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Deepwater Pipelines Design for Installation and Operation

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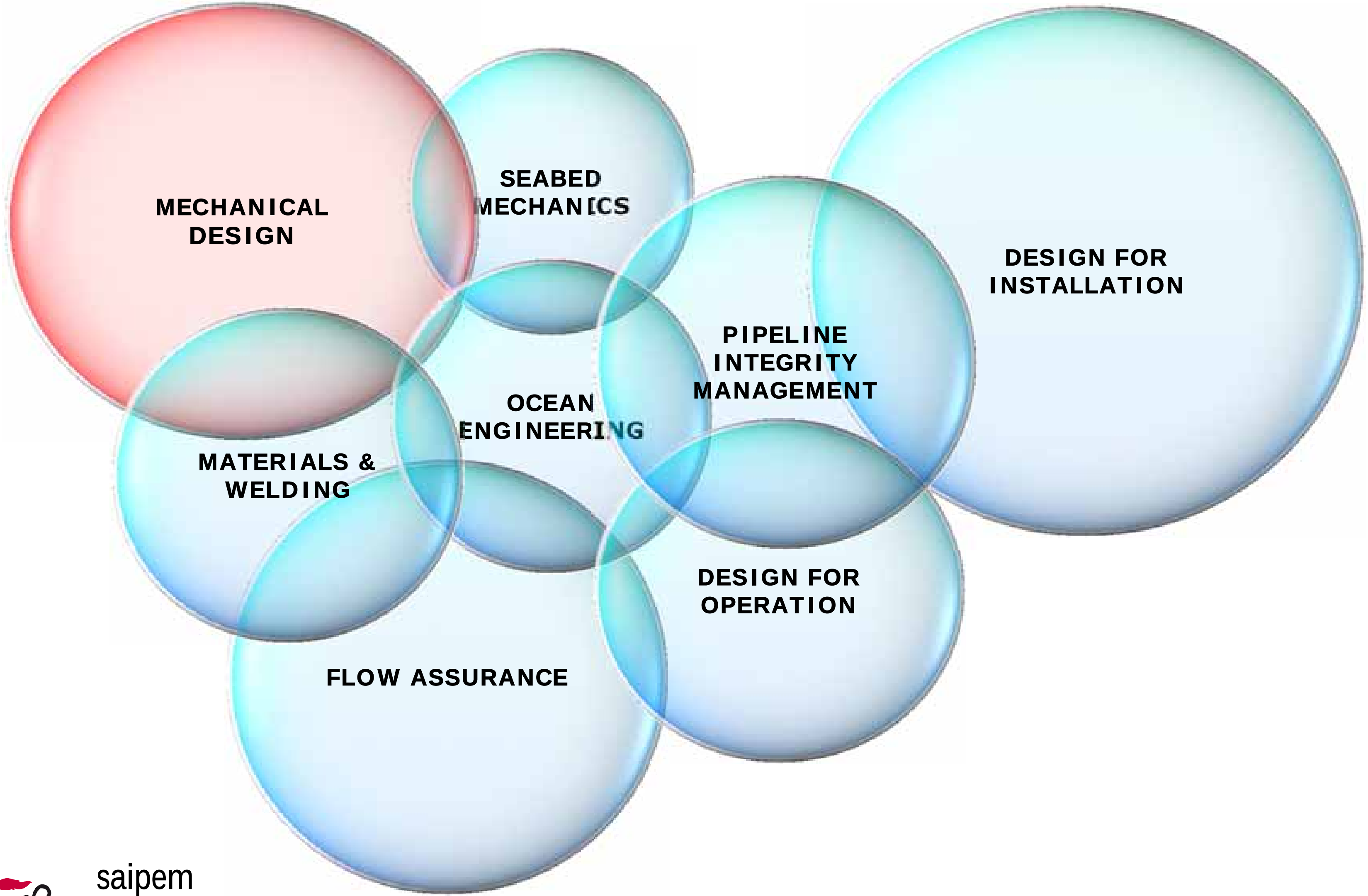
CHALLENGES BY DISCIPLINE …



MECHANICAL DESIGN – MEETING DEFINED SAFETY TARGETS

Design guidelines such as ISO and DNV OS-F101 adopt a LRFD (Load Resistant Factor Design) approach relating failure modes and consequences to "Safety Class" categorization.

- A set of limit state design formats, including partial safety factors for both load and resistance, are defined.
- The partial safety factors to meet a predefined safety target have been calibrated using structural reliability methods.

Reliability methods applied directly to specific structure, avoiding the use of pre-established partial safety factors, are allowed and sometimes recommended.

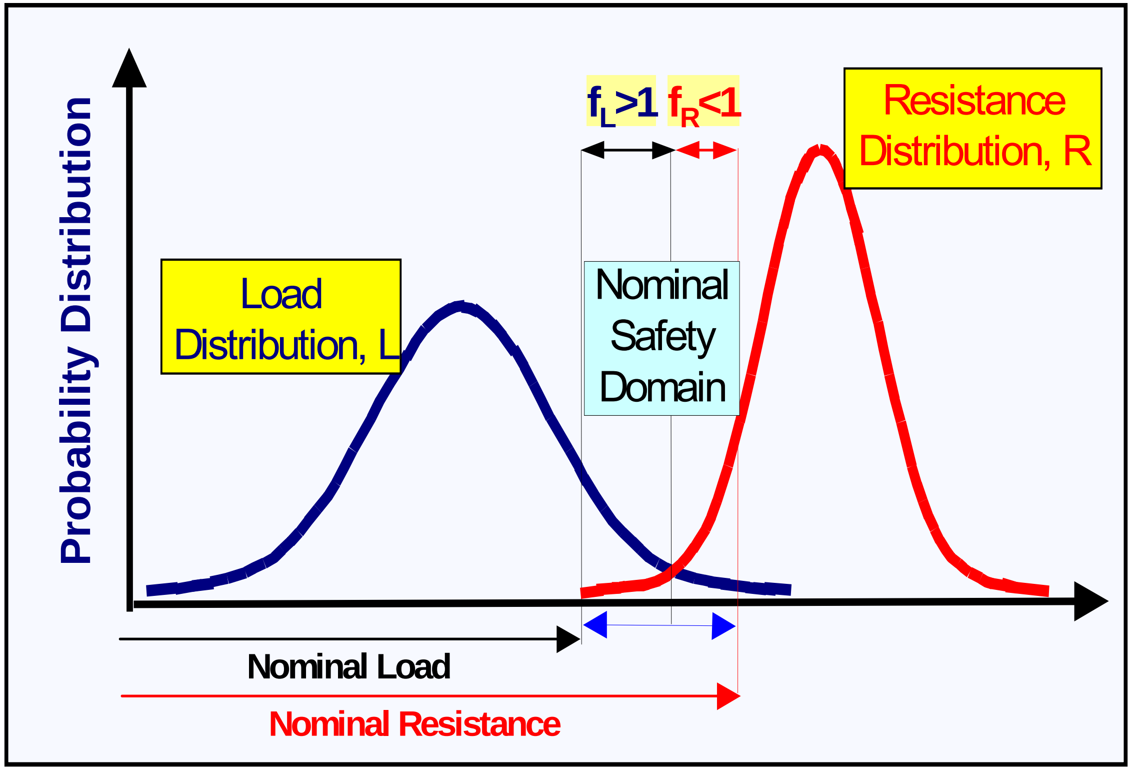
Table 2-5 Nominal failure probabilities vs. safety classes

Limit States	*Probability Bases*	*Safety Classes*			
		Low	*Medium*	*High*	*Very High*[4)]
SLS	Annual per Pipeline[1)]	10^{-2}	10^{-3}	10^{-3}	10^{-4}
ULS [2)]	Annual per Pipeline[1)]	10^{-3}	10^{-4}	10^{-5}	10^{-6}
FLS	Annual per Pipeline[3)]				
ALS	Annual per Pipeline				
-	Pressure containment	10^{-4}-10^{-5}	10^{-5}-10^{-6}	10^{-6}-10^{-7}	10^{-7}-10^{-8}

SLS serviceability limit state ; ULS ultimate limit state; FLS fatigue limit state; ALS accidental limit state

DNV OS-101 2013

Load and Resistance Factors Targeting given Safety Level



The limit state format is a functional relationship including any parameter influencing the relevant failure mode

LIMIT STATES DESIGN FORMAT

$$L_d(\gamma_E,\gamma_F,\gamma_C,\gamma_S) \leq R_d(\gamma_{SC},\gamma_m)$$

where:

L_d	design load effect function
R_d	design resistance function
γ_C	condition load factor
γ_E	environmental load factor
γ_F	functional load factor
γ_S	system safety factor
η	resistance usage factor

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- ULTIMATE LIMIT STATES (ULS):
  - Bursting / Pressure Containment
  - Collapse
  - Propagating Buckling
  - Local Buckling due to Combined Loading (DCC and LCC)
  - Fracture/Plastic Collapse/ Ductile Tearing of Defective Girth Welds
  - Ratcheting (accumulation of plastic deformation in case of excessive bending at the S-lay Stinger)
- SERVICEABILITY LIMIT STATES (SLS):
  - Ovalization Limit due to Bending
- FATIGUE LIMIT STATES (FLS)
- ACCIDENTAL LIMIT STATES (ALS)

MECHANICAL DESIGN - LRFD DNV OS-101 (BURSTING LS)

Minimum wall thickness for pressure containment / bursting according to DNV OS F101 design criteria

The criterion shall be fulfilled in both Operating and System Pressure Test conditions at the applicable water depths.

$$p_{li} - p_e \le \frac{p_b(t_1)}{\gamma_{SC} \cdot \gamma_m}$$

pb(t1)	**Pressure Containment Resistance**
pli	**Local Incidental Pressure**
pe	**Local External Pressure**
γsc	**Safety Class Resistance Factor as per Tab. 5-5 of DNV RP F101**
γm	**Material Resistance Factor as per Tab. 5-4 of DNV RP F101**

$$p_{li} = p_d \times \gamma_{inc} + \rho_{cont} \times g \times h$$

$$p_b(x) = \min(p_{b,s}(x); p_{b,u}(x))$$

$$p_{b,s}(x) = \frac{2x}{D-x} \times f_y \times \frac{2}{\sqrt{3}}$$

$$p_{b,u}(x) = \frac{2x}{D-x} \times \frac{f_u}{1.15} \times \frac{2}{\sqrt{3}}$$

$$x = t_1$$

$$\text{Operational} \Rightarrow t_1 = t_{nom} - t_{fab} - t_{corr}$$

$$\text{Pressure Test} \Rightarrow t_1 = t_{nom} - t_{fab}$$

$$p_{li} = p_d \cdot \gamma_{inc} + \rho_{cont} \cdot g \cdot h$$

Note:

ρ_{cont}	= Density pipeline content
P_b	= Bursting Pressure
D	= Nominal outside Diameter
fy	= SMYS
t_{nom}	= Nominal wall thickness of pipe (un-corroded)
t_{fab}	= Fabrication thickness tolerance
t_{corr}	= Corrosion allowance

Table 5-5 Safety class resistance factors, γ_{SC}

	γ_{SC}		
Safety class	*Low*	*Medium*	*High*
Pressure containment 2)	1.046 3),4)	1.138	1.308 1)
Other	1.04	1.14	1.26

1) For parts of pipelines in location class 1, resistance safety class medium may be applied (1.138).

2) The number of significant digits is given in order to comply with the ISO usage factors.

3) Safety class low will be governed by the system pressure test which is required to be 3% above the incidental pressure. Hence, for operation in safety class low, the resistance factor will effectively be 3% higher.

4) For system pressure test, α_U shall be equal to 1.00, which gives an allowable hoop stress of 96% of SMYS both for materials fulfilling supplementary requirement U and those not.

Table 5-4 Material resistance factor, γ_m

Limit state category1)	*SLS/ULS/ALS*	*FLS*
γ_m	1.15	1.00

1) The limit states (SLS, ULS, ALS and FLS) are defined in D.

According to DNV OS F101 Sect. 3 B305, the incidental over design pressure ratio, γ_{inc}, can be set to 1.05, which is the minimum allowed ratio, provided that the requirements to the Pressure Safety System are satisfied.
This implies that the Pressure Safety System shall guarantee the maximum incidental pressure does not exceed the design pressure by more than 5%.

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MECHANICAL DESIGN - LRFD DNV OS-101 (COLLAPSE LS)

$$p_e - p_{\min} \leq \frac{p_c(t_1)}{\gamma_m \cdot \gamma_{sc}}$$

P_e External Pressure

P_{min} Minimum Internal Pressure (zero for installation except in case of flooded pipe)

P_c Characteristic Resistance to External Pressure (collapse)

γ_{sc} Safety Class Resistance Factor as per DNV OS-F101 Tab. 5-5

γ_m Material Resistance Factor as per DNV OS-F101 Tab. 5-4

$$(p_c - p_{el}) \cdot (p_c^2 - p_p^2) = p_c \cdot p_{el} \cdot p_p \cdot f_o \cdot \frac{D}{t}$$

$$p_{el} = \frac{2E\left(\frac{t}{D}\right)^3}{1-\nu^2}$$

Elastic Collapse Pressure

$$p_p = 2 \cdot SMYS \cdot \alpha_U \cdot \alpha_{fab} \cdot \frac{t_2}{D_o}$$

Plastic Collapse Pressure

$$f_o = \frac{D_{\max} - D_{\min}}{D}$$

Ovality

Table 5-7 Maximum fabrication factor, α_{fab}

Pipe	*Seamless*	*UO & TRB & ERW*	*UOE*
α_{fab}	1.00	0.93	0.85

Table 5-5 Safety class resistance factors, γ_{SC}

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Table 5-4 Material resistance factor, γ_m

Limit state category1)	*SLS/ULS/ALS*	*FLS*
γ_m	1.15	1.00

1) The limit states (SLS, ULS, ALS and FLS) are defined in D.

Note:

D Nominal Outside Diam.

D_{max} Maximum In/Outside Diam.

D_{min} Minimum In/Outside Diam.

α_U Material Strength Factor

$t_1 = t_{nom} - t_{fab}$ (Install & Hydrotest)

$t_1 = t_{nom} - t_{fab} - t_{corr}$ (Operating)

t_{nom} Nominal Steel Wall Thickness

t_{fab} Fabrication Thick. Tolerance

t_{corr} Corrosion Allowance

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MECHANICAL DESIGN - LRFD DNV OS-101 (LOCAL BUCKLING LS LCC)

$$\left\{\gamma_m \cdot \gamma_{SC}\left(\frac{|M_{Sd}|}{\alpha_c \cdot M_p(t_2)}\right) + \left\{\frac{\gamma_m \cdot \gamma_{SC} \cdot S_{Sd}}{\alpha_c \cdot S_p(t_2)}\right\}^2\right\}^2 + \left(\gamma_m \cdot \gamma_{SC} \cdot \frac{p_e - p_{min}}{p_c(t_2)}\right)^2 \leq 1$$

P_e	External Pressure
P_{min}	Minimum Internal Pressure (zero for installation except in case of flooded pipe)
P_c	Characteristic Resistance to External Pressure (collapse)
α_c	Flow Stress Parameter
M_{Sd}	Design Moment
S_{Sd}	Design Effective Axial Force
γ_{sc}	Safety Class Resistance Factor as per DNV OS-F101 Tab. 5-5
γ_m	Material Resistance Factor as per DNV OS-F101 Tab. 5-4

$$S_P = f_y \cdot \pi \cdot (D_0 - t_2) \cdot t_2$$

Plastic Axial Capacity

$$M_P = f_y \cdot (D_0 - t_2)^2 \cdot t_2$$

Plastic Bending Capacity

$$\left(\frac{p_C}{p_{el}} - 1\right)\left(\left(\frac{p_C}{p_p}\right)^2 - 1\right) = f_0 \frac{p_C}{p_p}\frac{D_o}{t_2}$$

Collapse Pressure

- $f_0 = f(D_{max}, D_{min}, D_0)$
- $p_{el} = f(E, D_0, t)$
- $p_p = f(SMYS, \alpha_U, \alpha_{fab}, D_0, t)$

$$\alpha_c = (1 - \beta) + \beta \cdot \frac{f_u}{f_y}$$

$$\beta = \begin{cases} 0.5 & \text{for } D_0/t_2 < 15 \\ \left(\frac{60 - D_0/t_2}{90}\right) & \text{for } 15 \leq D_0/t_2 < 60 \\ 0 & \text{for } D_0/t_2 > 60 \end{cases}$$

Table 5-5 Safety class resistance factors, γ_{SC}

Safety class	γ_{SC} Low	Medium	High
Pressure containment 2)	1.046 3),4)	1.138	1.308 1)
Other	1.04	1.14	1.26

Table 5-4 Material resistance factor, γ_m

Limit state category1)	SLS/ULS/ALS	FLS
γ_m	1.15	1.00

Note:

- D_0 Nominal Outside Diam.
- α_U Material Strength Factor
- $t_2 = t_{nom}$ (Install & Hydrotest)
- $t_2 = t_{nom} - t_{corr}$ (Operating)
- t_{nom} Nominal Steel Wall Thickness
- t_{corr} Corrosion Allowance

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MECHANICAL DESIGN - LRFD DNV OS-101 (LOCAL BUCKLING LS DCC)

$$\left(\frac{\gamma_\varepsilon \cdot \varepsilon_{Sd}}{\varepsilon_C(t_2,0)}\right)^{0.8} + \frac{\gamma_m \cdot \gamma_{SC} \cdot (p_e - p_{min})}{p_C(t_2)} \le 1$$

P_e	External Pressure
P_{min}	Minimum Internal Pressure (zero for installation except in case of flooded pipe)
ε_c	Characteristic Bending Strain Resistance
ε_{Sd}	Design Compressive Strain
P_c	Characteristic Resistance to External Pressure (collapse)
γ_{sc}	Safety Class Resistance Factor as per DNV OS-F101 Tab. 5-5
γ_m	Material Resistance Factor as per DNV OS-F101 Tab. 5-4
γ_ε	Resistance Strain Factor as per DNV OS-F101 Tab. 5-8

$$\varepsilon_C = 0.78 \cdot \left(\frac{t_2}{D_0} - 0.01\right)\frac{\alpha_{gw}}{\alpha_{h,d}^{3/2}}$$

Yield to Tensile Strength Ratio

$$\alpha_{h,d} = \max\left(SMYS/SMTS\right)$$

Girth Weld Factor

$$\alpha_{gw} = \begin{cases} 1.0 & if \quad D_0/t_2 \le 20 \\ 1.0 - \dfrac{\left(D_0/t_2 - 20\right)}{100} & if \quad 20 < D_0/t_2 \le 60 \\ not\ defined & if \quad D_0/t_2 > 60 \end{cases}$$

Collapse Pressure

$$\left(\frac{p_C}{p_{el}} - 1\right)\left(\left(\frac{p_C}{p_p}\right)^2 - 1\right) = f_0 \frac{p_C}{p_p}\frac{D_0}{t_2}$$

- $f_0 = f(D_{max}, D_{min}, D_0)$
- $p_{el} = f(E, D_0, t)$
- $p_p = f(SMYS, \alpha_U, \alpha_{fab}, D_0, t)$

Table 5-5 Safety class resistance factors, γ_{SC}

Safety class	Low	Medium	High
	γ_{SC}		
Pressure containment 2)	1.046 3),4)	1.138	1.308 1)
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Table 5-4 Material resistance factor, γ_m

Limit state category1)	SLS/ULS/ALS	FLS
γ_m	1.15	1.00

1) The limit states (SLS, ULS, ALS and FLS) are defined in D.

