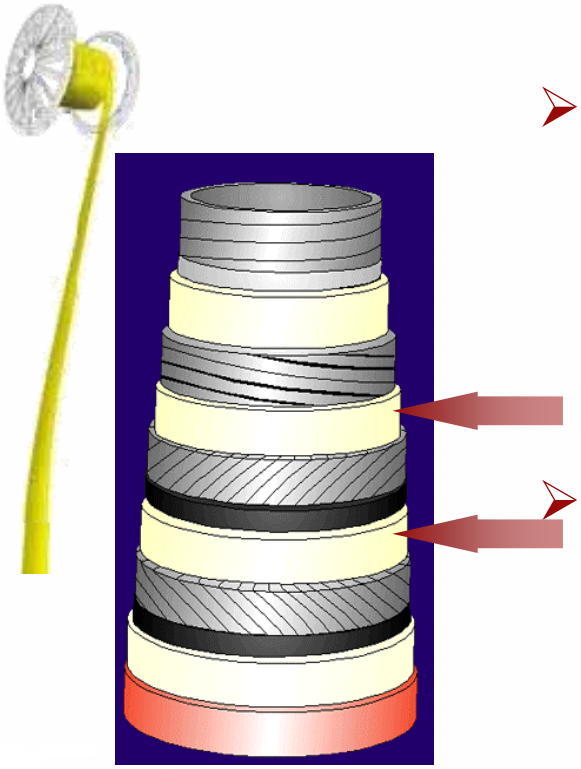
- **The Flexlok machine applies a shaped, rolled, carbon steel wire which is preformed and interlocked as it is wound around the pipe, providing a smooth, flexible, continuous layer to support the barrier and increase pipe burst pressure.**
- **When design and pressure requirements demand higher burst strengths, Flexpress, a wide flat wire, may be wound over the Flexlok layer.**
- **Machines that apply from 1 to 4 wires simultaneously are used.**



Material Selection

Sweet & Sour Service

Taping Head



- The tape heads are suitable for the application of either two or four tapes. A fabricated steel frame supports the rotating head.
- The following tapes are applied -
  - Manufacturing aids
  - Anti-birdcaging (Deepwater)
  - Anti-wear (Dynamic Risers)
  - Thermal Insulation

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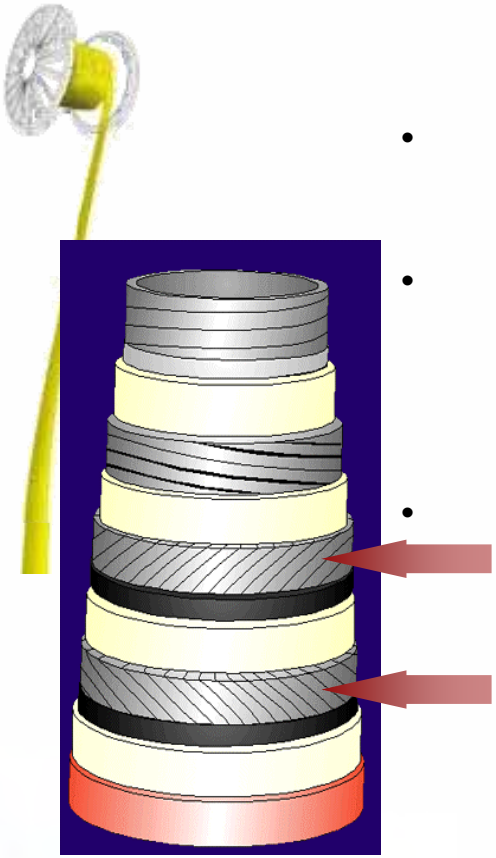
Tensile Armour



- The Armour machine applies a layer of helical steel armour wires to the pipe.
- The flat wires increase burst strength and give the pipe axial strength. There are two machines that apply the flat wire contra-helically.
- The flat wire can be of various sizes and tensile strengths depending on the pipe design. As the wire is applied, it runs through pre-form tooling heads which twist the wire so it lays flat against the pipe's surface.

