Fracture Assessments of Marine Pipelines and Subsea Components in Hostile Environments: Critical Concerns and Recent Developments

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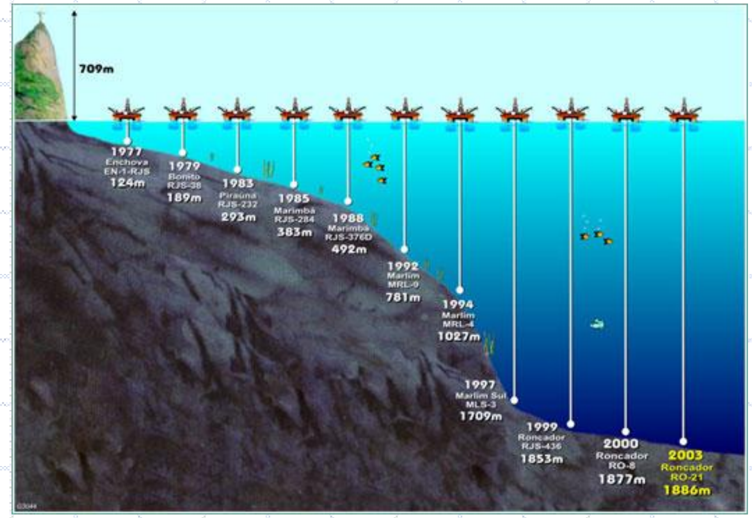
Outline

- ***Challenges in Pipeline Safety Standards: Linking Design and Operation***
- ***Current Practices and Standards for Defect and Safety Assessments of Pipelines***
- ***Innovative Approaches as More Rational and Yet More Efficient Integrity Assessment Procedures for High Perfomance Pipelines***
- ***Some Key Critical Concerns Driving Further Research and Development***

Going Farther and Deeper......

Increasing Demand for Fossil Fuels, Including Natural Gas, is Pushing Oil and Gas Exploitation and Production to Farther and Deeper Reservois in Difficult and Hostile Environments

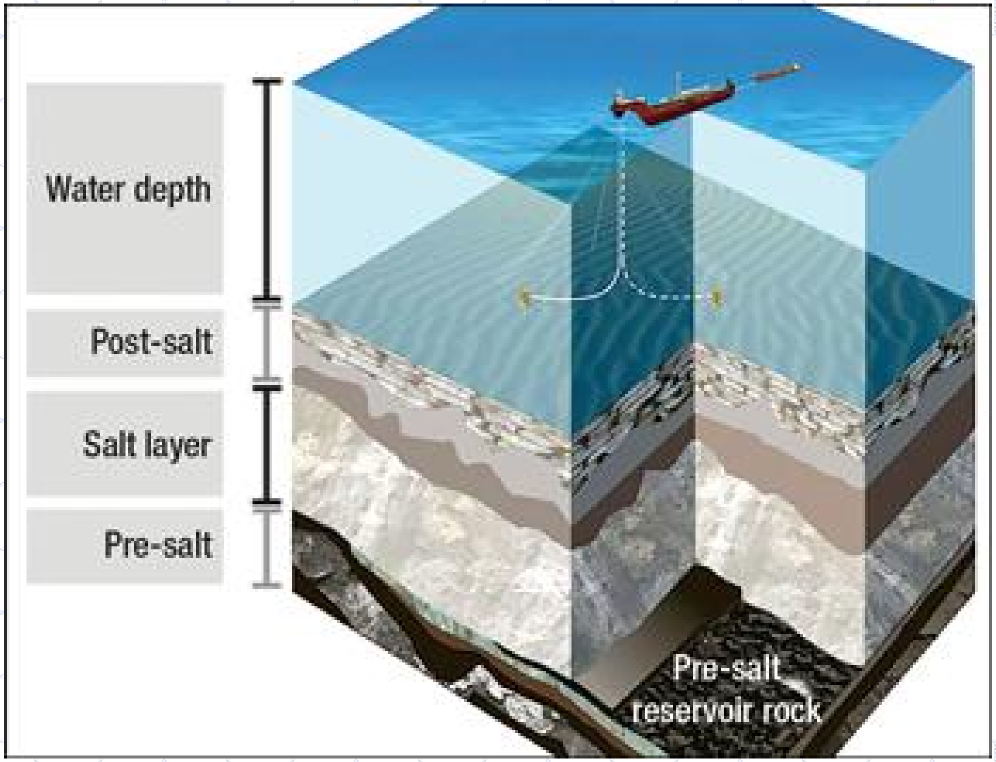


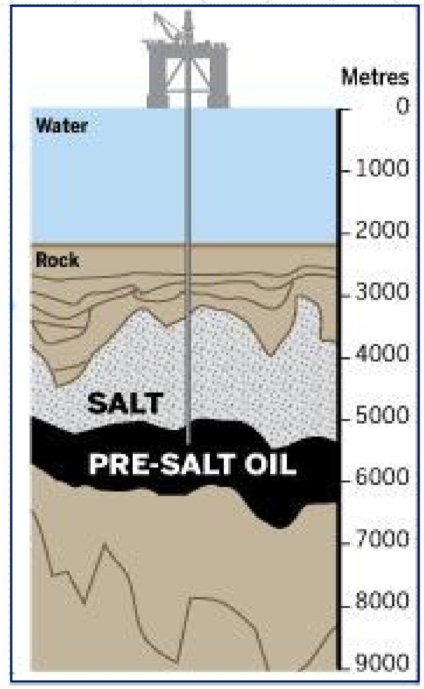
Technological Challenges in Pipeline and Riser Design, Installation, Operation, Inspection and Repair