Table 5-8 Resistance strain factors, $\gamma\varepsilon$

Safety class		
Low	Medium	High
2.0	2.5	3.3

Note:

D_0 Nominal Outside Diam.

$t_2 = t_{nom}$ (Install & Hydrotest)

$t_2 = t_{nom} - t_{corr}$ (Operating)

t_{nom} Nominal Steel Wall Thickness

t_{corr} Corrosion Allowance

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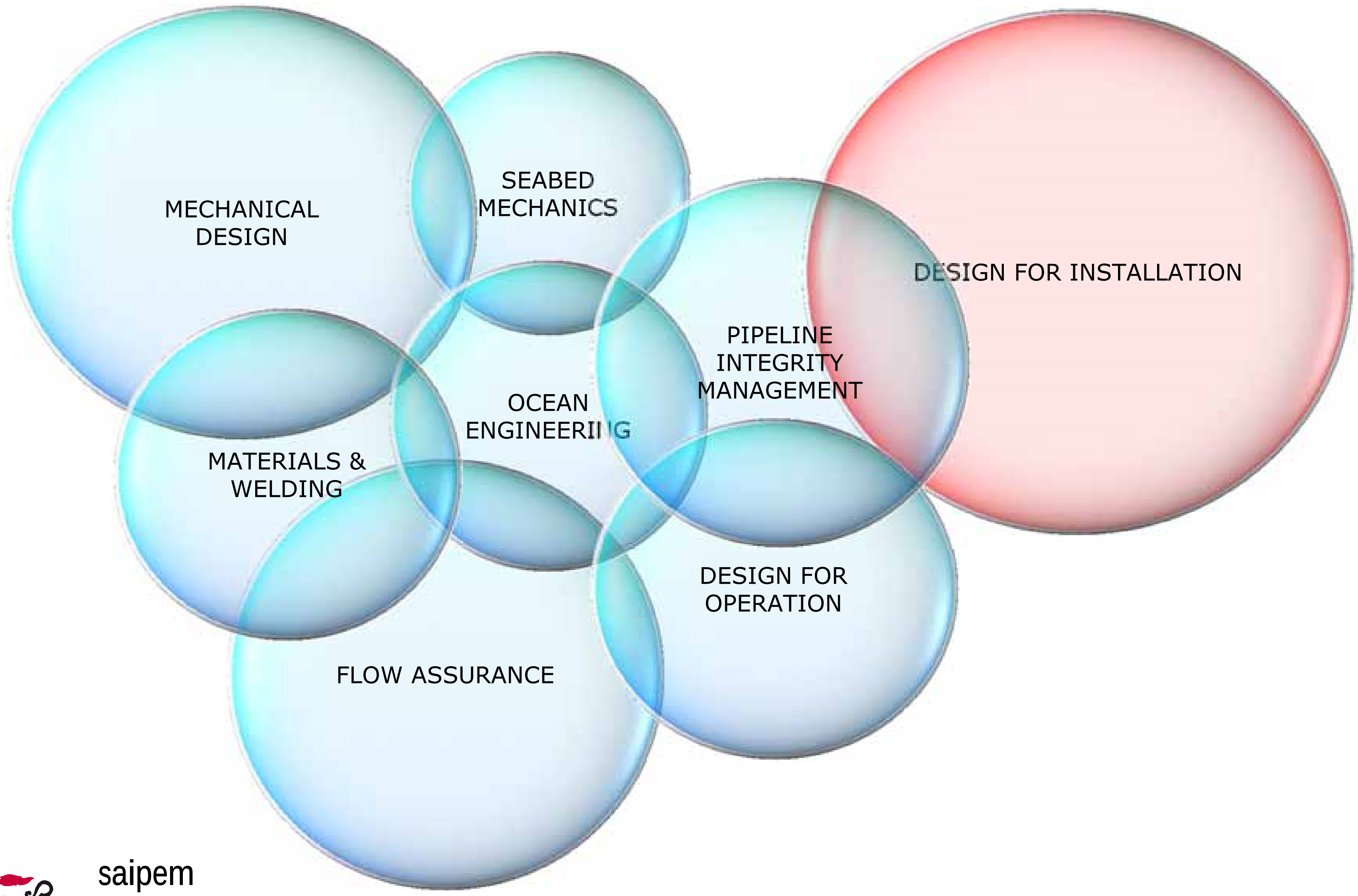
CHALLENGES BY DISCIPLINE …



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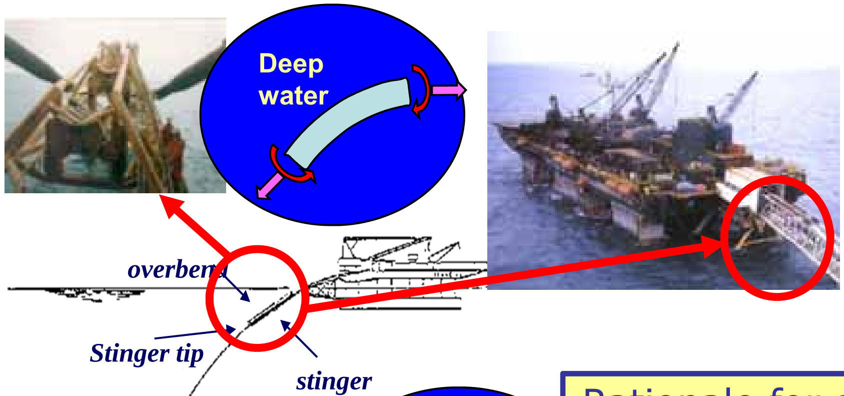
DESIGN FOR INSTALLATION – RELEVANT LIMIT STATES

The relevant failure modes and limit states for offshore pipeline installation are the following:

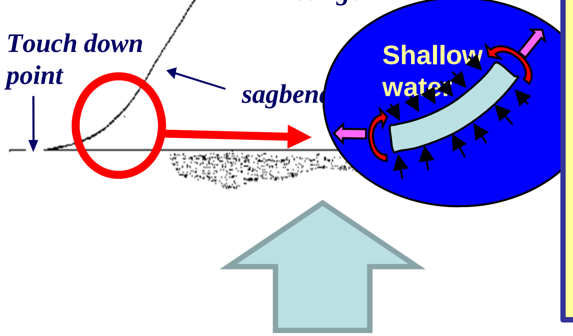
- **Collapse** due to external pressure.
- **Buckle propagation** due to the external pressure in case of buckle initiation.
- **Local buckling** due to external pressure and bending at the sagbend and due to tensioner and bending on the stinger in case of S-Lay installation or in flute of the J-Lay tower.
- **Concrete crushing** at the stinger in case of S-lay technology.
- **Plastic collapse & fracture** of defective girth welds.
- **Fatigue damage** of the girth welds due to severe loads and long time interval from ramp exit to touch down point.

DESIGN FOR INSTALLATION - PIPE “S” AND “J” LAYING



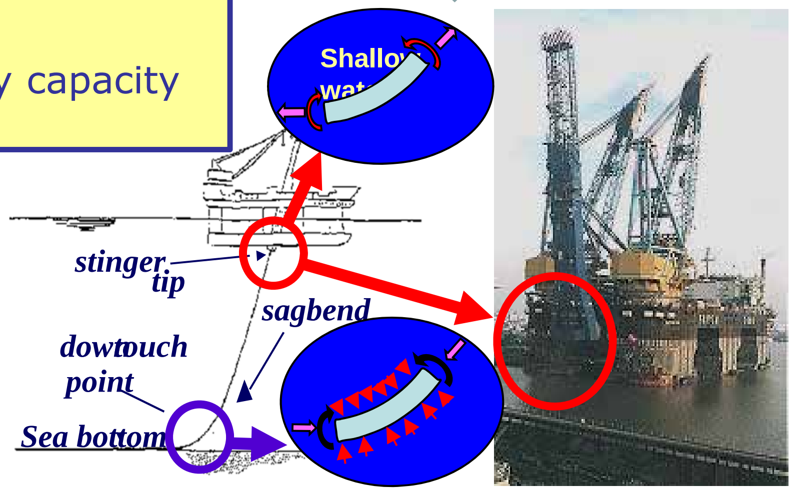
J-laying: the pipe departs from the lay vessel at a near vertical angle, hanging like a cable and gently curving towards the horizontal as it approaches the seabed.

- Low tension forces required to hold the pipe in suitably “J” shaped lay span
- Slow lay rate, 2-3 (5) km/day
- Low curvatures of the lay span



Rationale for safe installation of subsea and sealines:

- pipeline
- lay operation mode
- lay equipment
- vessel strength/stability capacity
- calculation



S-laying: consists of assembling the pipe joints on the horizontal ramp of the lay vessel.

- Even for large diameter pipes, 2-4 (6) km/day
- High curvature applied on the overbend
- High tensioner forces required to hold the pipe in suitably “S” shaped lay span

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DESIGN FOR INSTALLATION - CRITERIA

Laying Criteria aiming to define allowable moments and strains is the following:

- At the Overbend region (mainly S-Lay):
  - Strain (DNV OS – F101) Simplified Criteria
  - **Strain (DNV Design Guideline) Design Criteria**
  - **Allowable Bending Moment (JIP Design Guideline) Design Criteria**

- At the Stinger Tip (mainly S-Lay):
  - Allowable Bending Moment (DNV OS – F101) Design Criteria
  - No contact to the Stinger Tip (Recommended Practice)

- At the Sagbend region (both S & J-Lay):
  - Bending Moment (DNV OS – F101) Design Criteria (2)
  - **Bending Strain (JIP Design Guideline) Design Criteria**
  - Bending Strain of 0.15% (API Recommended Practice) Design Criteria (3)

1. The red one are generally used.
2. Load Controlled Condition (LCC) i.e. Bending moment criterion is generally used in Shallow Waters.
3. Displacement Controlled Condition (DCC) i.e. Bending strain criterion is generally used in Deep Waters.

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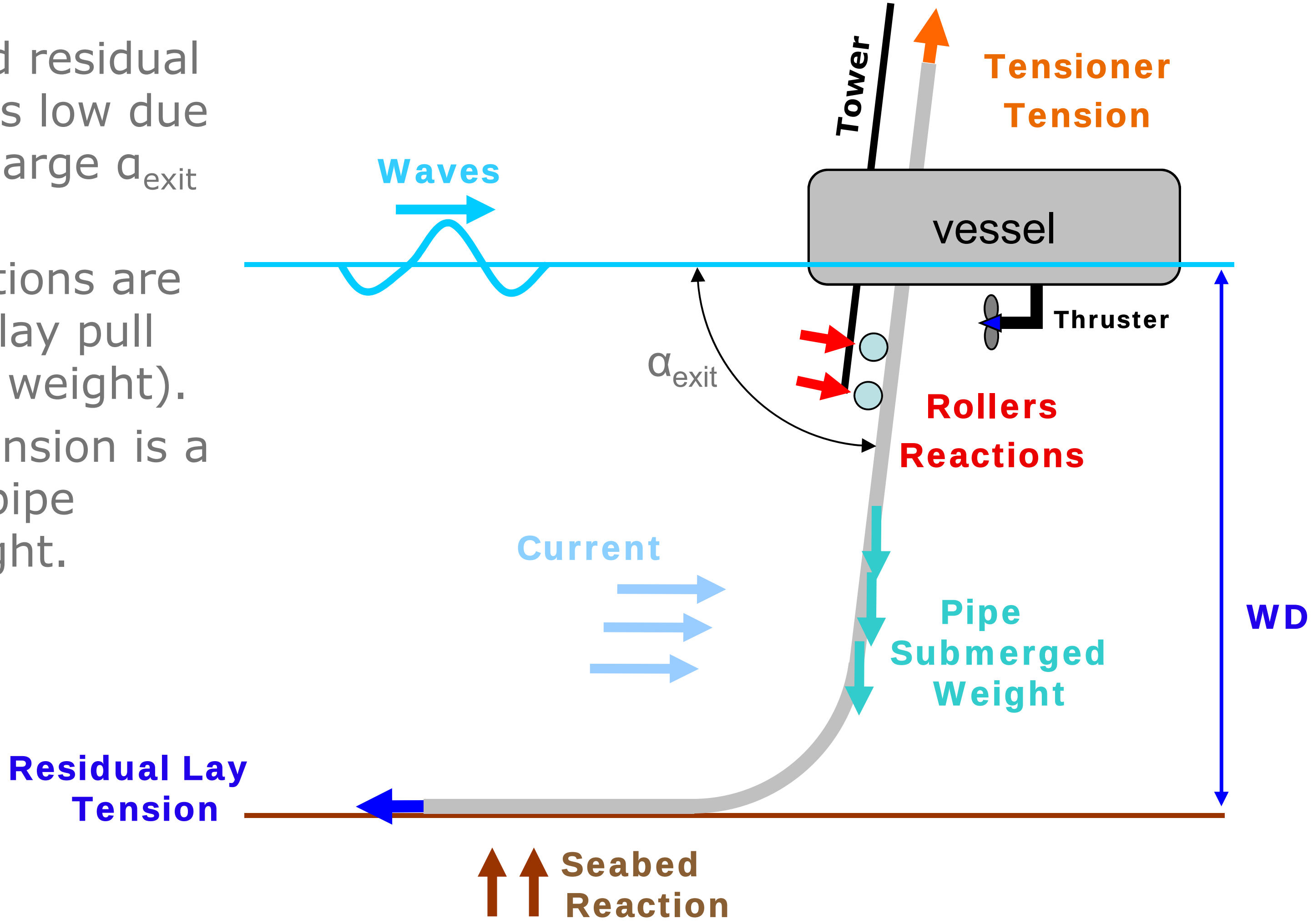
DESIGN FOR INSTALLATION - J-LAY LOAD CONDITIONS

- The required residual lay tension is low due to the very large α_{exit} (~90 deg).
- Rollers reactions are due to pipe lay pull (not to pipe weight).
- Tensioner tension is a function of pipe column weight.