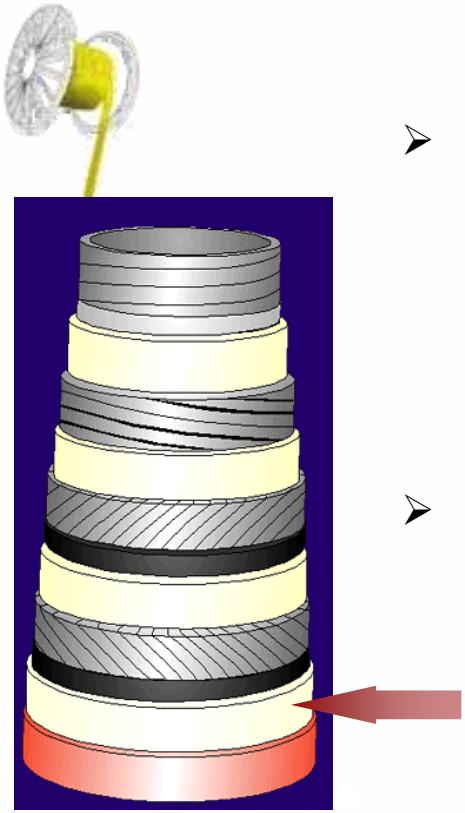
Material Selection

Sweet & Sour Service

Armour Line

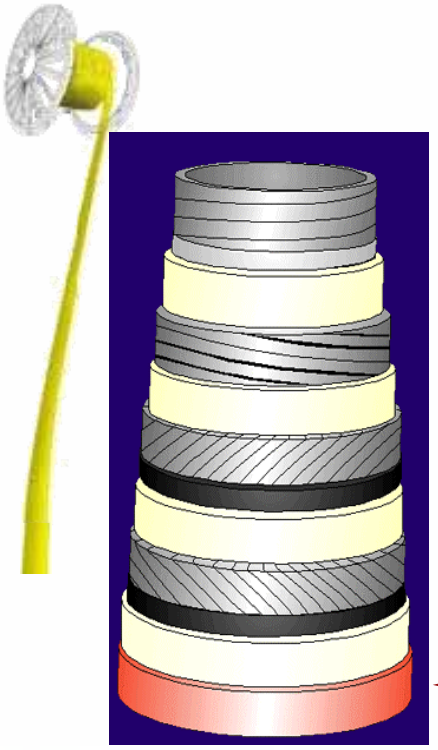
- The armour line consists of two Armoring machines which rotate in opposite directions from one another.
- Stationed throughout the line are tape machines which apply the tape layers.

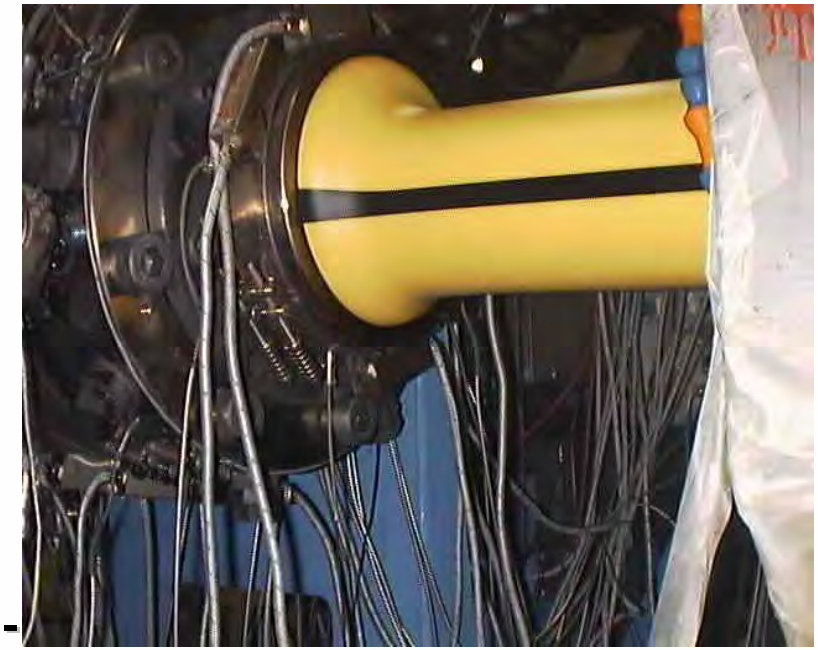
Insulation



- Reduce heat loss from the bore fluids (in order to maintain low viscosity bore fluids hence high flow rates).
- (Application: 1st layer melt extruded onto pipe, 2nd wrapped onto pipe)

Flexible Pipe Construction





Outer Sheath -

The Outer Sheath is an external polymer barrier applied to resist mechanical damage and intrusion of seawater.