The Brazilian Pre-Salt Reservoir

Figure 1: Brazil's pre-salt region

The Brazilian Pre-Salt Reservoir



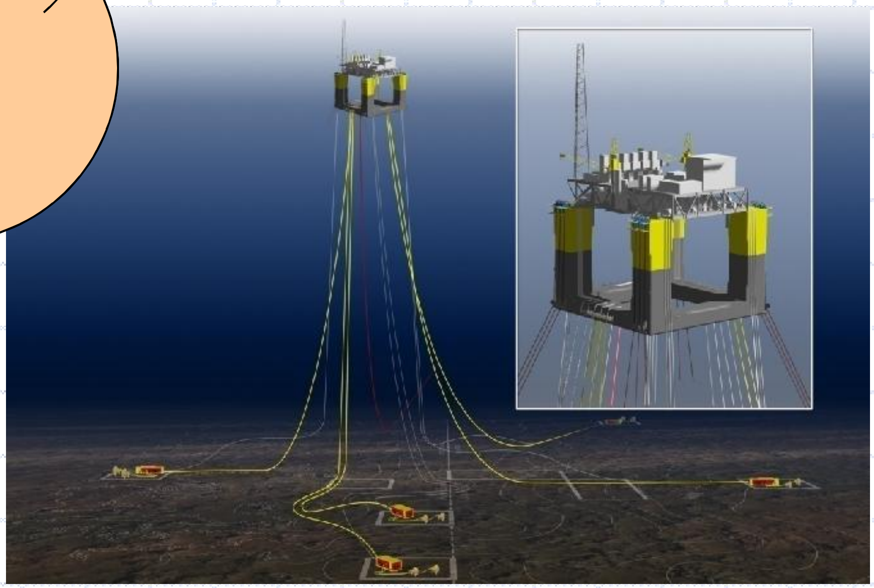


Key Characteristics

- **More than 2500 m Water Depth.**
- **2000 m Thickness Salt Layer.**
- **Gas Pipeline Larger than 18” in 2500 m**
- **Long Distance to Shore (300 km)**
- ***High CO_2 Content (8 ~ 20%)***

Technological Challenges

- *Higher Stresses / Strains During Installation*
- *Larger Thickness Including Weldments*
- *Sour Conditions*



Impact on FFS / ECA Procedures and How Does It Affect Tolerable Defect Sizes?

The “Mysterious” Design Factor….

- ***The 0.72 Design Factor is a Historical Factor Set More than 50 Years Ago !***
- ***There is No Rational and Convincing Basis Against Increasing It.***

High Design Stresses Do Not Cause Failure.
Damage Does!

Fracture is Always a Concern ....

Failure of Brazilian Pressure Vessel (2000)
(Fracture Initiated at Weld Defect)

Conventional Defect Assessments

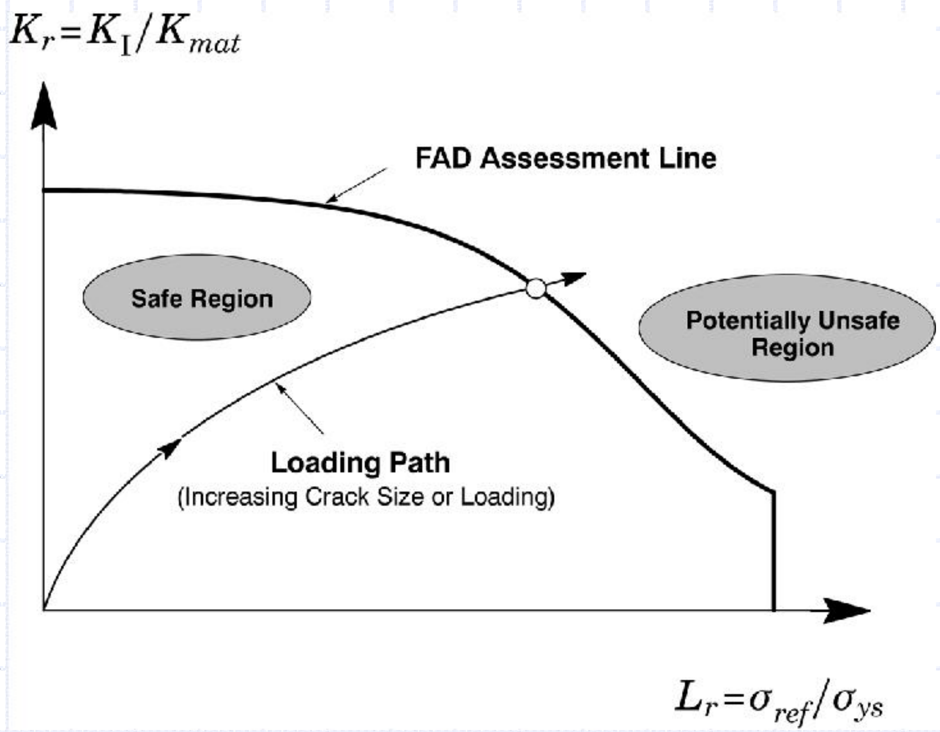
- ***Fundamental Procedure is Based on the "Good Workmanship" Philosophy To Ensure That the Pipeline/Riser is Free of Fabrication Defects***

- ***However, Larger and Often Severe Defects Will Invariably Occur During the Pipeline and Riser Service Life.***