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DESIGN FOR INSTALLATION - S-LAY LOAD CONDITIONS

From:

- Average Stinger Radius ←→ Exit Angle
- Allowable Strain at Stinger ←→ Wall Thickness

To:

- Top Tension ←→ Tension Capacity
- Bottom Tension ←→ Propeller Capacity

Main Relationship:

- $ST_T \sim BT + SW*WD - BK^2/2$

Where:

ST_T *is the stinger Tip Tension*

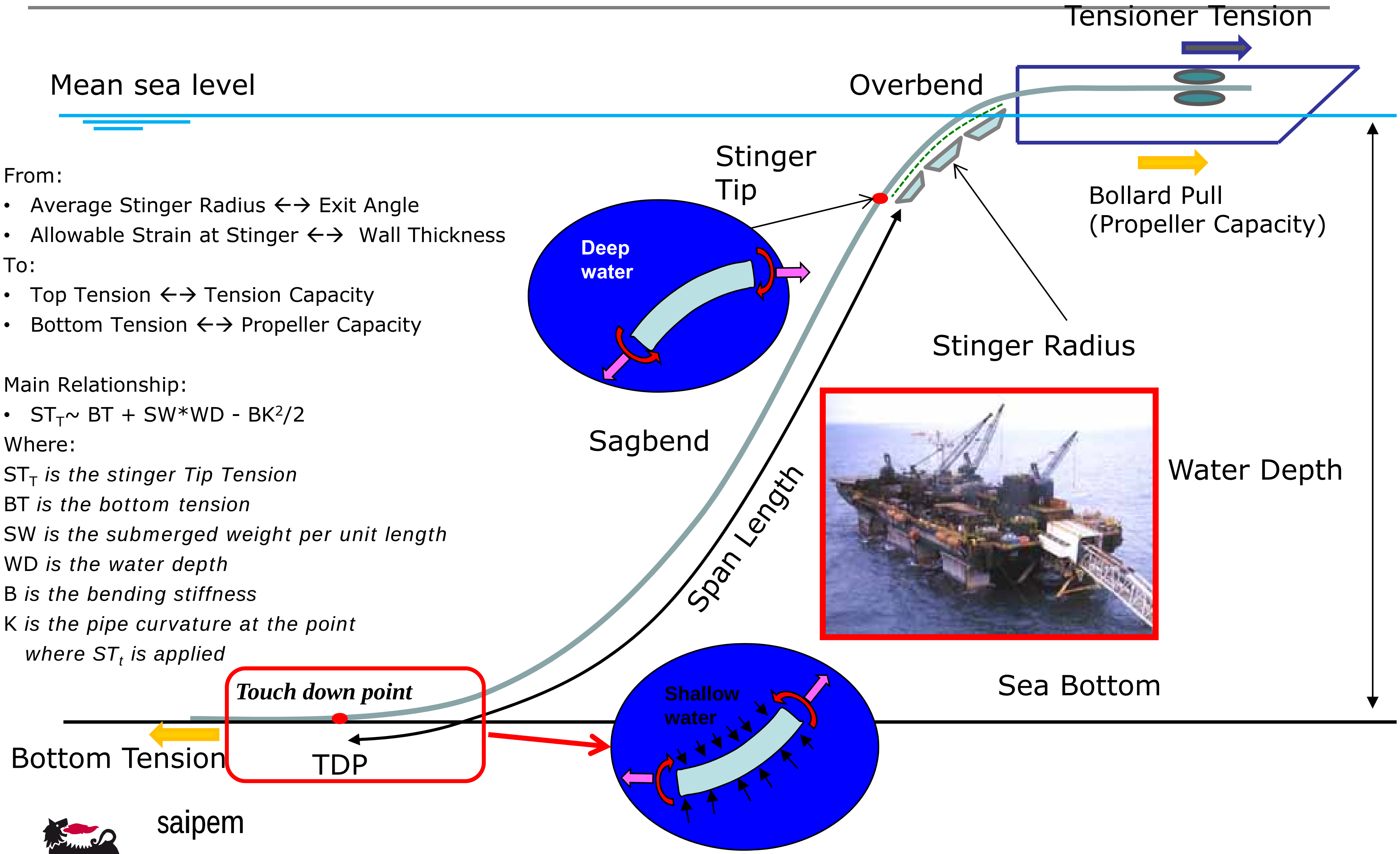
BT *is the bottom tension*

SW *is the submerged weight per unit length*

WD *is the water depth*

B *is the bending stiffness*

K *is the pipe curvature at the point where* ST_t *is applied*



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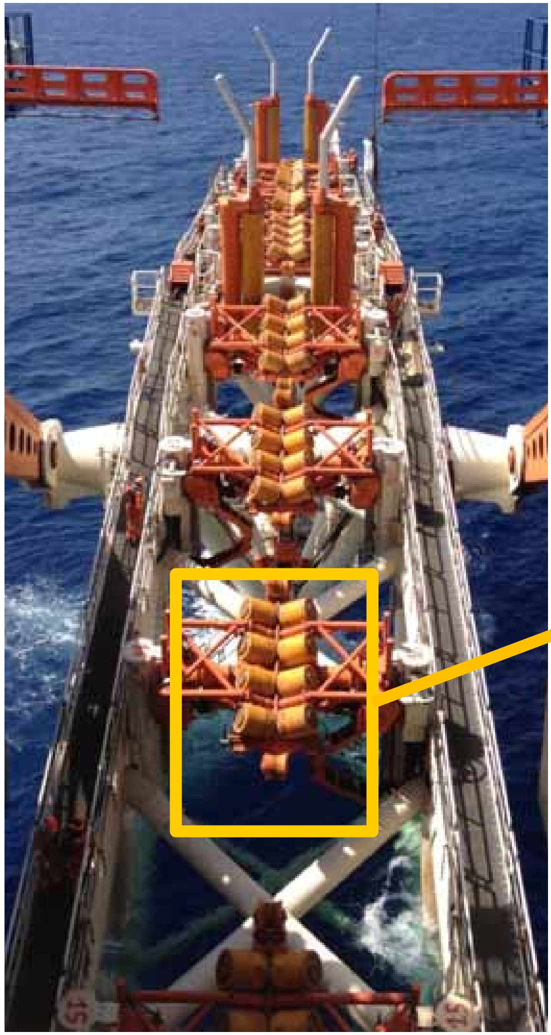
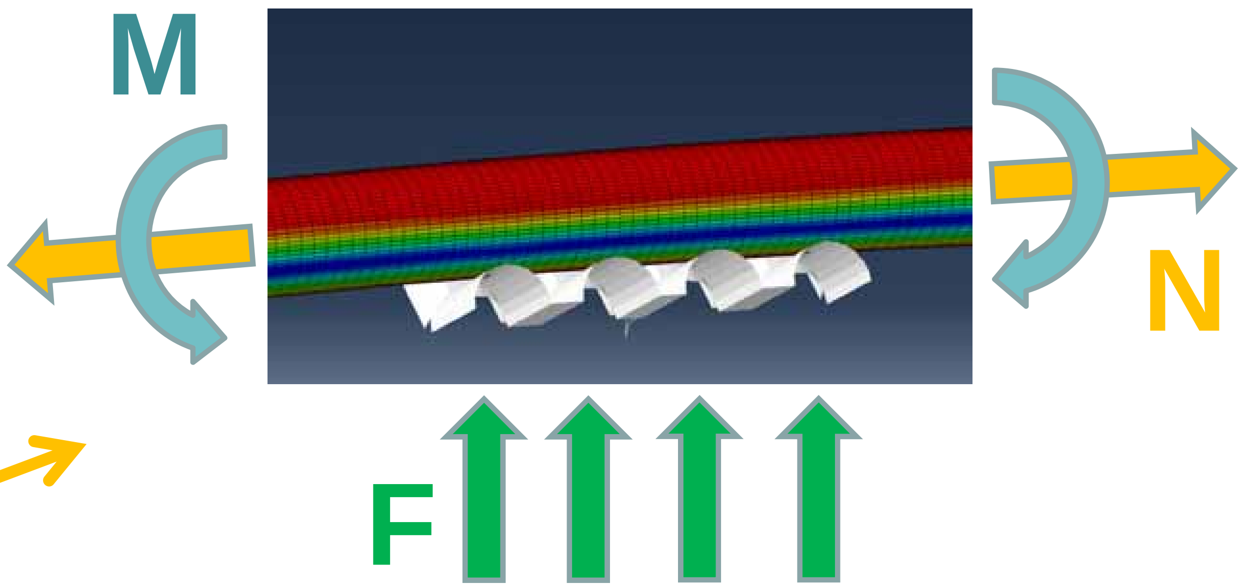
DESIGN FOR INSTALLATION - S-LAY LOCAL LOAD CONDITIONS





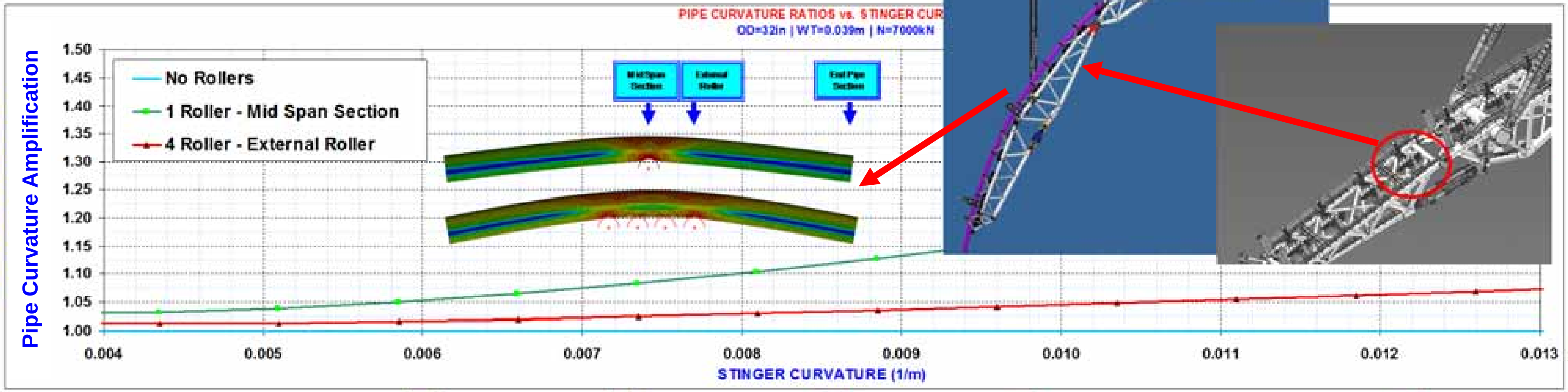
$M = f(R_{stinger})$

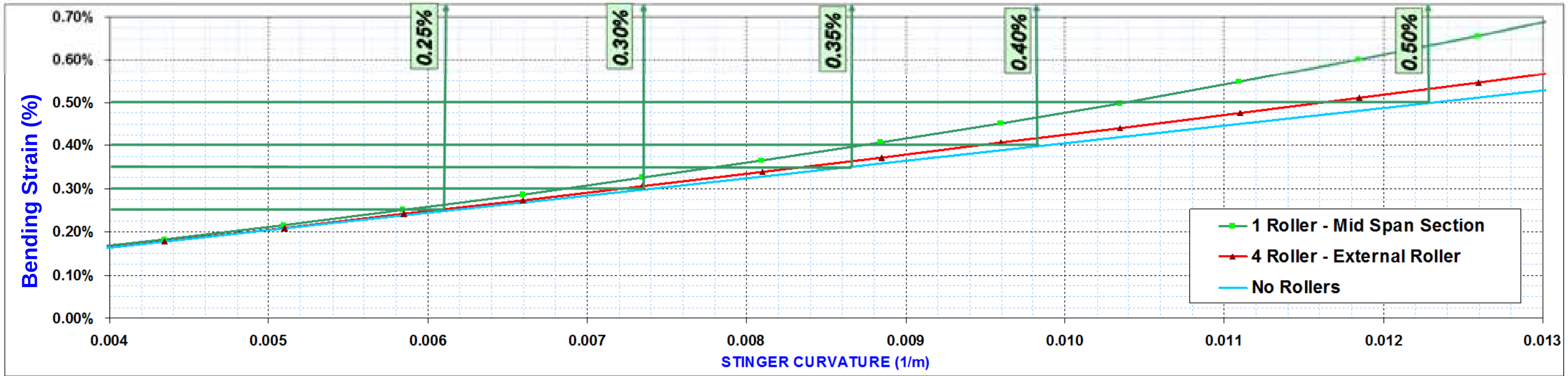
$F = f(N, R_{stinger})$

$N = \frac{1}{2} EJ * k^2 + RLT + WD*S_{Weight}$

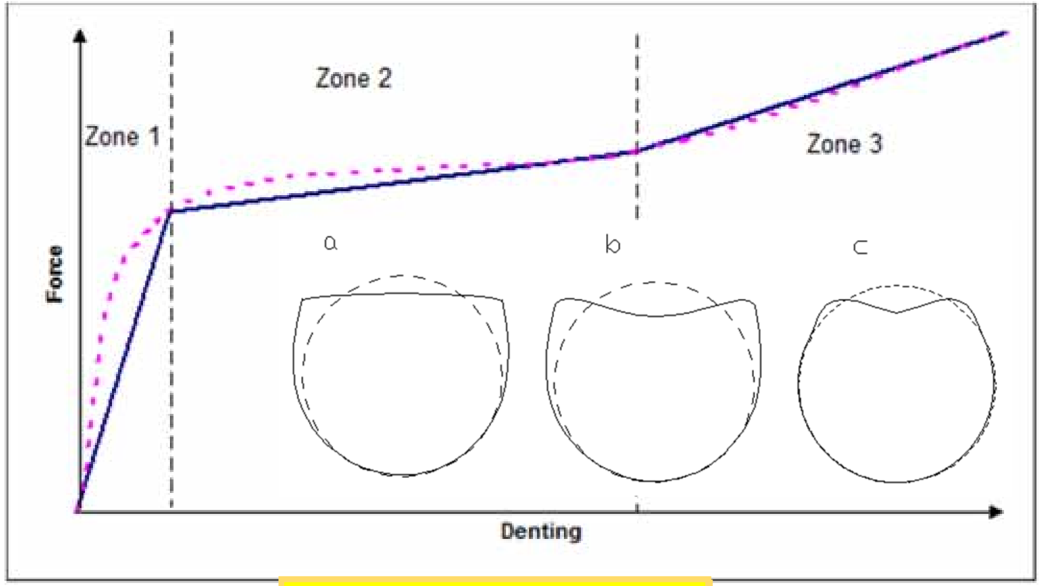
DESIGN FOR INSTALLATION - S-LAY LOCAL LOAD CONDITIONS

The amplification of the pipe local curvature increases considering a concentrated contact (1 roller vs. 4 rollers) and reducing the stinger curvature radius





DESIGN FOR INSTALLATION – MINIMUM PIPE WALL THICKNESS



$$F_{elastic} = 3.9 \cdot \sigma_y \cdot t^2$$

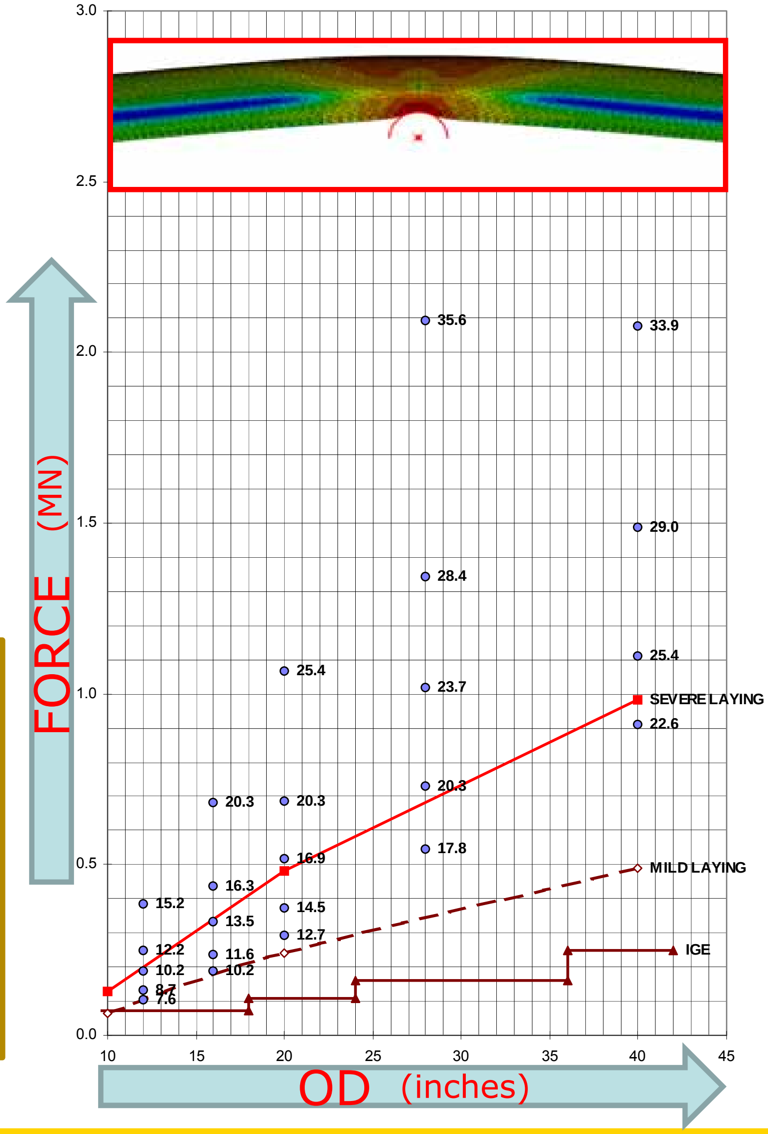
Generally:

- for pipeline exposed to frequent point load events (occurrence >= 10-4 per year per km)

  16"<OD<20" : 14 mm wall thickness
  20"<OD<36" : 16 mm wall thickness
  OD>36" : 18 mm wall thickness