Material Selection

HDPE, & PA-11/PA-12

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Pipe Completion / Logistic Base in Brazil

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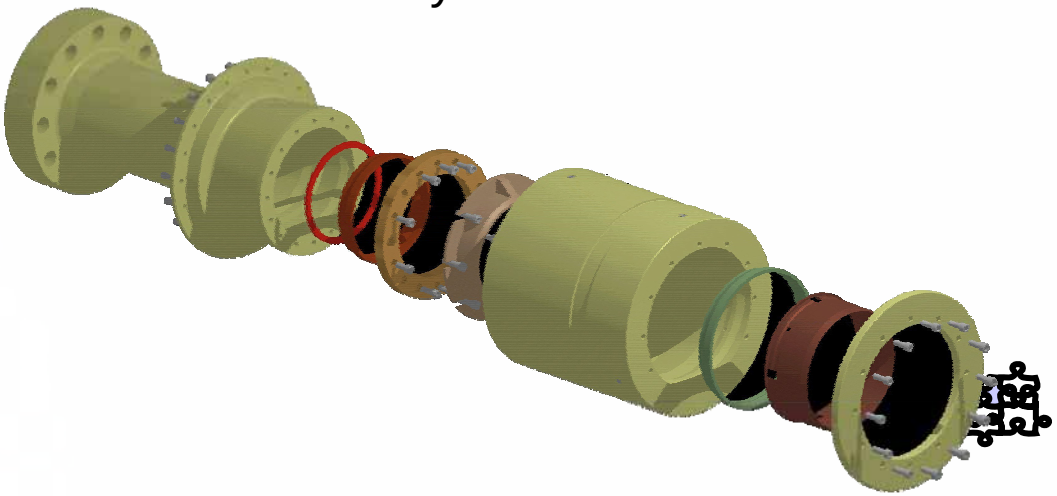
End Fitting Technology

- End fittings are critical components of any flexible pipe system
  - Custom designed for each flexible pipe structure
  - Each layer of the pipe individually terminated
- Designed to:
  - Assure a leak tight transition between subsea and surface facilities
  - Withstand severe environmental loads and thermal cycling
  - Stronger than pipe in burst and failure tension
  - Allow for the venting of permeated gases
- Terminations can be any design - API/ANSI flanges, hubs, welded, or other
- Most common structural material is AISI 4130 low alloy steel



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Factory Acceptance Tests

- **The FAT requirements are specified in the Fabrication Specification and Quality Plan.**
- **API 17 J FAT section**
  - **9.2 Gauge Test**
  - **9.3 Hydro Test**
  - **9.4 Electrical Continuity/Resistance**
  - **9.5 Gas Venting Test**

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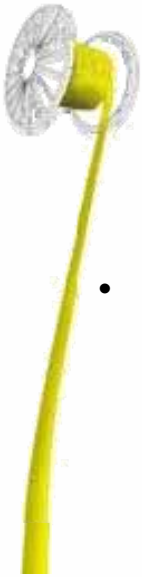
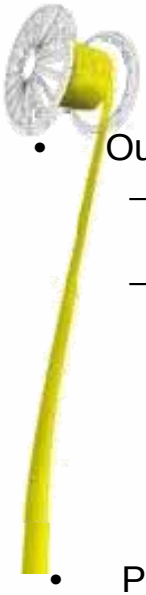
Factory Acceptance Testing (FAT)



- Hydrostatic
  - Minimum hydrotest pressure is 1.5 times the design pressure and the maximum pressure is 1.04 times the minimum hydrotest pressure
  - After the 24 hour period if the pressure has not dropped more than 4% the pipe is considered to have passed hydrotest

Factory Acceptance Testing (FAT)