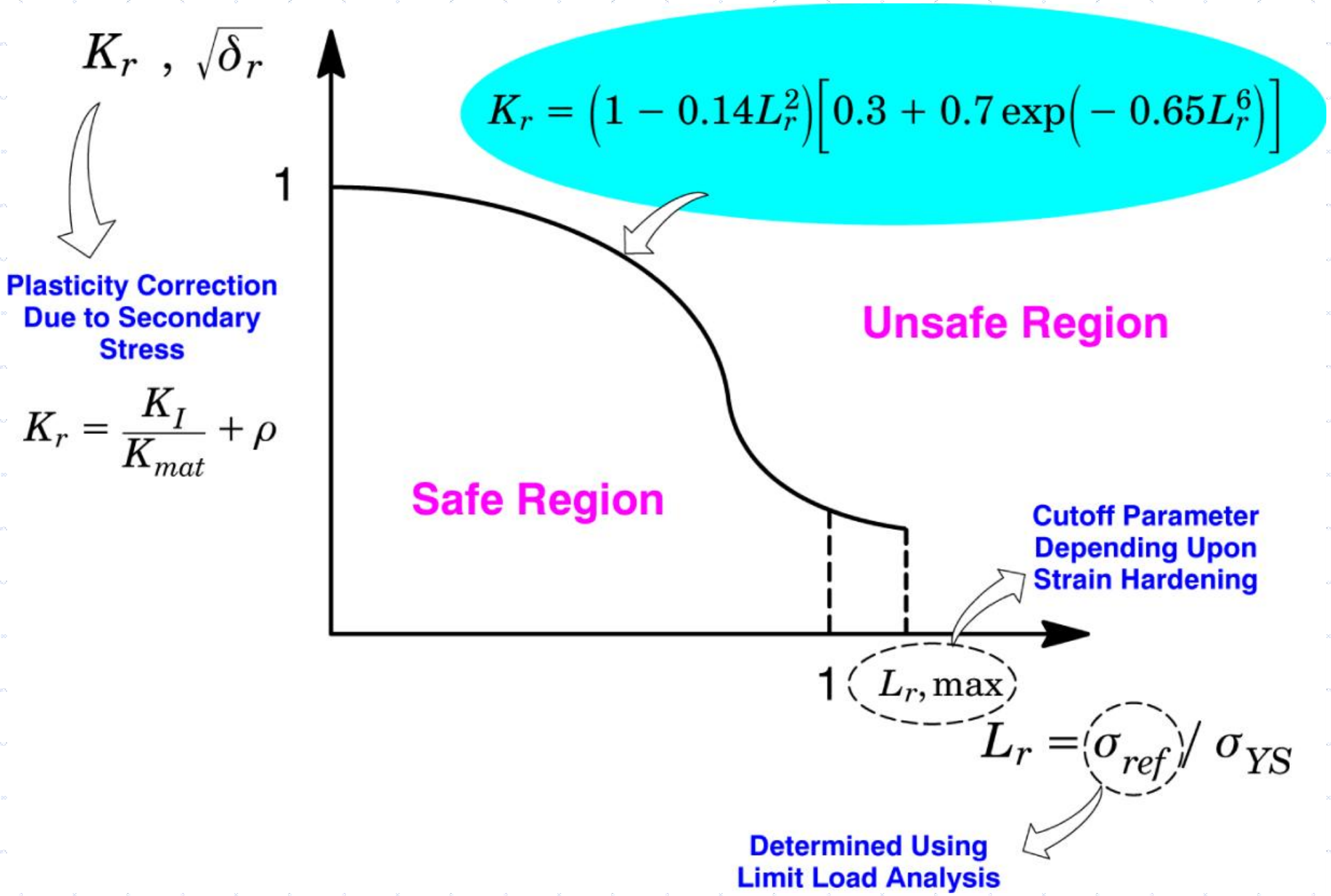
FFS or ECA Analysis Required

Failure Assessment Diagram Approach

Two-Parameter Assessment Line Describing the Interacion of Two Failure Modes:
Brittle Fracture and Plastic Collapse



BS 7910 Level 2A



FAD Approach

- **Key Assumption is that the FAD Curve Does Not Depend on Specimen Geometry and Strain Hardening:**
  - ***High Constraint Conditions***
  - ***Low to Moderate Ductile Material***

⇓

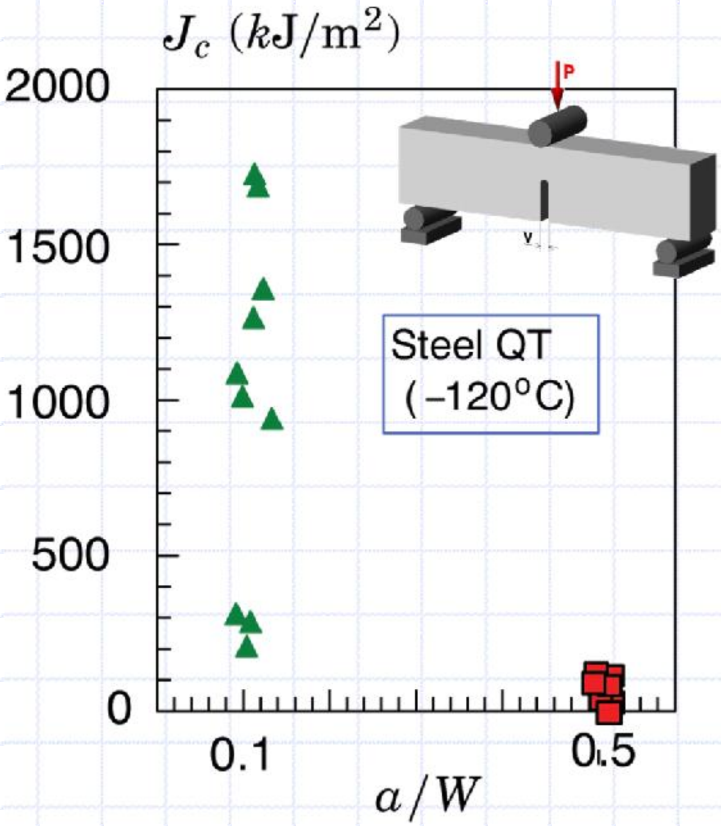
More Important, FAD Procedure is a Stress-Based Approach !