- for pipeline not exposed to frequent point load event

  10<OD<16" : 10 mm wall thickness
  16<OD<20" : 12 mm wall thickness



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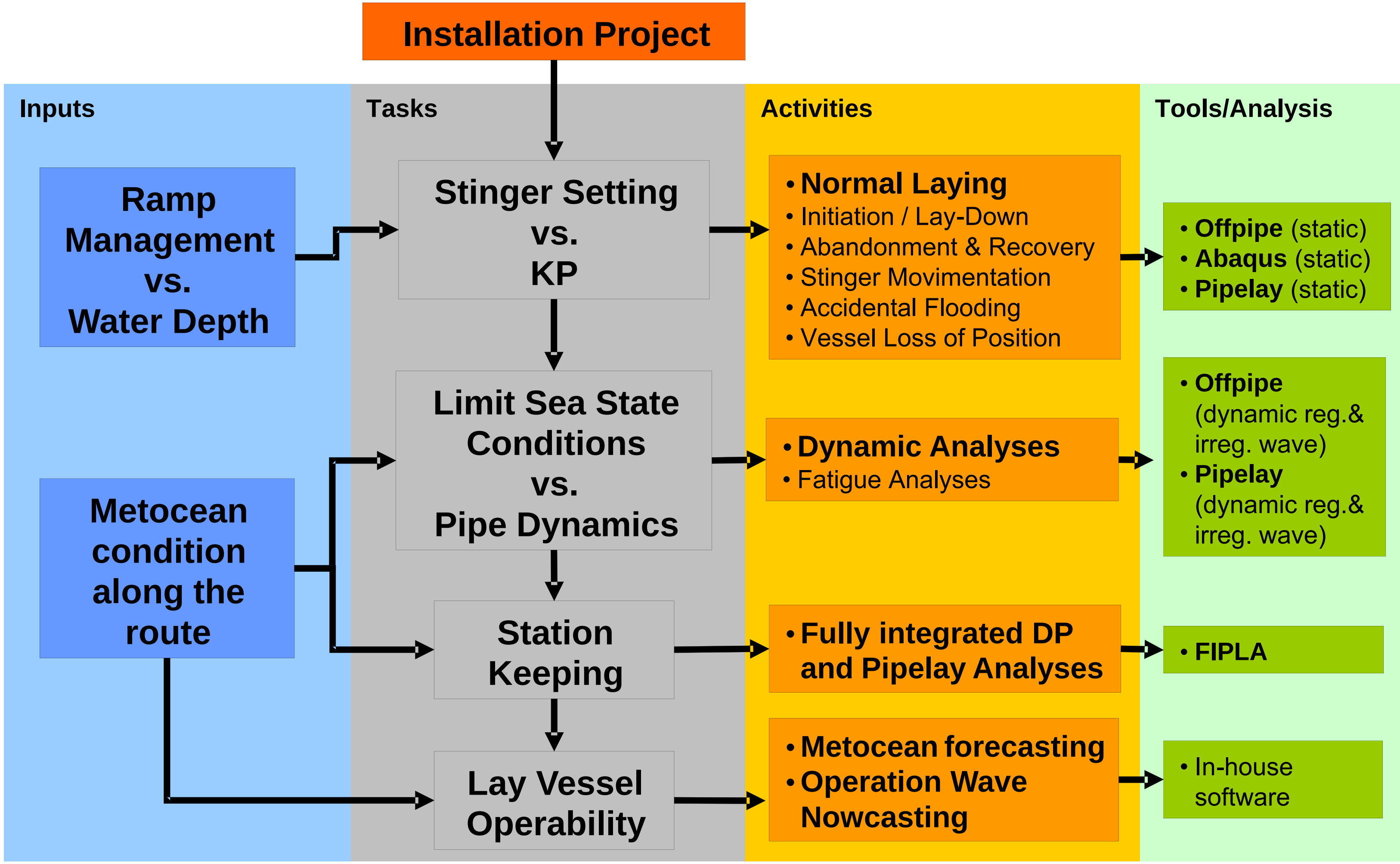
DESIGN FOR INSTALLATION - ANALYSIS



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DESIGN FOR INSTALLATION – ANALYSIS OUTCOME

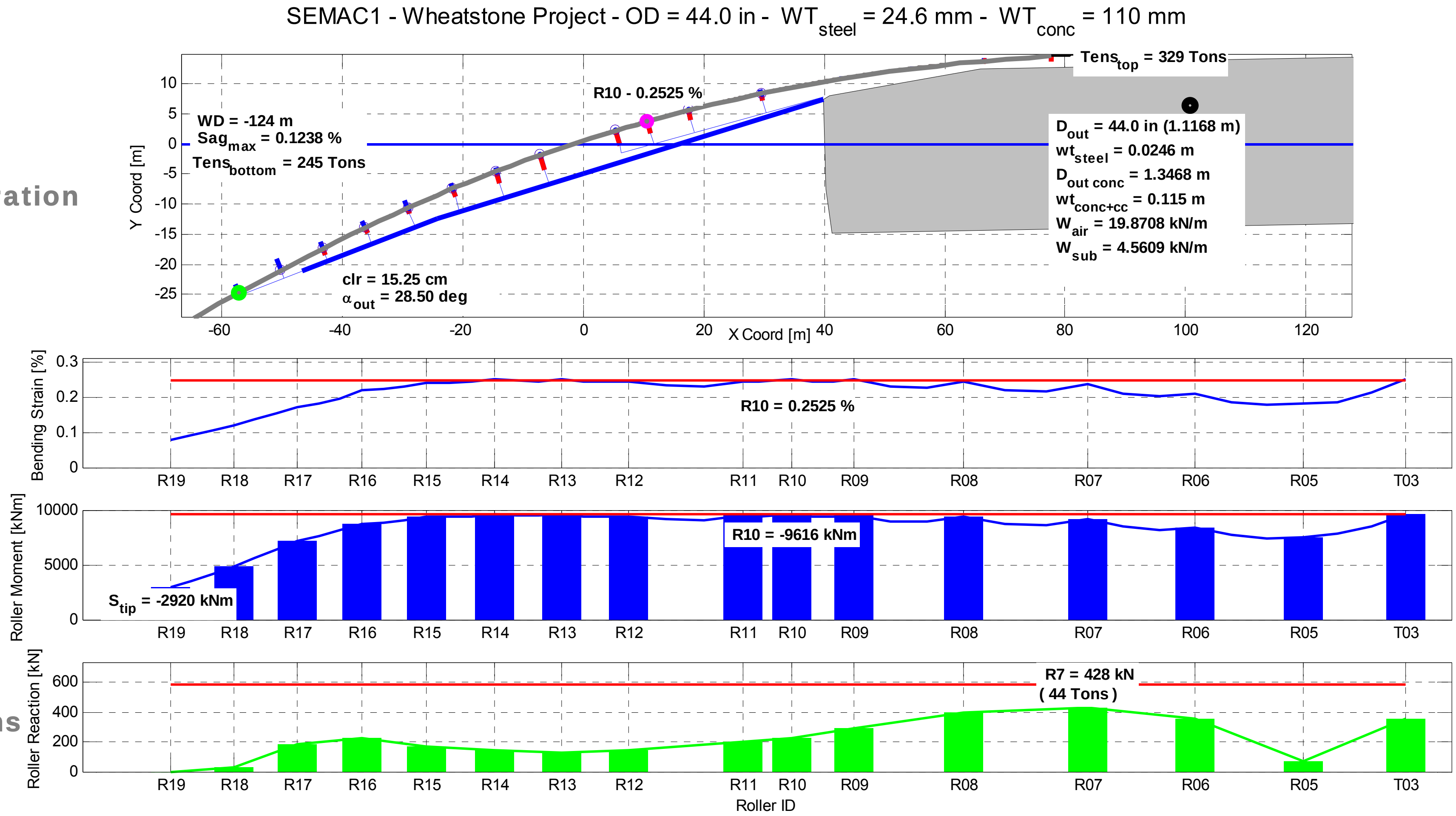
Analysis results (Overbend region & Stinger Tip)

Pipe Configuration

Strain

Moment

Reactions



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DESIGN FOR INSTALLATION – LARGE CAPACITY EQUIPMENT

A&R/SUBSEA DEPLOYMENT SYSTEM WITH **HIGHER CAPACITY**

- Fabrication: feasibility up to dia 180mm, MBL 2500mT, length 3800 m
- Testing: availability of test facilities up to 2500 t
- Alternative solutions (use of multiple steel wires system) move problems from the fabrication/testing of the steel wire to the inspection/discard criteria

DESIGN CRITERIA

- Applicable standards for offshore A&R/Subsea deployment winches/steel wire
- Safety factor definition criteria in Normal/Emergency Operation
- Wire Rope Fatigue Life design Criteria
- Test Requirements: break testing and test facilities available

MAINTENANCE/INSPECTION CRITERIA

- Maintenance of subsea ropes: lubrications (type of lubricants, application methods, regulations)
- Monitoring/inspection during operation: method and criteria (visual inspection, NDE, cut back and test, cycles data logging and fatigue monitoring)
- Discard criteria: definition, methodology and regulation

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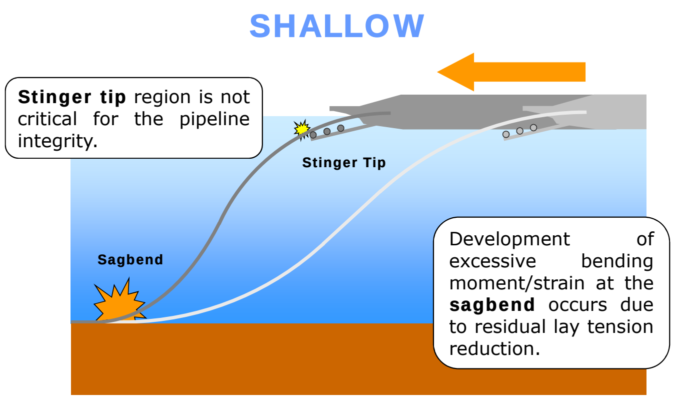
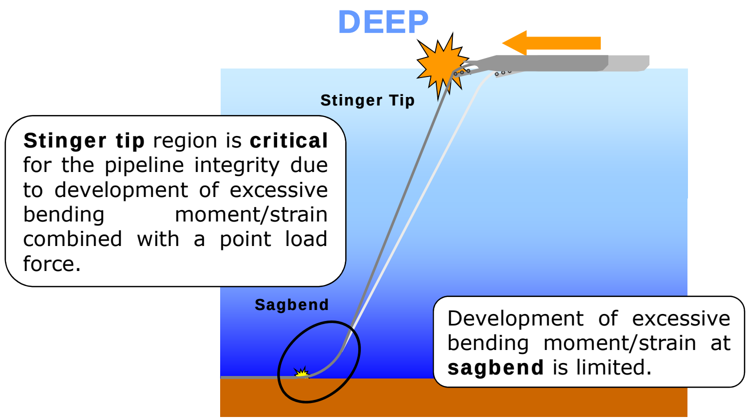
DESIGN FOR INSTALLATION – INCIDENTAL FLOODING

Pipe S and J Laying, Water Flooding during Installation

- Accidental Flooding Scenarios **failure modes**:
  - Excessive Bending Moment/Strain combined with Point Load Force at **stinger tip** (mainly Deep Water scenarios);
  - Excessive Bending Moment/Strain at **TDP region** (mainly Shallow Water scenarios)
  - **Defective** through thickness **girth weld**
  - **Leaking valve** on special items

- **Accidental Flooding Scenarios shall take into account**:
  - Distinguish **Deep** vs. **shallow** water scenarios;
  - Distinguish **Trunkline vs. flowline** (different pipe flooding time and evolution);
  - Contingency measures, if any, and lay vessel structural integrity more than pipe integrity;
  - Accidental flooding is **generally driven by the lay equipment and vessel integrity**;
  - Vessel equipment includes a **smart wet buckle detection system**.





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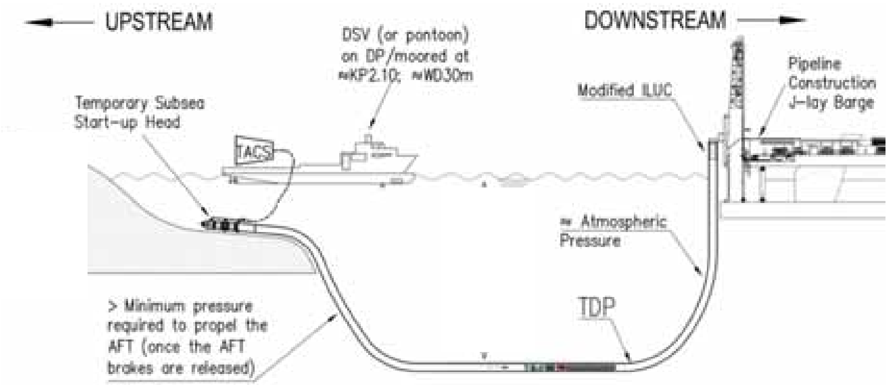
Parameters on a large and complex project
55000 hp => 1000 hp
100 M€ => 10 M€
3600 psi => 36 psi
RTO 72 h => 72 s
RTO = Ready To Operate

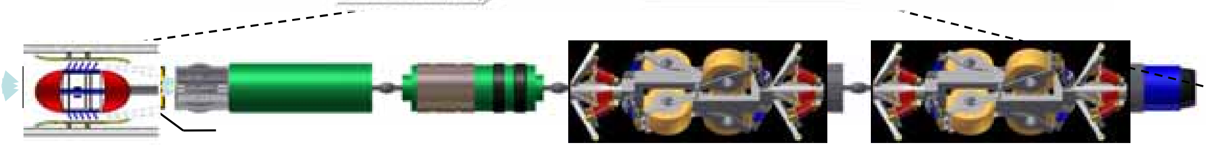
- **Principles / Application**

Use a market available pipeline isolation tool for reducing flooding risk when laying in deepwater.

- **Objectives**

Drastically reduce the need for a compression station at land, which is needed for pipeline recovery operations in case of pipeline rupture during laying.
Compression station cost reduction.
Reduce time to recover a pipeline damage situation, because only the last part of the pipeline need to be deflooded.





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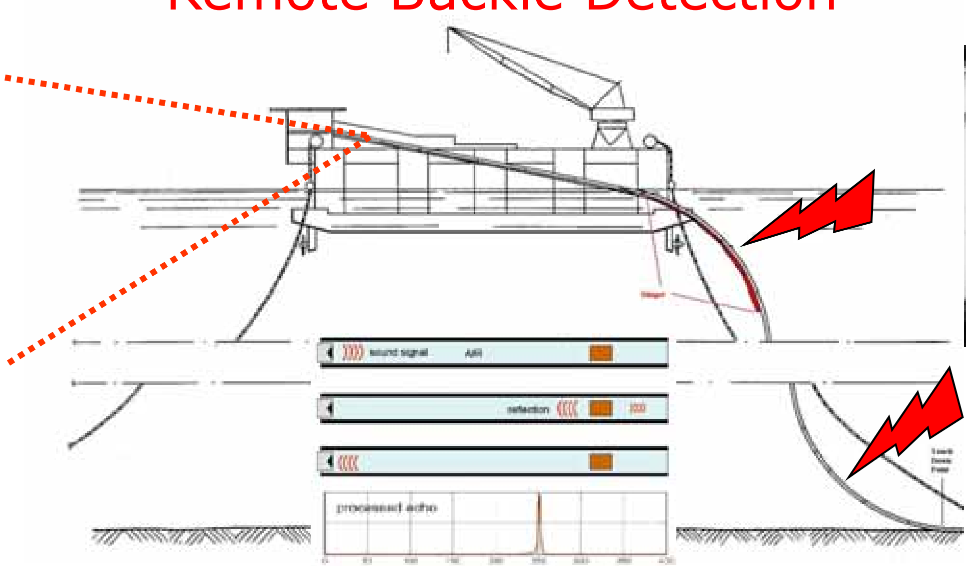
Remote Buckle Detection



- Principles / Application

Injecting a signal (radio, pressure wave) into a waveguide (pipeline) face-end, each geometrical anomaly reflect part of the signal depending on its characteristics.

- Objectives

A system which can provide a certified Buckle Measure up to the end of the stinger and capable to detect obstructions up to about 4 Km.

Reduce risk in case of mechanical BD failure and retrieval. Reduce time for corrective actions.

TECHNOLOGY COMPARISON

	Radio (RF),	Pressure Wave (AC)
Pros	Fast	Good Range
	Hi-Repeatability	Hi-Repeatability
	On board noise proof	Simple technology
Cons	Accuracy	Accuracy
	Range	On board noise influence
	Complex technology	

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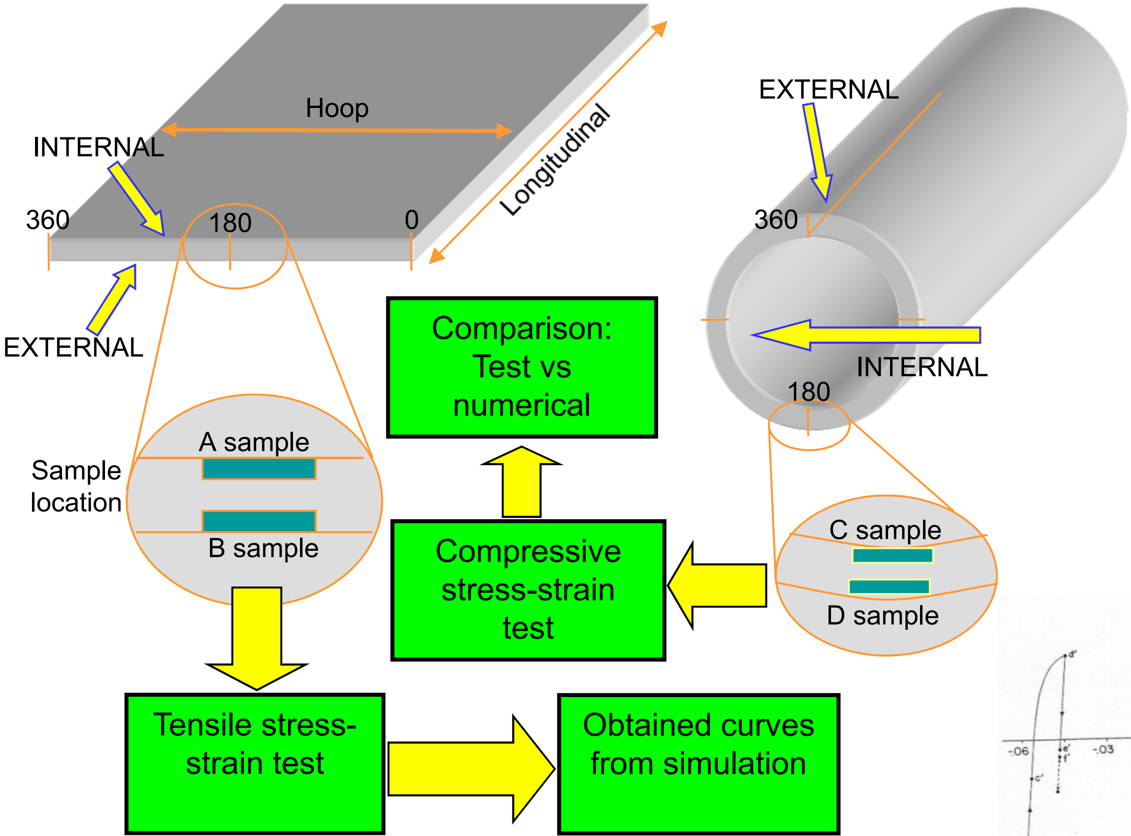
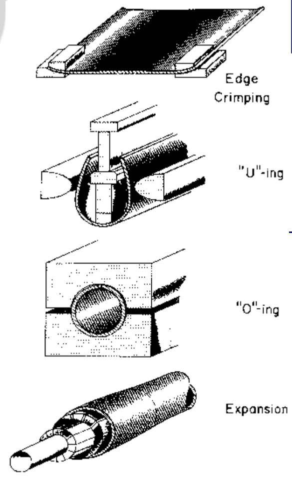
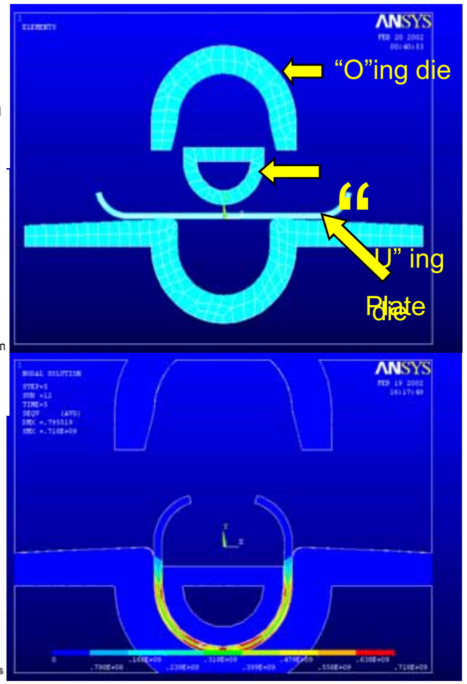
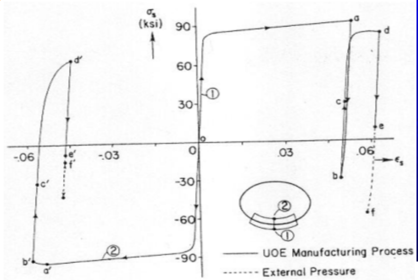
DESIGN FOR INSTALLATION – MANUFACTURING VERY THICK LP