- Outer Sheath Integrity
  - By pressurizing the annulus of the pipe to 30psi maximum for a period of 30 minutes
  - The pressure must remain above 20psi during the test period and should not reduce by more than 1psi during the last 15 minutes of the 30 minute hold period

- Pressure relief system test (Annulus gas venting)
  - To verify the flow of air through the annulus, over the full length of the pipe
  - Hoses are attached to the vent holes at the in-board endfitting then pressure is introduced slowly to a maximum of 90psi
  - Hoses are then attached at the out-board endfitting and the pressure and flow rate are recorded. A show of air bubbles are also required

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Factory Acceptance Testing (FAT)

- Endfitting testing
  - Electrical Resistance - To confirm the insulation from the Barrier layer/Insulation ring between the Carcass and the Endfitting by measurement of resistance
  - Electrical continuity test – To measure that the resistance between both endfittings is less than the omhs (Ω) advised on the MWO/PWO for the length of pipe tested

Wellstream

Storage

- Reel diameters are from 26ft to 35ft, typical way of handling flexible pipe
- Carousels used for very long lengths

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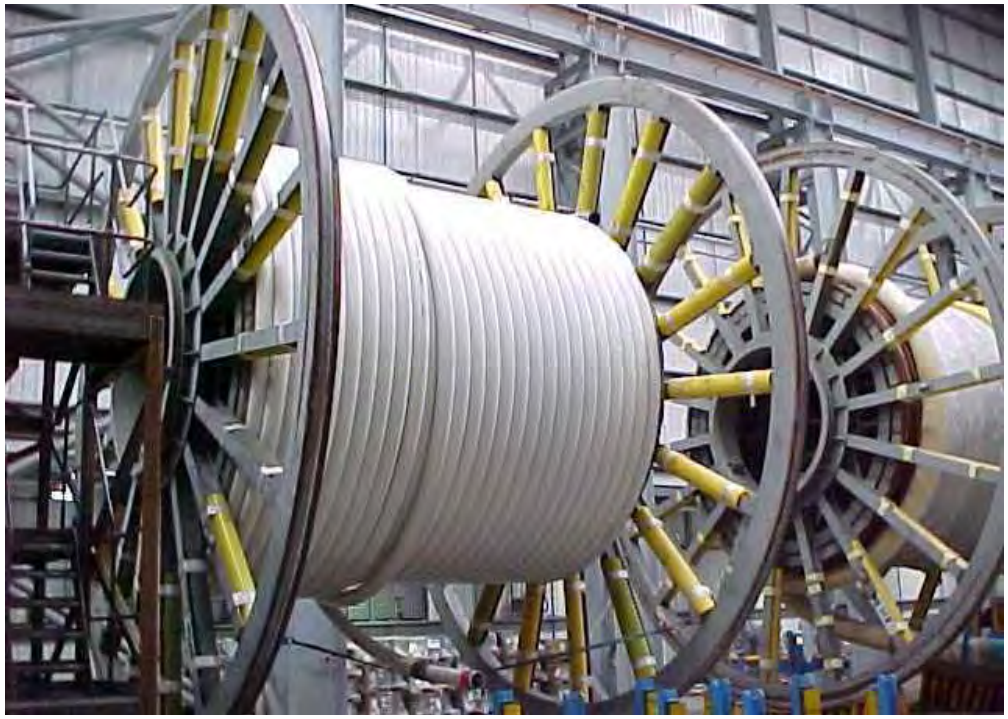
Load-out

- Once the pipe is completed it is secured to a reel or installed in to a carousel.



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Load-out

Innovation is in the pipeline

Flexible Pipe and Umbilical loud-out at Wellstream Base

Load-out

Innovation is in the pipeline™

Load-out

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Qualification Criteria & Scaling Limitations

- Two Objectives to Prototype testing:
  - Prove or validate new or unproven pipe designs
  - Validate the manufacturers' design methodology for a new pipe design
- Scaling of previous test results can be used
  - Pressure – the test pipe may be used to qualify pipes of the same family having equal or lower pressure rating
  - Internal Diameter – testing of one pipe of a product family should verify products two inches larger or smaller than the size tested
- Scaling comparisons also based on pressure and internal diameter (*P x ID*), with the test pipe qualifying pipes with a lower *P x ID* value.