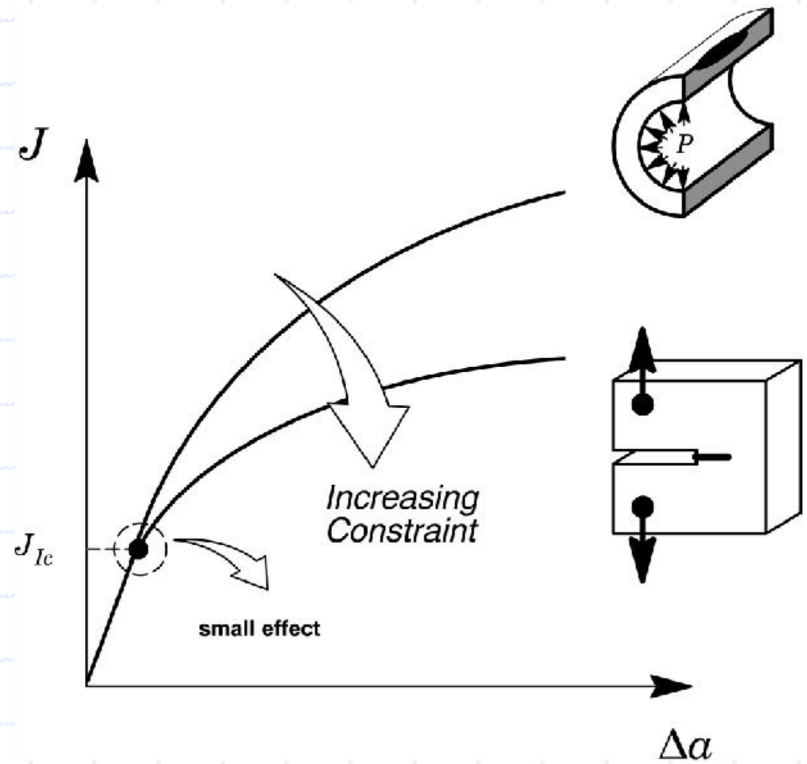
Current Scenario

There is Growing Concern Supported by Strong Field Evidences that Conventional FFS Procedures are not Necessarily Applicable to Newer Materials and Complex Conditions: X100 Grade Steel, Ultra Deep Waters, Heavy Thickness Pipes, Sour Environment, etc.