FINITE ELEMENT MODELING







WHERE (across thickness) and WHEN (plate, pipe, before or after coating) to characterise the compression capacity of the line pipe steel → a_{fab}

Line Pipe Manufacturing Issues (JC vs. UO)

Bauschinger effects included in design criteria equation by a_{fab} (see DNV OS-F101)

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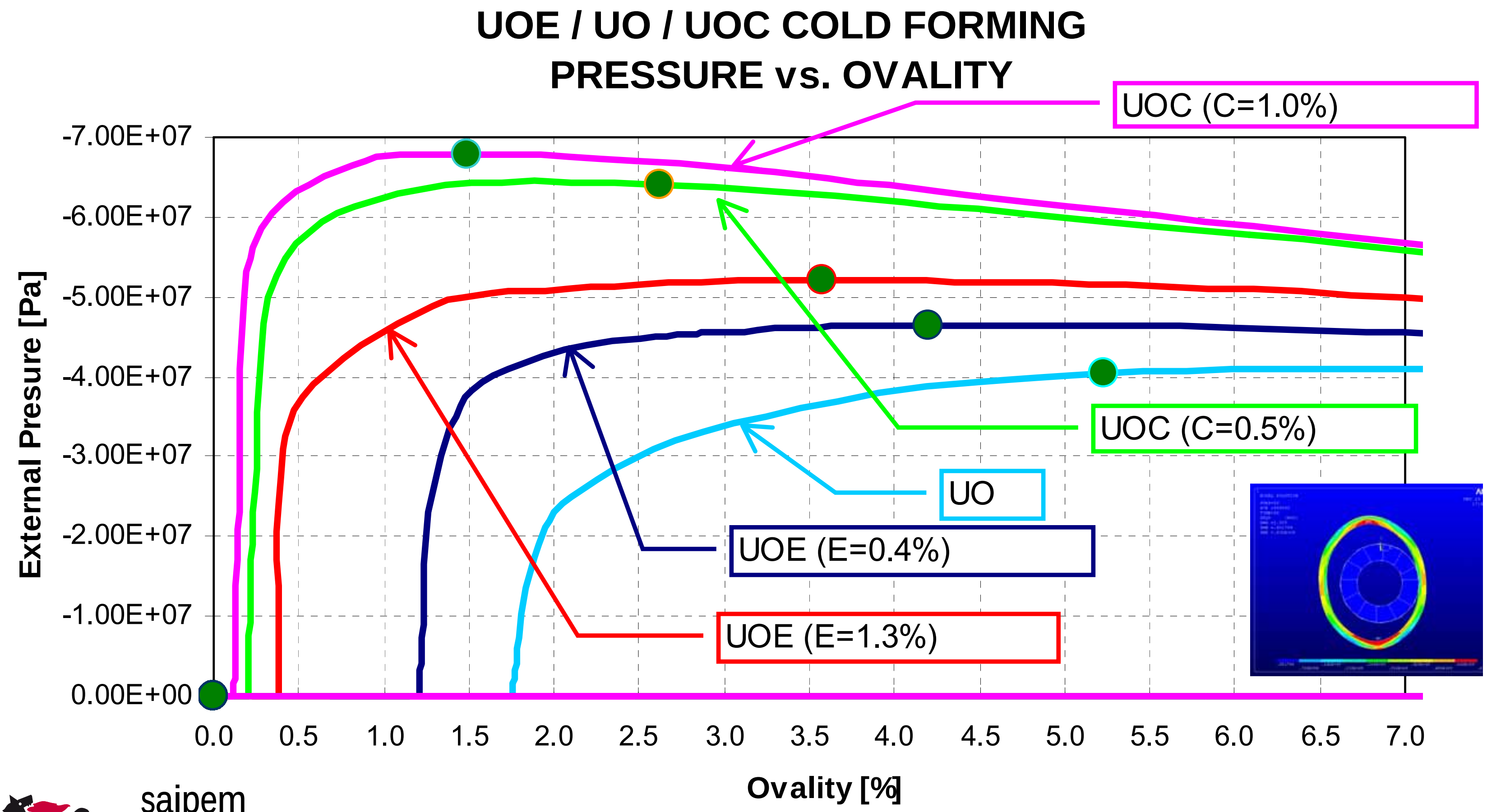
Ovality and Collapse Resistance vs. Expansion/Compression Strain

X65 OD=24" t=31.8mm - NUMERICAL ANALYSES (ABAQUS)



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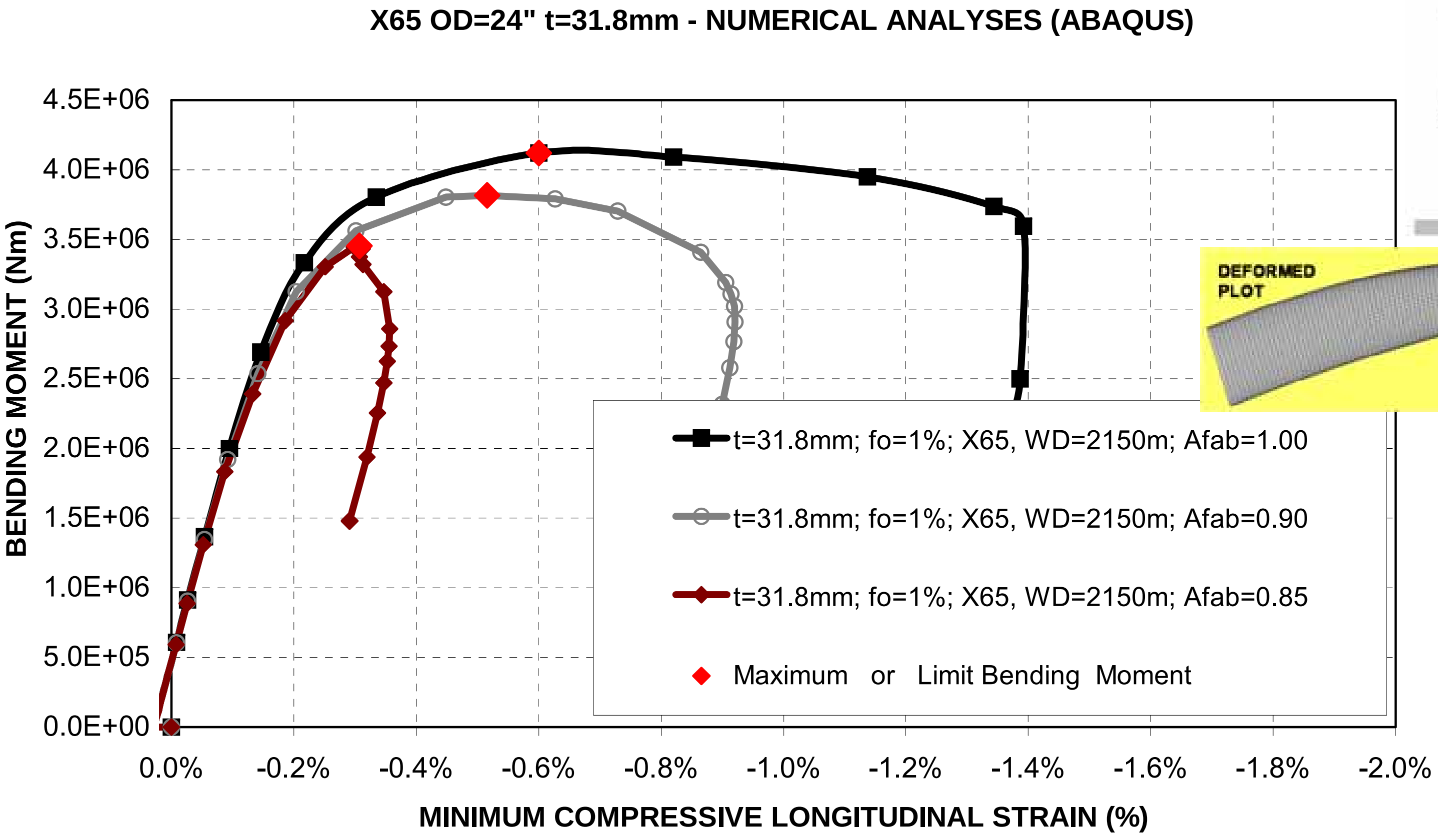
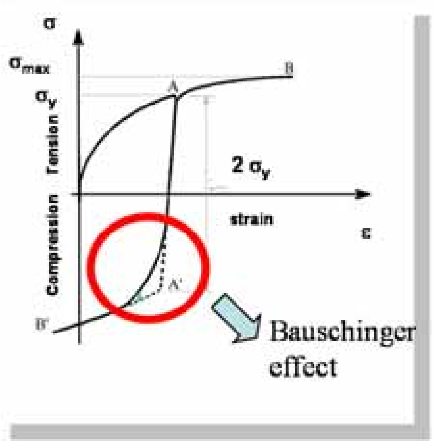
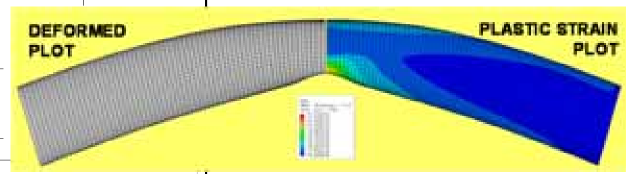
Combined External Pressure and Bending (Baushinger Effect)







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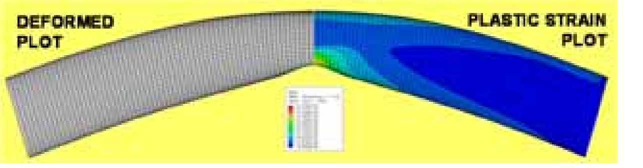
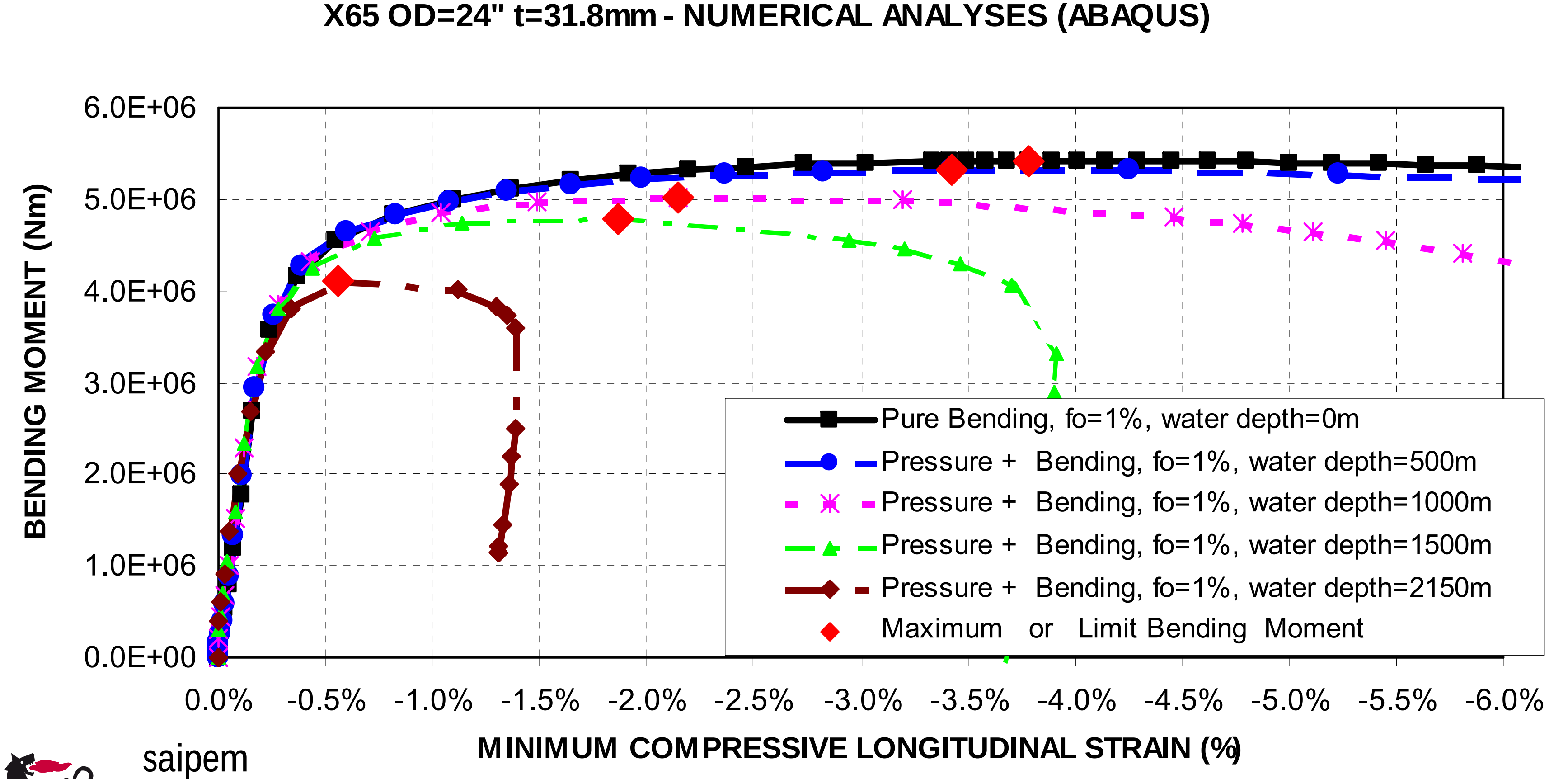
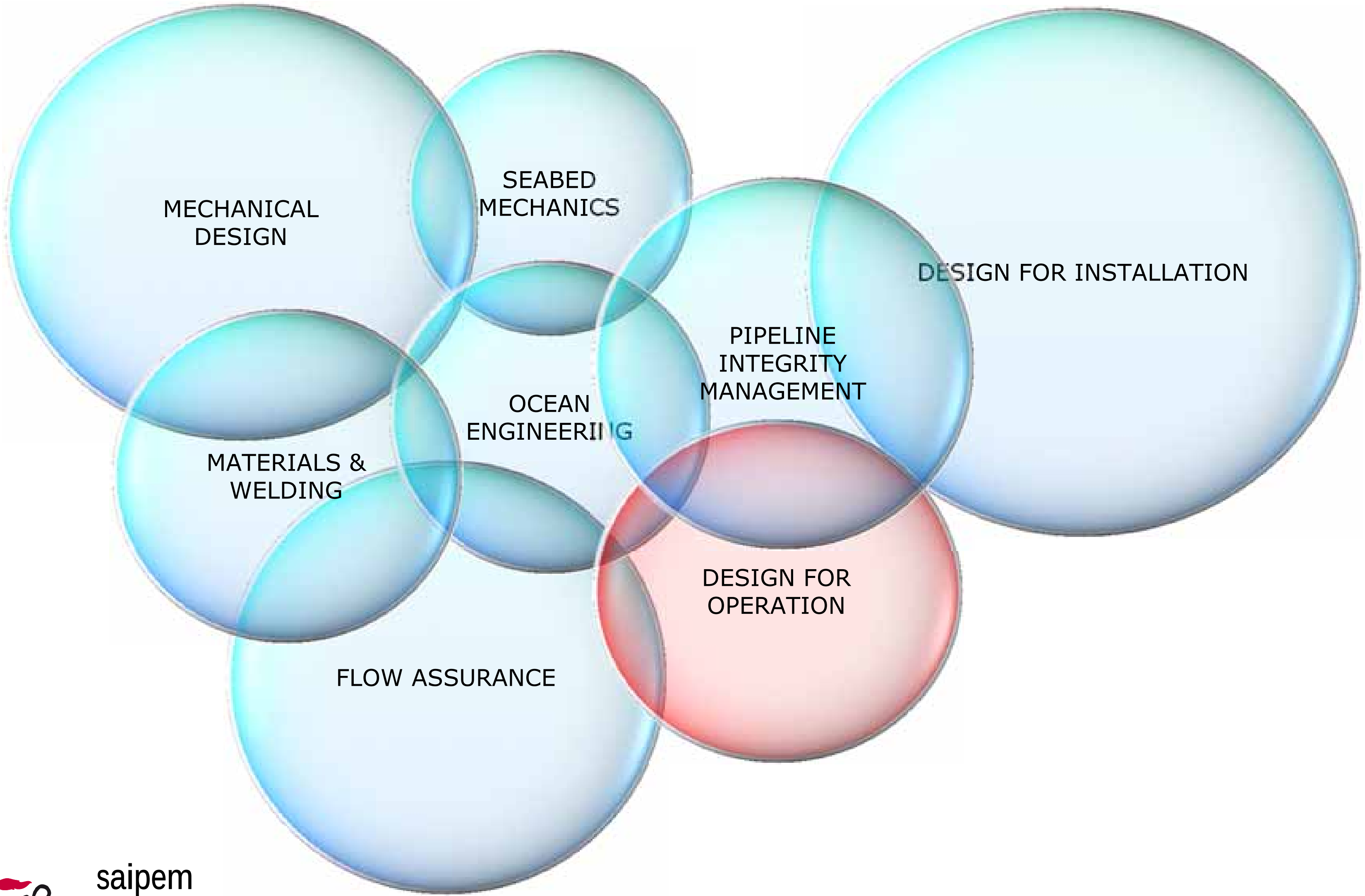
Combined External Pressure and Bending