Testing Classes

- All Unbonded Flexible Pipe testing is executed in accordance with API Recommended Practice 17B
- API RP 17B categorizes test types into three classes:
  - Class I – basic tests identifying ultimate capacity under simple loading
  - Class II – tests verifying specific aspects of a flexible pipes performance
  - Class III – tests characterizing the flexible pipe behaviour
  - Petrobras NI-2409 A additional Tests as Tension-Tension, DIP Test, etc…

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Classification of Prototype Testing

Class I

- Burst
- Tension
- Collapse

Class II

- Dynamic Fatigue
- Crush Strength
- Combined Bending & Tension
- Sour Service
- Fire
- Erosion
- DIP TEST – (Bird Cage Test)

Class III

- Bending Stiffness
- Axial Stiffness
- Abrasion
- Rapid Decompression
- Axial Compression
- Thermal Characteristics
- Thermal Cycling
- Artic, Weathering
- Structural Damping

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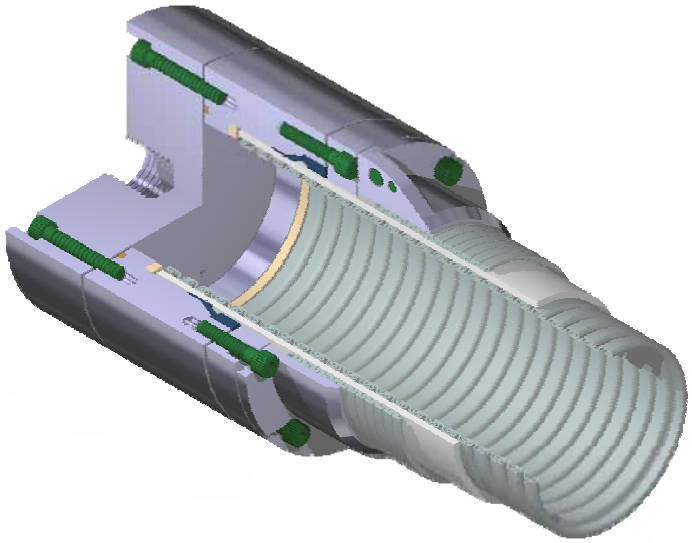
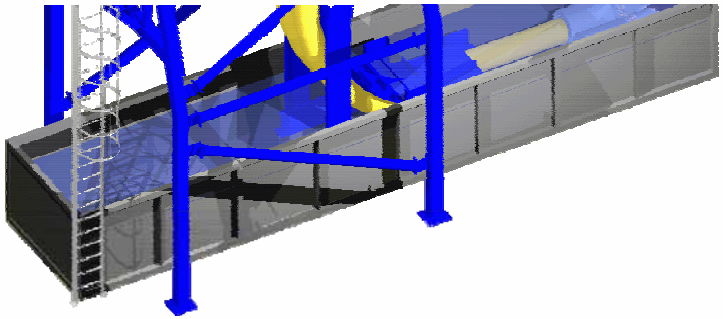
Thermal Cycling

Mid-Scale Thermal Cycle Tests evaluate the swaging and sealing arrangements under thermal loading during start-up, shutdowns and changing properties of the intermediate sheath material over the service life

Full-Scale Thermal Cycle Test As a minimum 50 thermal cycles at specified max / min temperature for two samples. Following completion, pipe is dissected for evidence of barrier slippage





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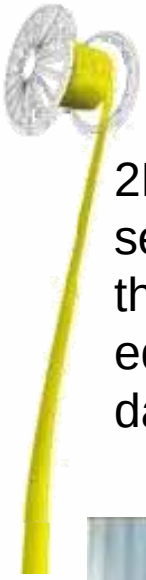
Full-scale Dynamic Fatigue Tests



2M Cycles representing the most severe operating load cases. Also the total test fatigue damage is equivalent to in service fatigue damage. Bore pressure = MAOP

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Wellstream Golfinho C240/C272 Field Product Tests

- Deep Immersion Performance Test, “DIP” test (OFFSHORE)

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