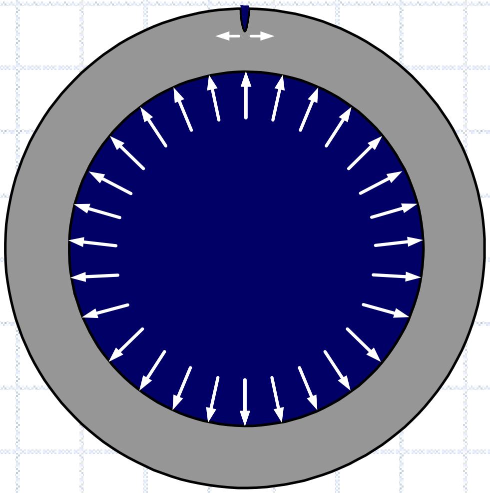
New Methods Should be Developed

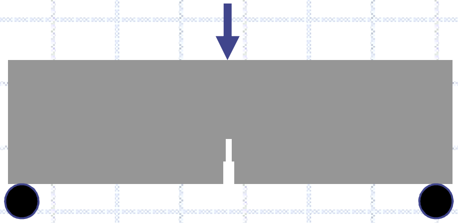
Constraint Effects on Toughness

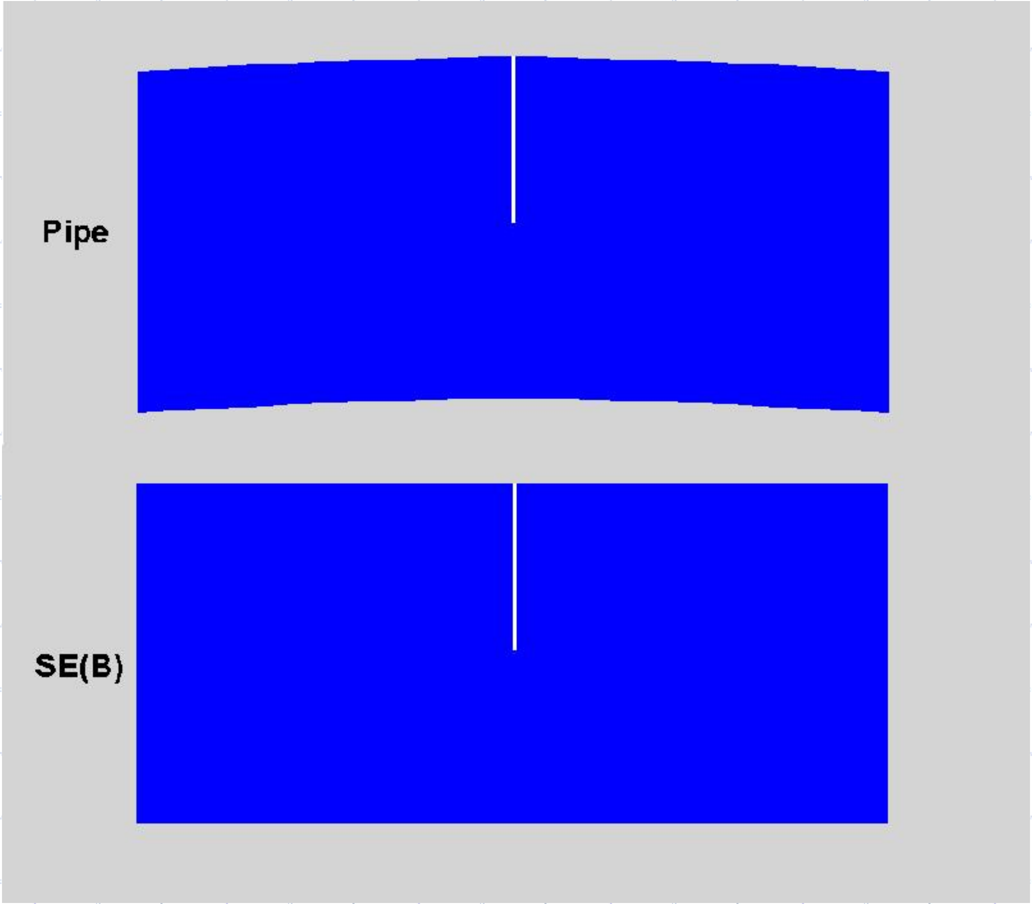




Flawed Pipes *vs.* SE(B) Specimens

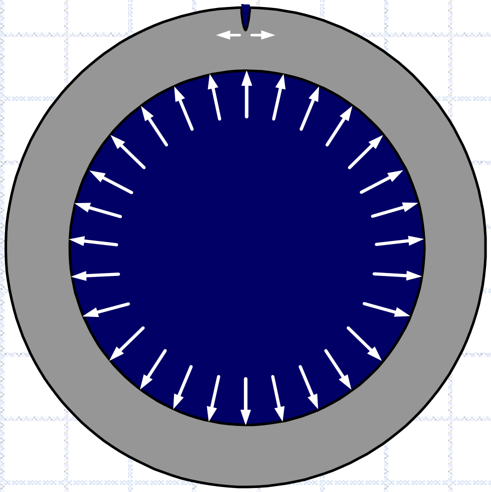


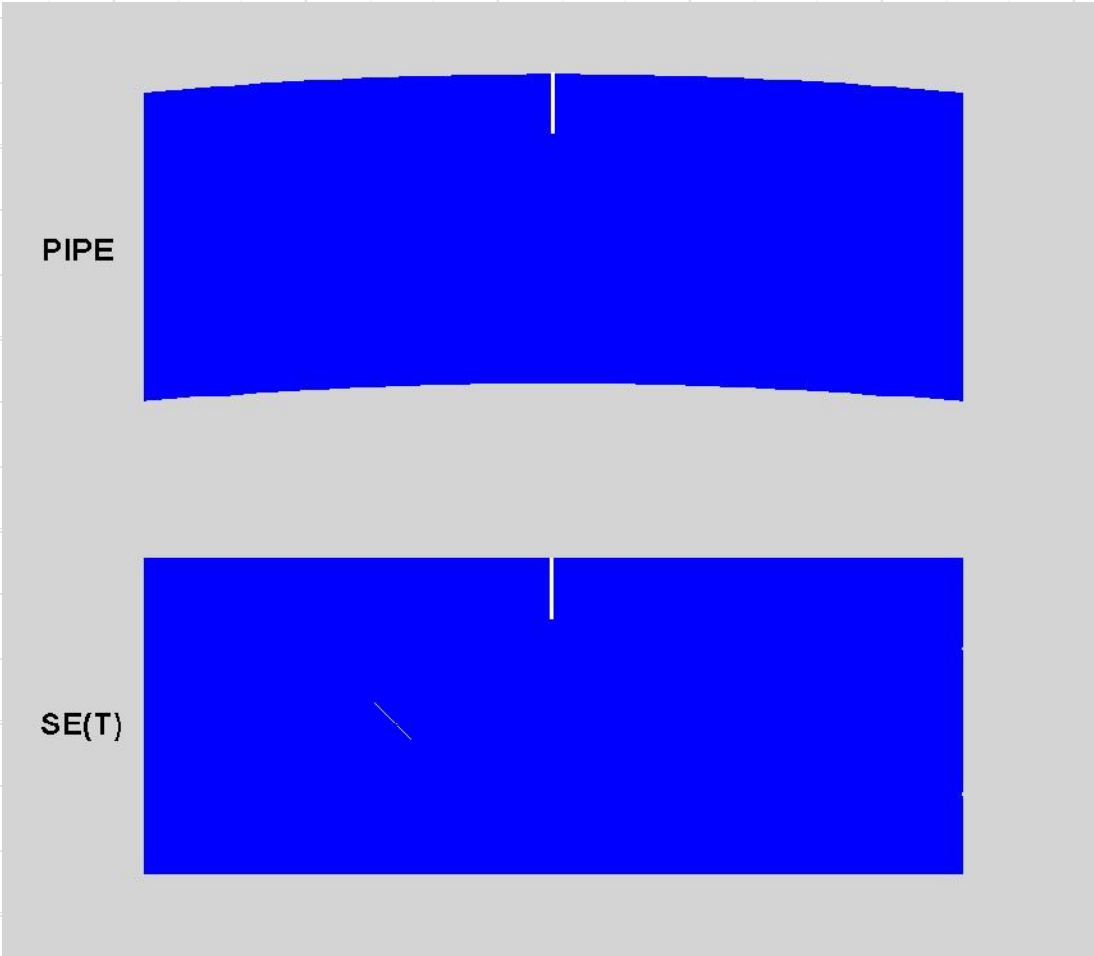




Cravero and Ruggieri (2007)