CHALLENGES BY DISCIPLINE …



DESIGN FOR OPERATION – LIMIT STATES

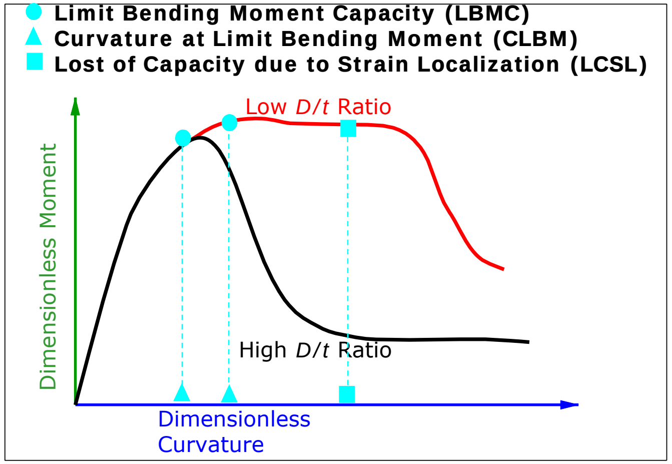
The relevant failure modes and limit states for offshore pipeline in operation are the following:

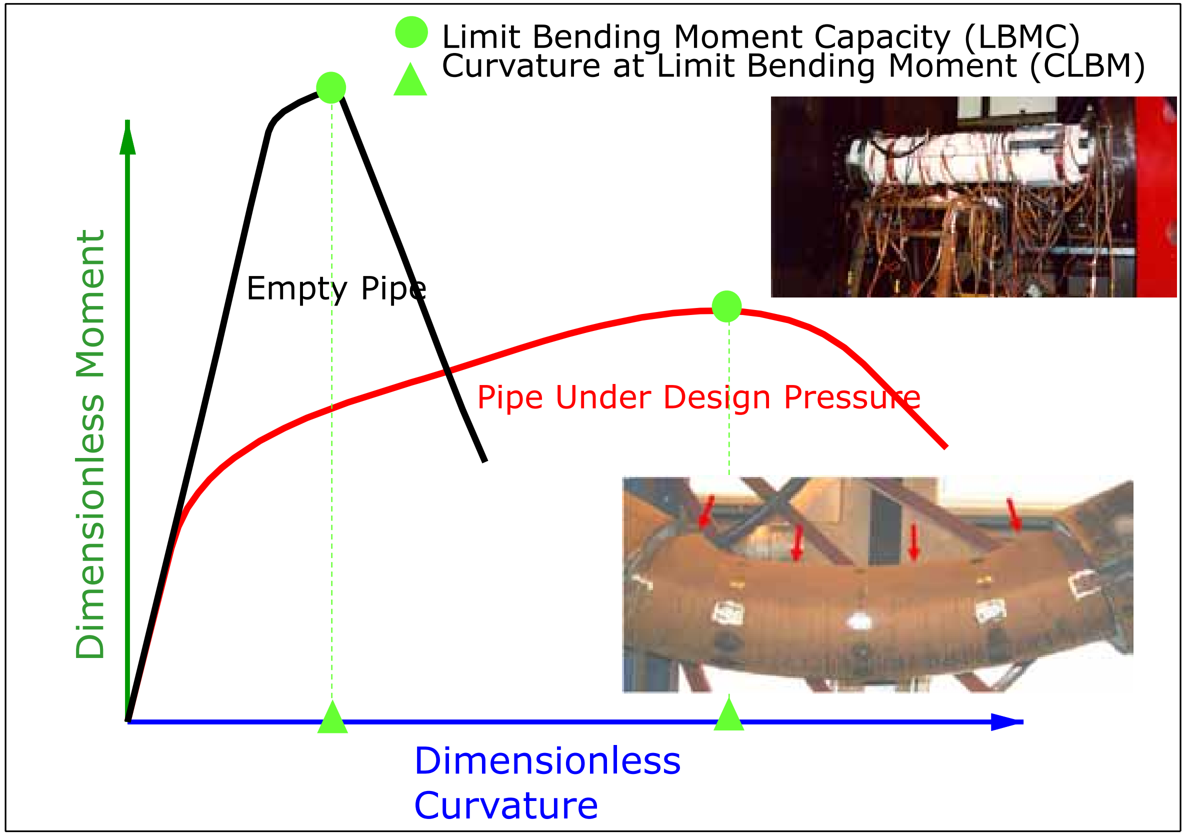
- **Pressure Containment Capacity** due to internal overpressure during operation and in field pressure tests;
- **Shear Running Fracture** due to internal pressure;
- **Collapse** due to external pressure in case of pipeline depressurization;
- **Buckle Propagation** due to the external pressure in case of buckle initiation and pipeline depressurization;
- **Local Buckling** due to internal and/or external pressure and bending due to bottom roughness or lateral buckling in case of pipeline depressurization and high pressure and temperature conditions.
- **Stress-Strain Capacity** of defective girth welds during operation (it is normal practice to say that an export pipeline has to withstand applied tensile stress - strain up to yielding - 0.5%.
- **Fatigue** damage of the girth welds due to environmental loads in operation (at free spans) and pressure and temperature fluctuations (oligocyclic).

PIPELINE CAPACITY UNDER COMBINED LOADS

Pipeline strength and deformation capacity aims to quantify the maximum loads and the associated deformation the pipeline can taken when subject to:

- Differential Pressure (Internal and/or External)
- Steel Axial Force
- Bending Moment





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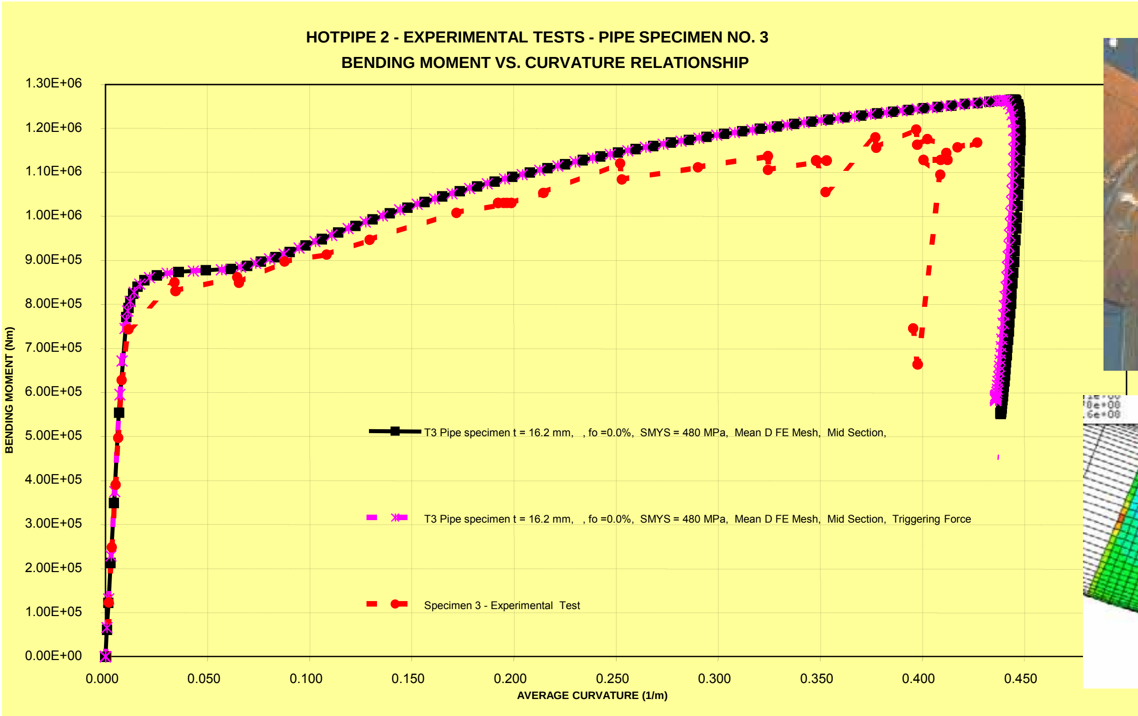
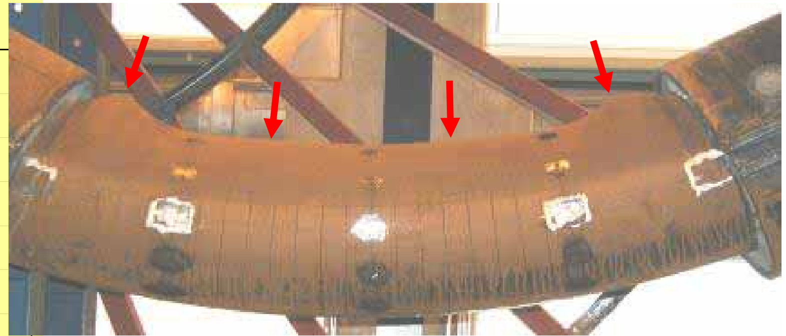
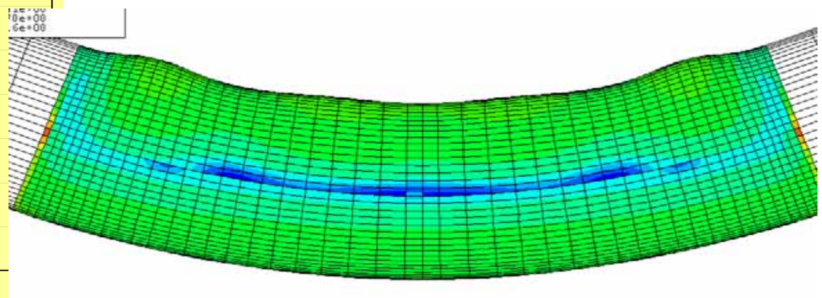
PIPE BENDING MOMENT CAPACITY
FEM ANALYSIS vs. LABORATORY TESTS RESULTS

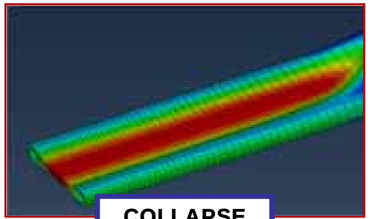


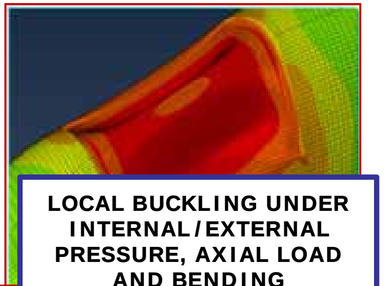


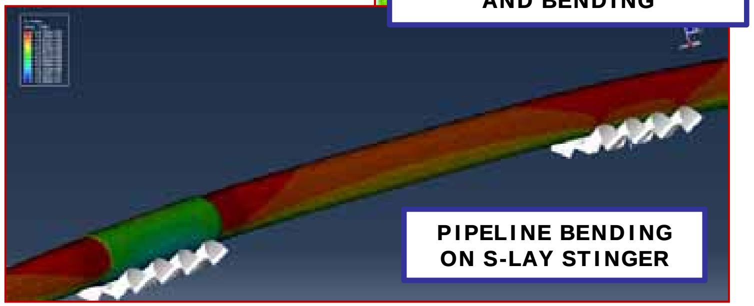


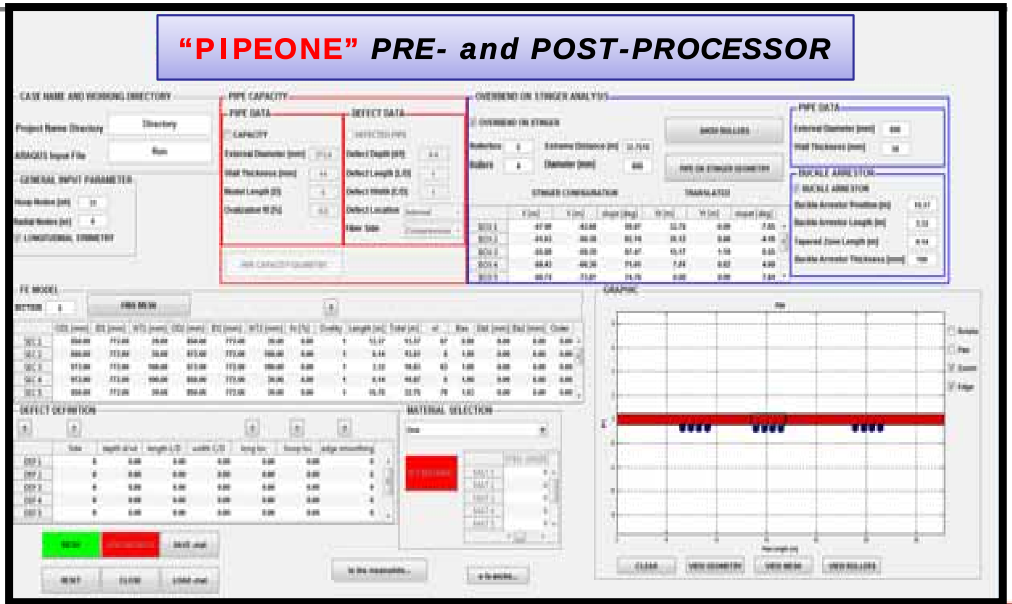
ABAQUS FE Models have been developed to evaluate the strength and deformation capacity of pipes subjected to combined loads (int/ext pressure, axial force and bending)

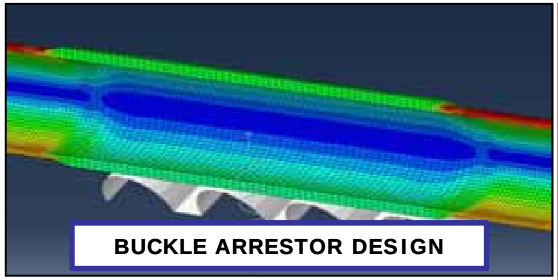
PIPELINE CAPACITY UNDER COMBINED LOADS

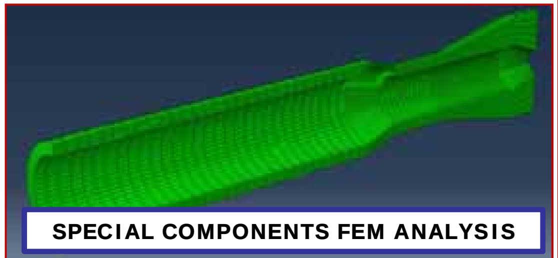


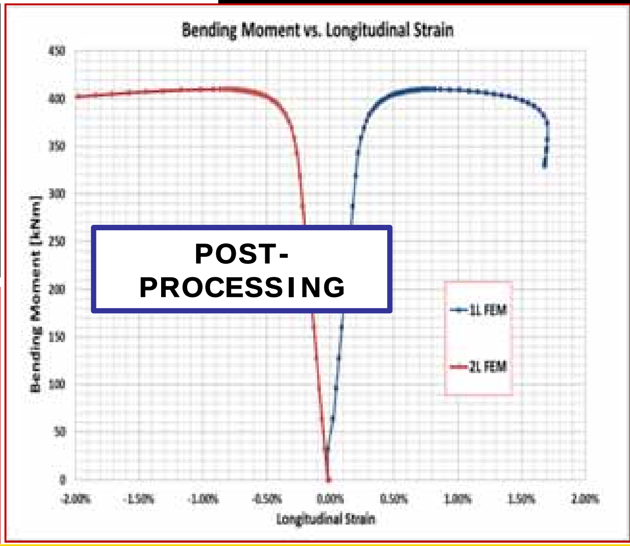


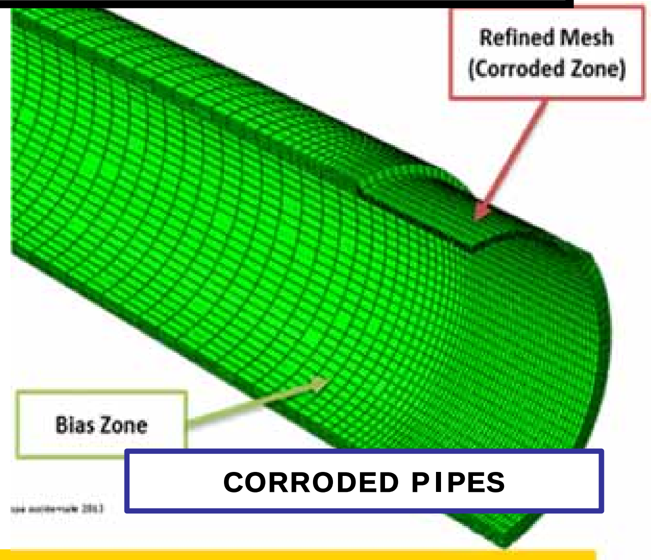










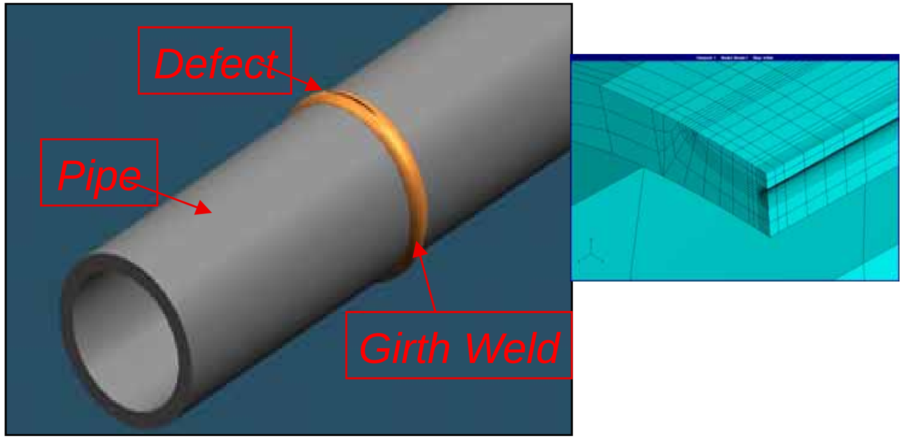


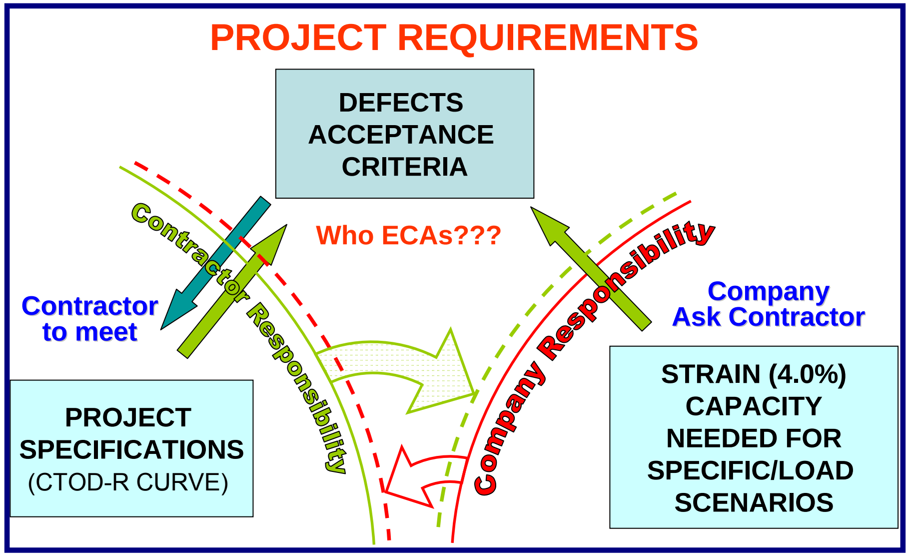
ECA - MINIMUM STRENGTH CAPACITY REQUIREMENTS

- The need of safely withstanding bending load effects (axial load effects are minor) both during installation and in operation (including hoop load effects).
- The strength capacity of girth welds threatened by weld defects must be suitably analysed to establish:

- For given load condition, allowable defect size

- For given defect acceptance, allowable stresses and strains





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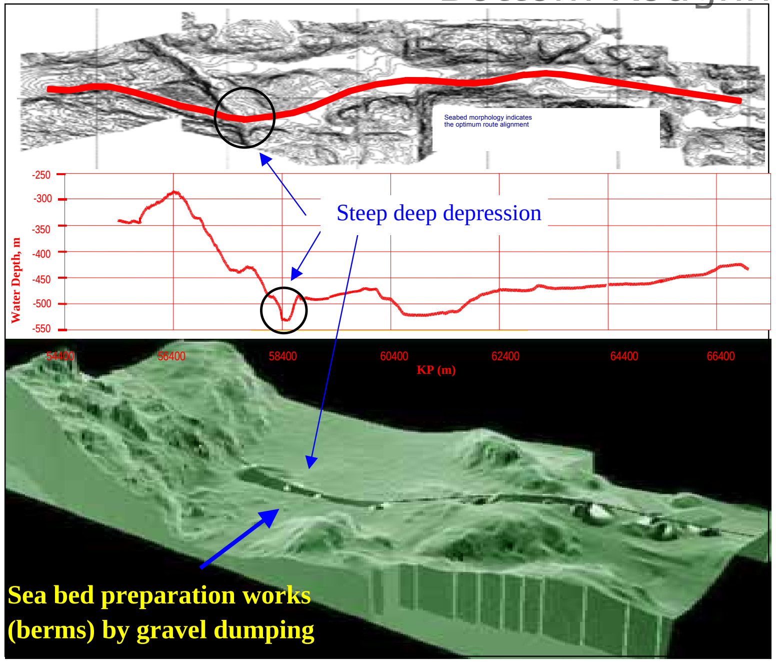
DESIGN FOR OPERATION – EXTERNAL LOAD CONDITIONS

The relevant load condition for offshore pipeline in operation are the following:

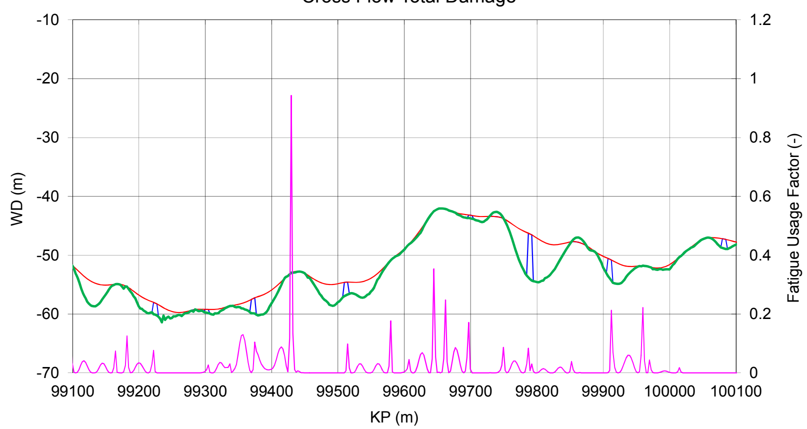
- Operational conditions i.e. design pressure and min and max design temperature;
- External pressure during shut – down;
- Sea bottom roughness giving rise to the formation of free span;
- Environmental loads (surface waves and marine currents) in the shallow water section;
- High pressure and high temperature conditions giving rise to the development of lateral buckling;
- Geohazards particularly plastic flows and turbidity currents.

DESIGN FOR OPERATION – BOTTOM ROUGHNESS

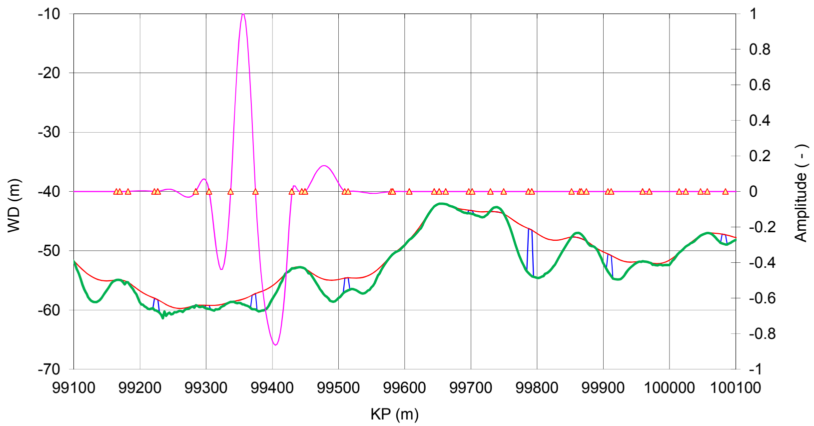
Bottom Roughness and Free Span Analysis



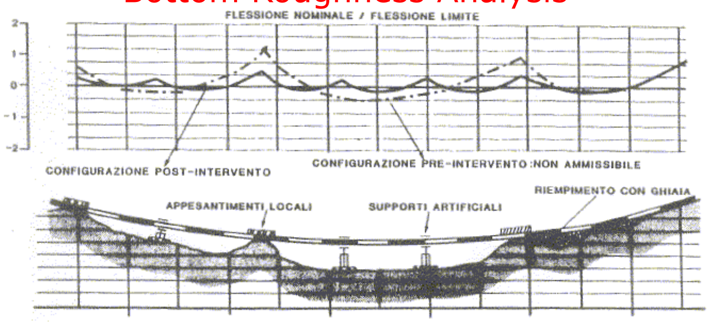
Fatigue Damage



Cross-Flow Modal Analysis

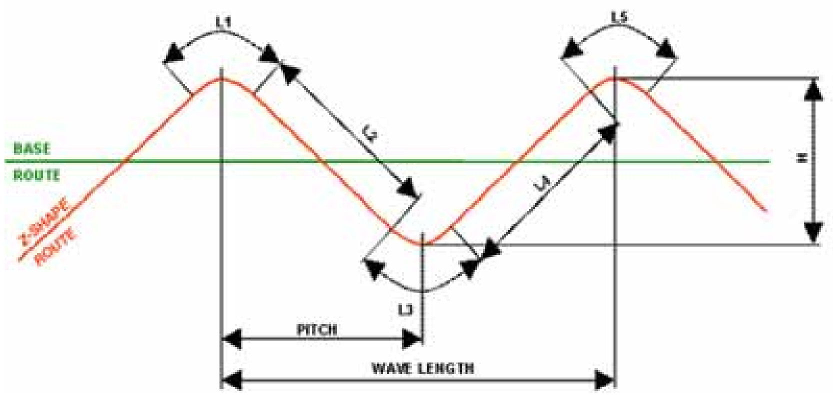


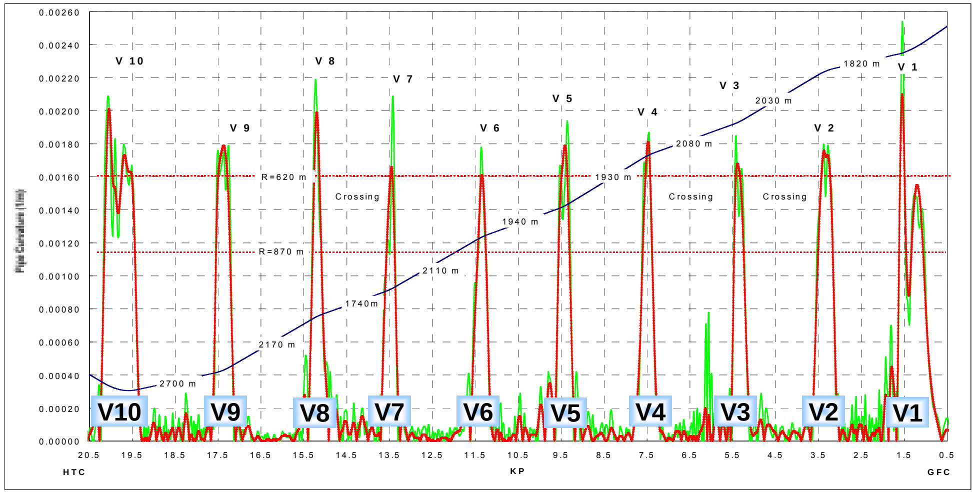
Bottom Roughness Analysis

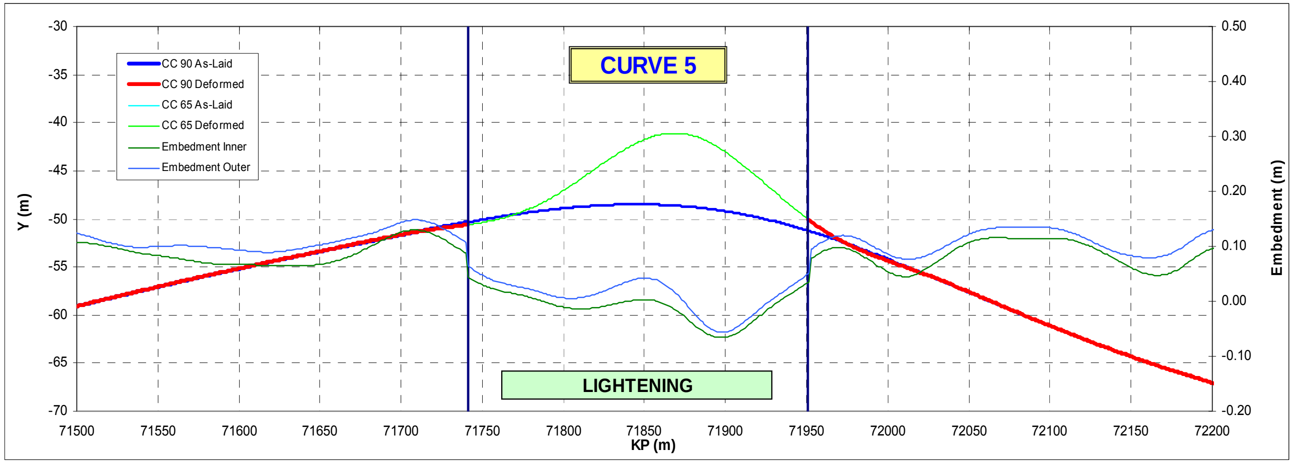


DESIGN FOR OPERATION – HIGH TEMPERATURE HIGH PRESSURE

In-Service Buckling due to HP/HT Conditions







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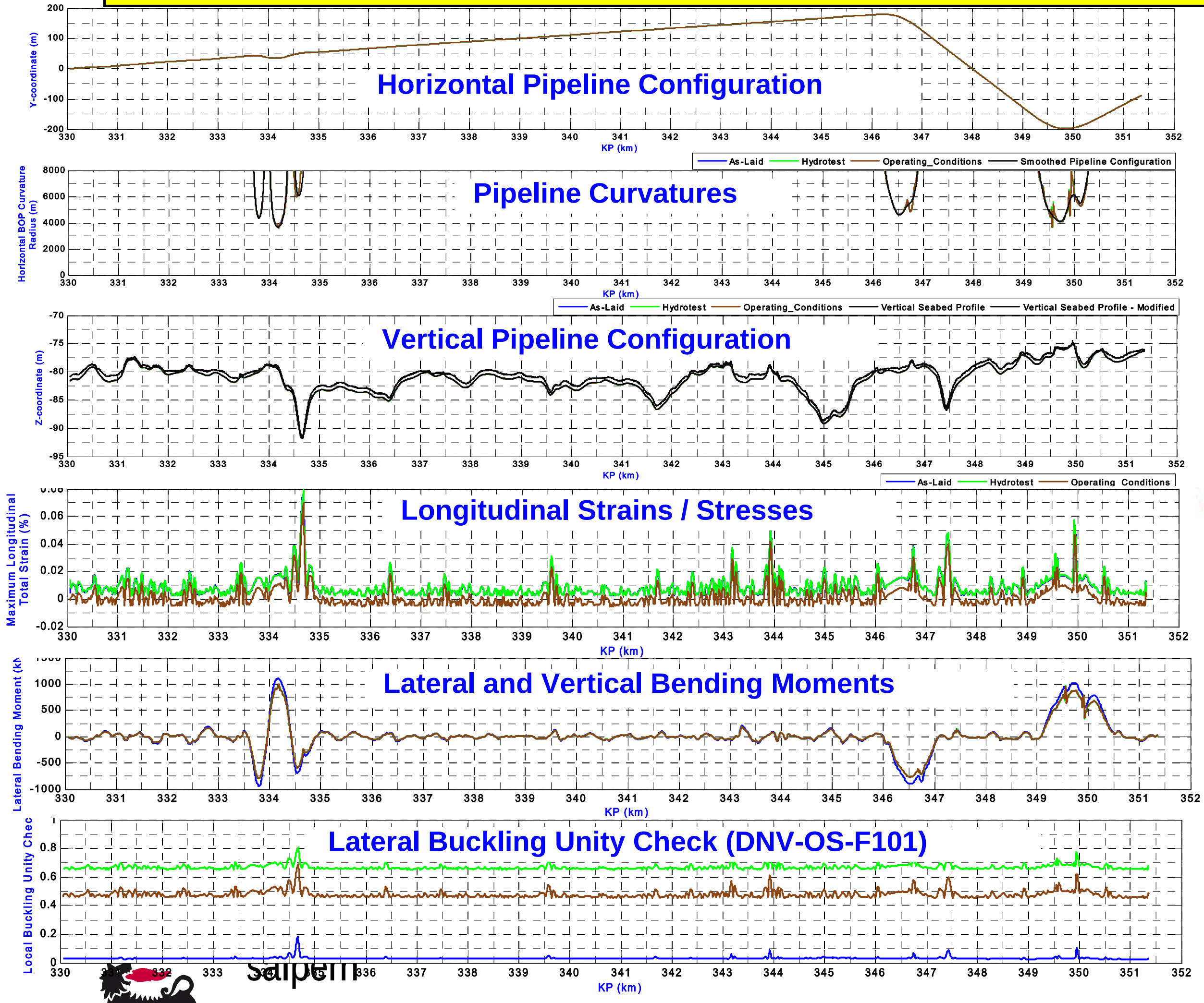
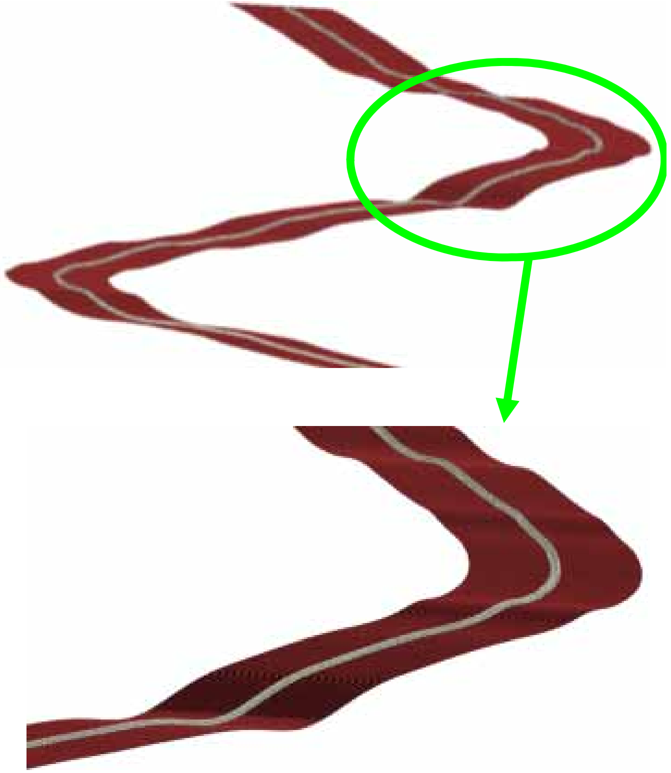
IN-SERVICE BUCKLING ANALYSIS USING 3-D SEA BOTTOM PROFILE