Flawed Pipes vs. SE(T) Specimens

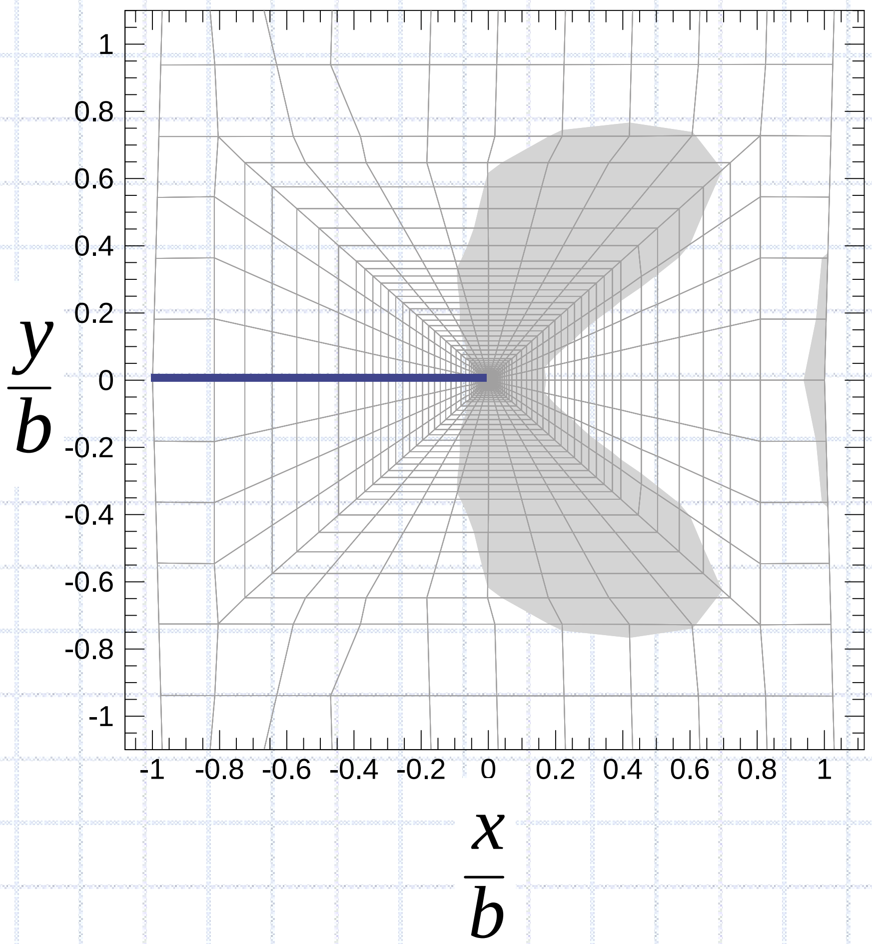




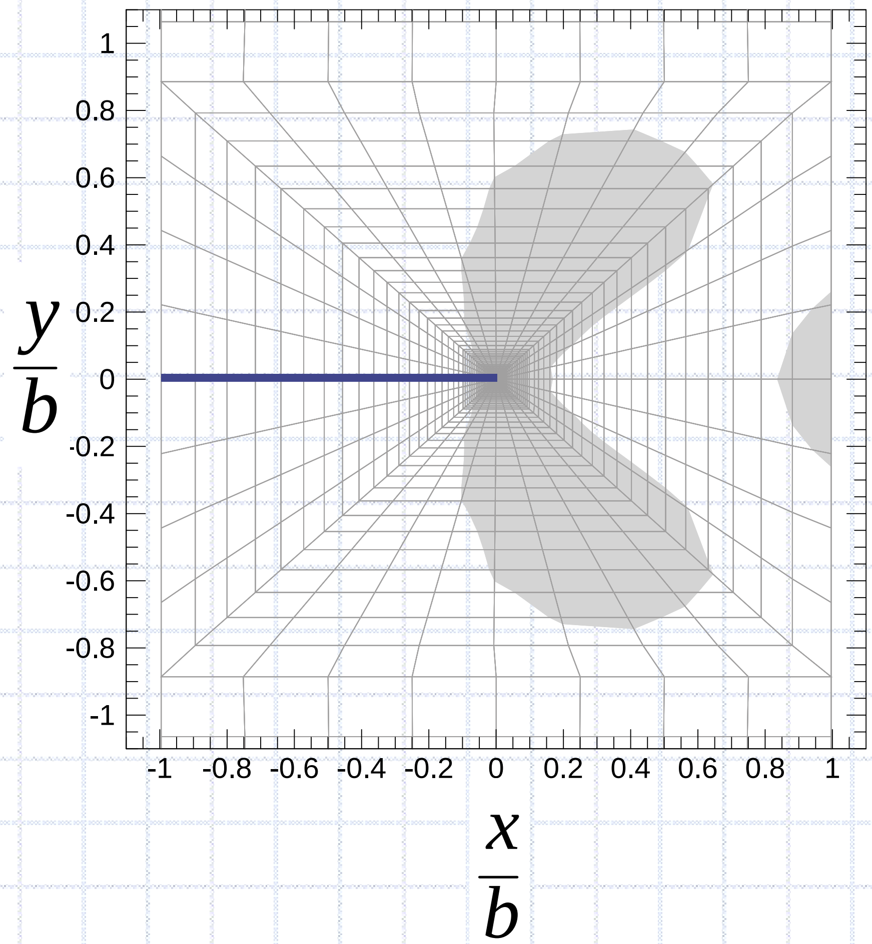
Cravero and Ruggieri (2007)

Crack-Tip Plastic Zones

20” Pipe a/t=0,5



SE(T)-P a/W=0,5



Cravero and Ruggieri (2007)

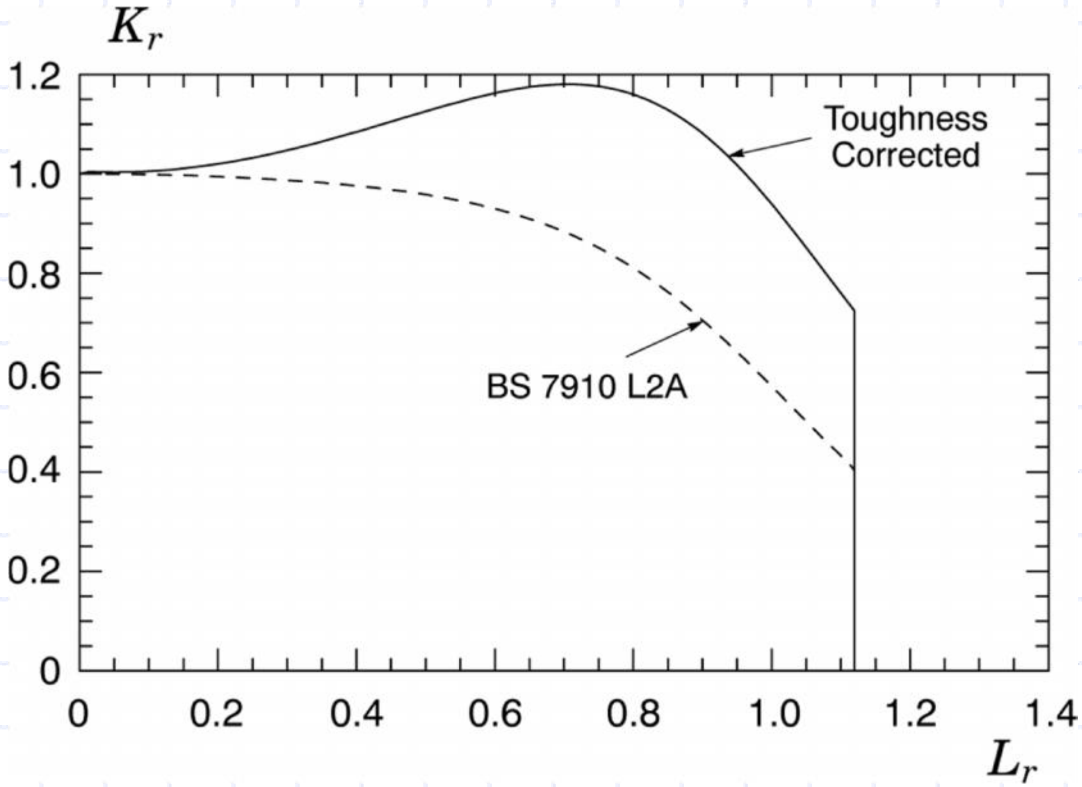
Constraint Modified FAD Approach

Toughness Correction

$$K_{mat}^{Q} = K_{mat}^{0}\,[1 + \sim \; {}_{Q}L_{r}]$$

$$K_{r} = f(L_{r})\,[1 + \sim \; {}_{Q}L_{r}]$$

Constraint Modified FAD



Strain-Based Analysis

- *Strain-Based Analysis Defines a Limit State Condition in Which Structural Behavior is Controlled by Imposed Displacements*
- *The Collapse Analysis Built Into FAD Procedures Relies on Determinig Net Section Yielding in the Crack Ligament*

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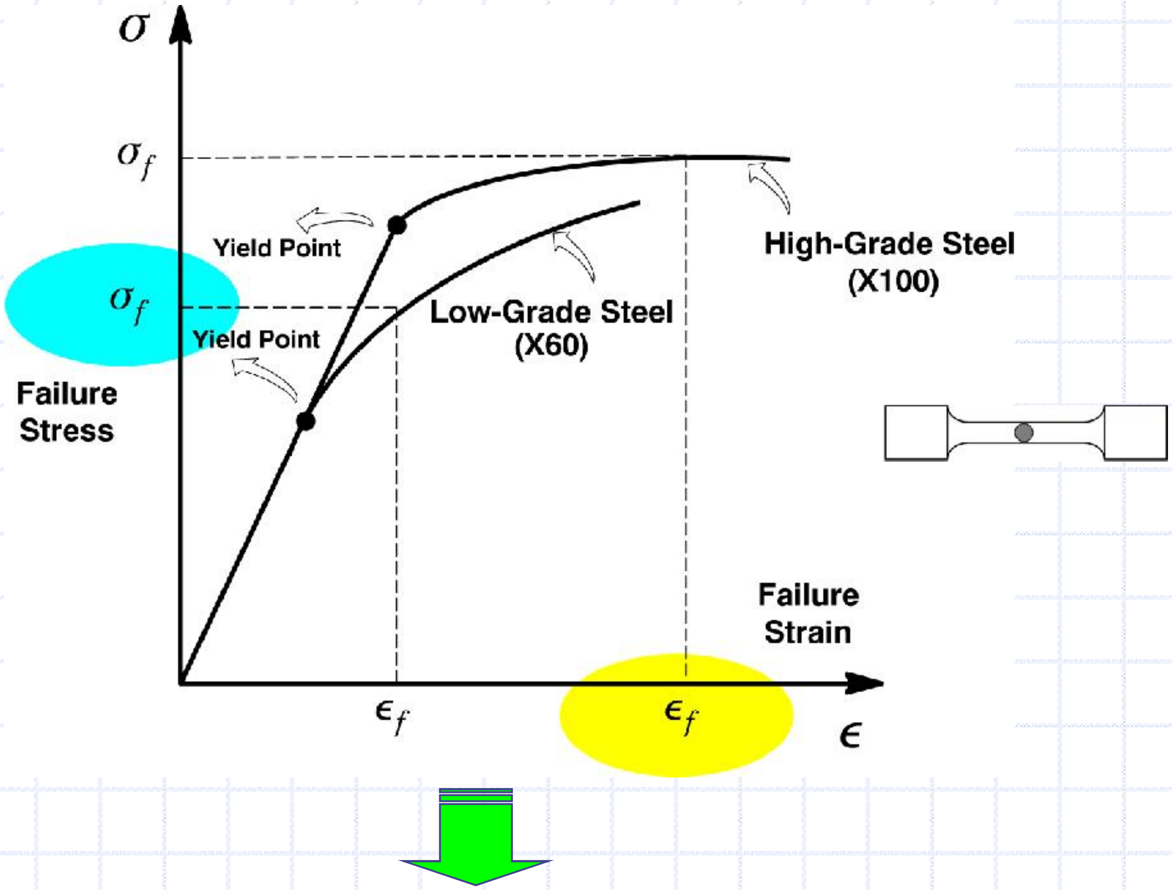
For Higher Grade Steels or Overmatched Girth Welds the Applied Strain Can Be Much Higher than the Yield Strain