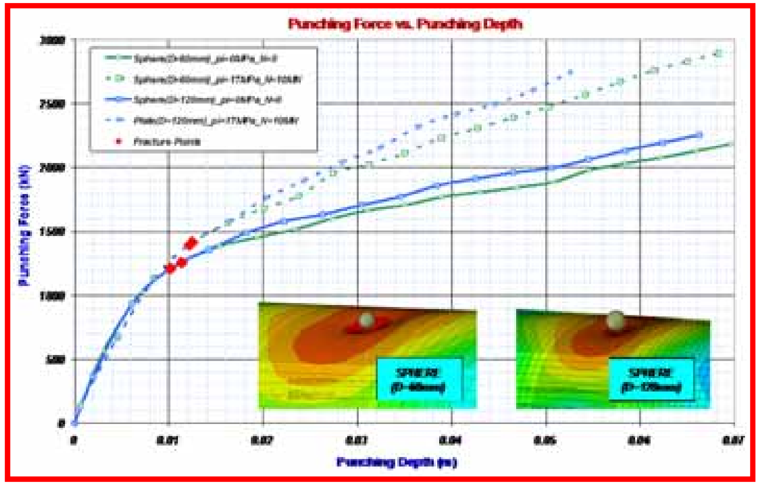
All the relevant pipe parameters are plotted as a function of the KP

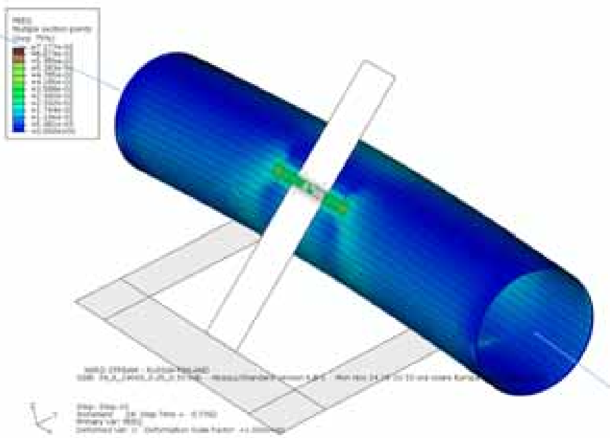


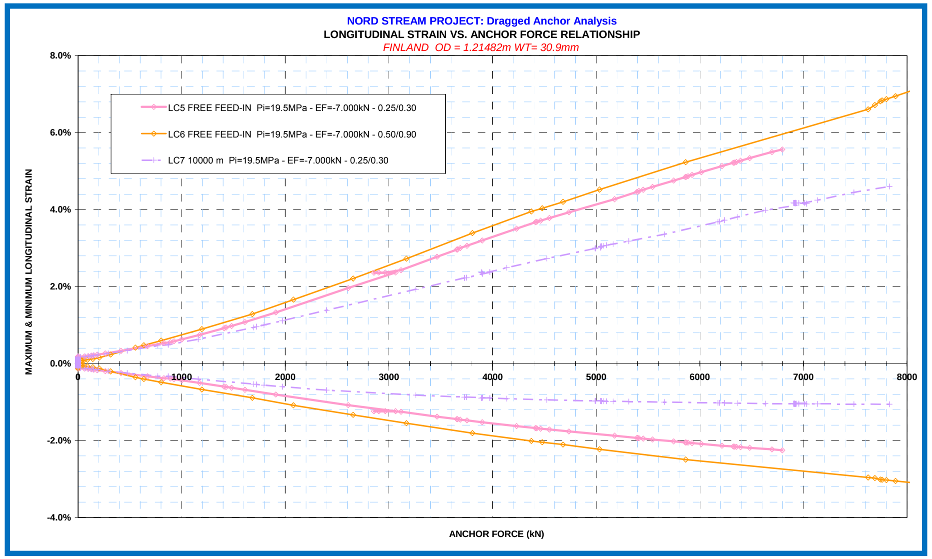
Pipeline Structural Integrity against Ship Traffic Related Threats Anchor Hooking

Detailed ABAQUS FEM analyses to:

- **Investigate the puncture resistance of the pipe shell due to the impact**
- **Quantify the pipe shell behavior due to the interaction with a dragged anchor during hooking**
- Quantify the global-local behavior of the pipe beam hooked by large dragged anchors







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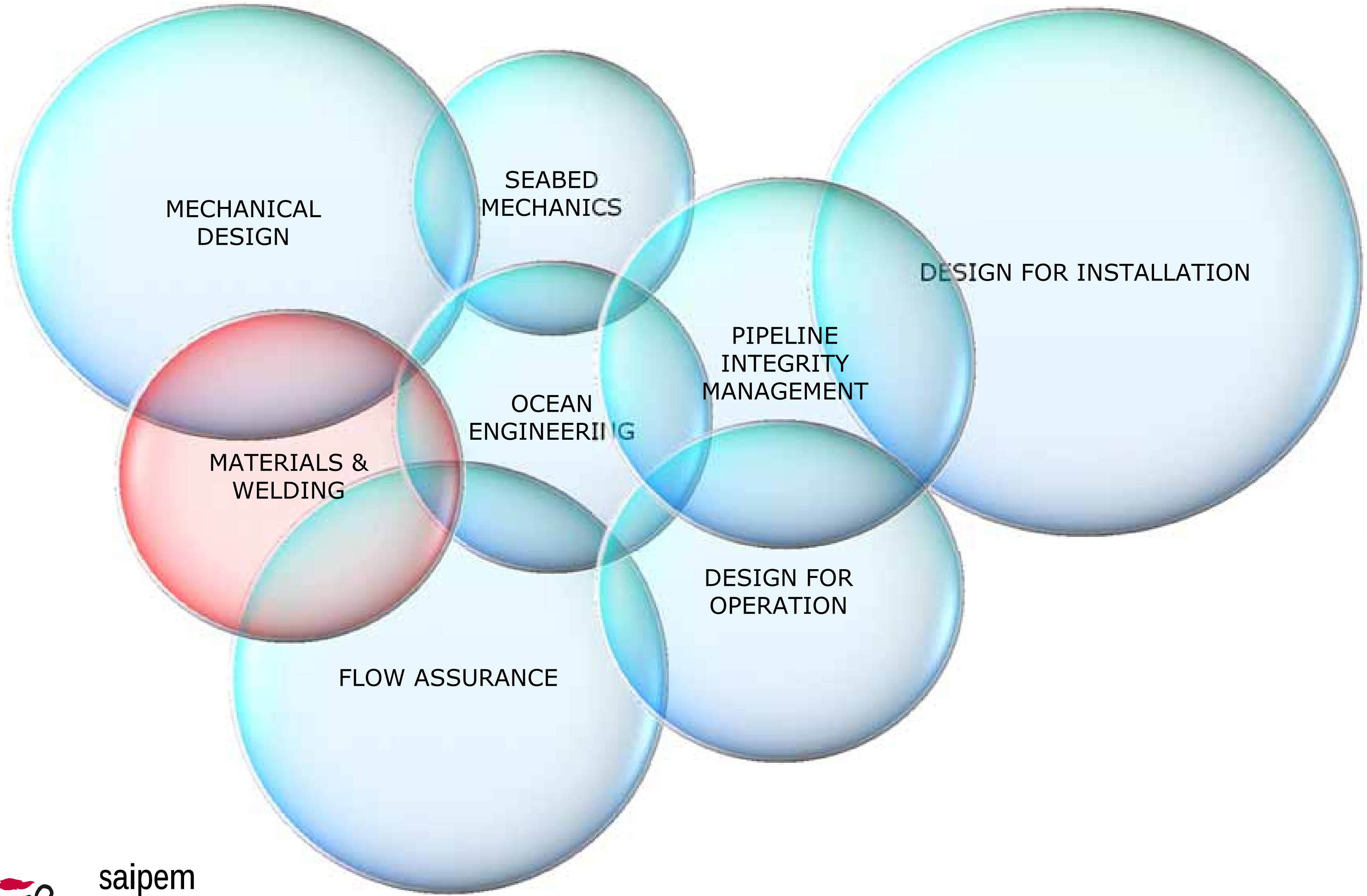
CHALLENGES BY DISCIPLINE …



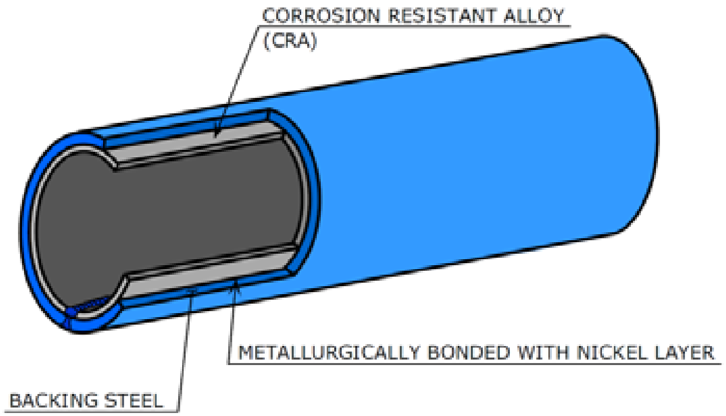
MATERIAL - ALTERNATIVE PIPE CONCEPTS

SOLID CORROSION RESISTANT ALLOY PIPE

- DUPLEX OR SUPERDUPLEX

CS OUTER PIPE & CRA INNER PIPE

- MECHANICAL BOND OR LINED PIPE
- METALLURGICAL BOND OR CLADDED PIPE



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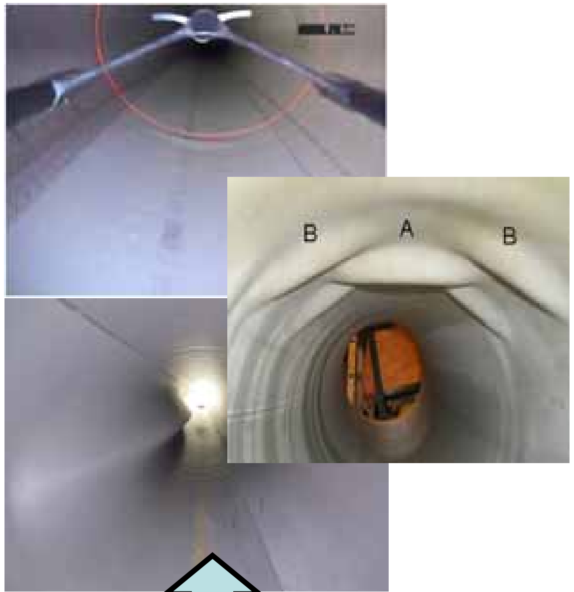
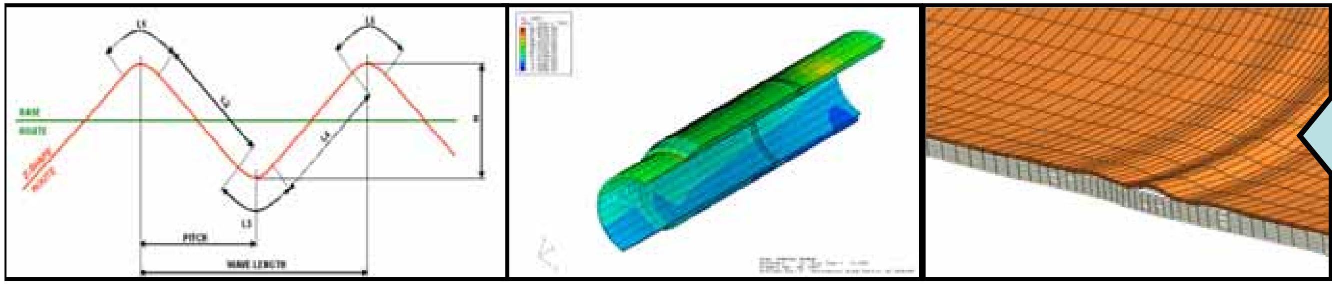
MATERIAL - PERFORMANCES OF NEW CONCEPTS

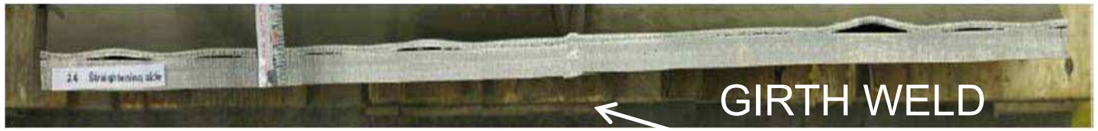
- DUPLEX OR SUPERDUPLEX EXPENSIVE NOT SUITABLE FOR EXTENSIVE APPLICATION AND SENSITIVE TO THERMAL DE-RATING
- CLADDED PIPE AND LINED PIPE ARE LESS EXPENSIVE BUT…
- SOME TECHNOLOGICAL GAPS TO BE ADDRESSED BY SUPPLIERS, CONTRACTORS AND OPERATORS JOINT EFFORTS
- APPLICATION FOR HT/HP PIP SYSTEM IN A SNAKED LAY CONFIGURATION PERFORMED BUT EXTREME COMPLEX AND AT THE TECHNOLOGY LIMIT

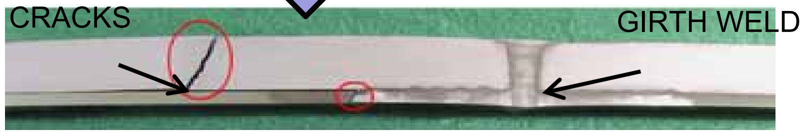




LINER DISBONDMENT

FATIGUE RESISTANCE





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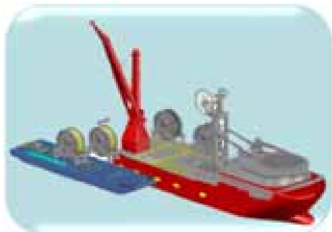
MATERIAL – TRADITIONAL, NEW PIPE CONCEPT FOR REEL LAY

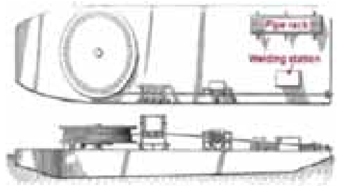
- Reel-lay is the process where rigid pipes are:
  1. Prefabricated as long strings and stacked in dedicated onshore bases;
  2. Spooled onto a storage reel on-board the reel-lay vessel, yielding the steel;
  3. Transported onto the offshore field;
  4. Unwounded, straightened and laid by a dedicated system on-board the vessel.

- New Competitors (Heerema, EMAS) are entering in the market with an alternative process different from the conventional one by:
  2. Spooling the pipe onto a storage reel placed on-board a dedicated barge/supply vessel;
  3. Transporting it onto the offshore field and lifting it by the reel-lay vessel crane.

MATERIAL – REEL LAY TECHNOLOGY

- Conventional reeling applications (**since '70 up to 2k**):
  - More than **6000 km** of **steel pipelines** laid especially in GoM and North Sea
  - Mainly **flowlines (up to 16")** in water depths that were increasing through the years
  - In the **'90** also more complex products (e.g. **PiP, SCR, thick insulation, …**) were laid in deep water (**up to 1000 m**)by reeling
  - The best in class vessel of those years, the "**Apache**", is still operative (re-hulled in 2010) and owned by Technip



- Late reeling applications (2000-2010):
  - More than 14000 km of pipelines laid worldwide
  - Contractors invested both in new vessels and in onshore spoolbases to warrant presence in "golden triangle"
  - Complex field development projects in deep water (up to 3000 m) increases their market share
  - To face new demanding market needs Technip delivered the best in class multi-lay vessel Deep Blue (lay tension 550 tons)

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Thanks!

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