Strain-Based Analysis



When the Material is in the Plastic Range, Small Changes in Stress Cause Large Changes in Strain

Strain-Based Analysis

- *Post-Yield Behavior Does Affect the Tolerable Defect Size in a Structural Component*

- *After Yielding, the Evolving Near-Tip Stresses and Crack Driving Forces (J, CTOD) Strongly Depend on the Plastic Straining Capacity*

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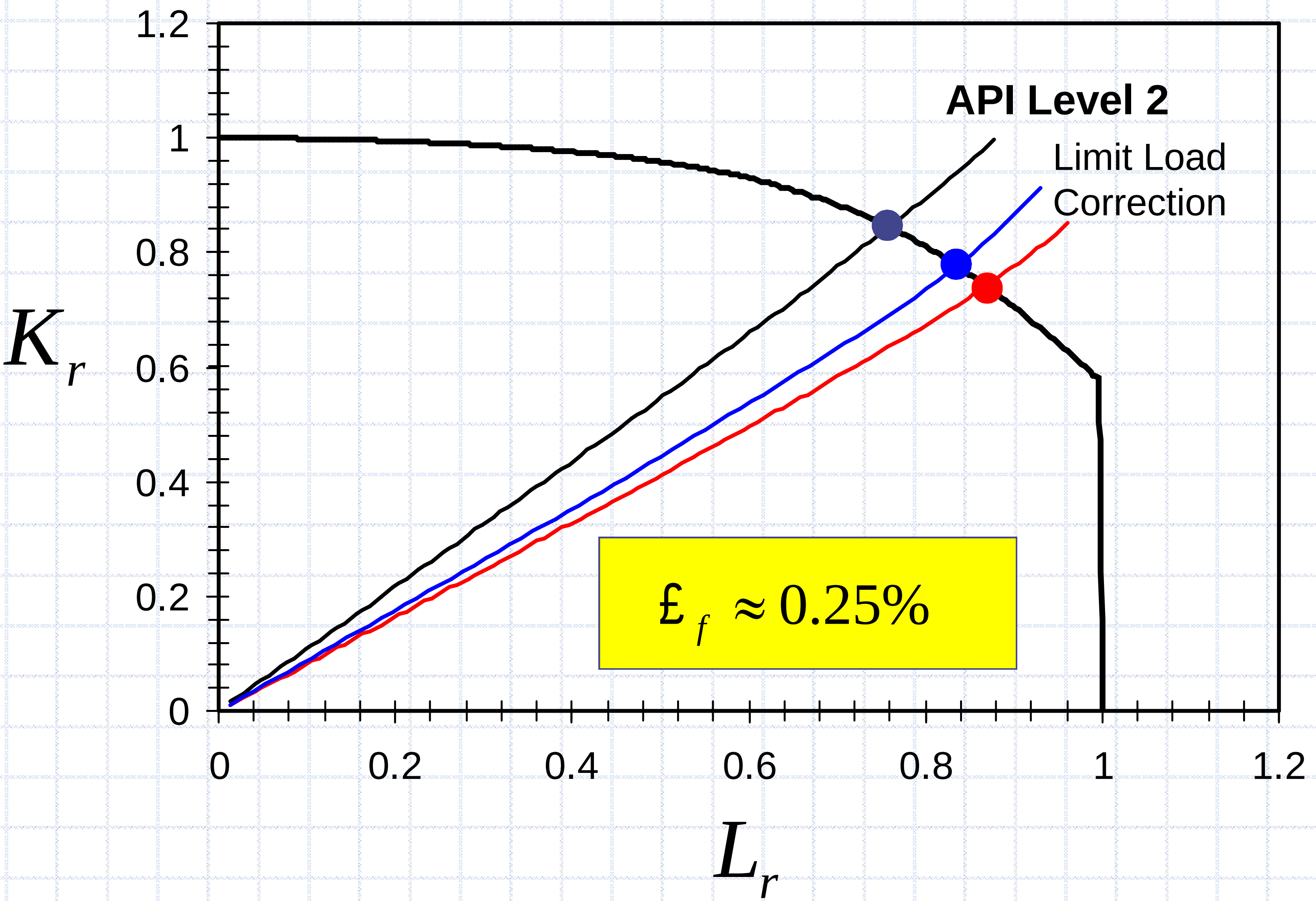
Pipe Steels with Lower YT-Ratios (X60) May Allow Larger Defects than Higher YT-Ratios (X100)

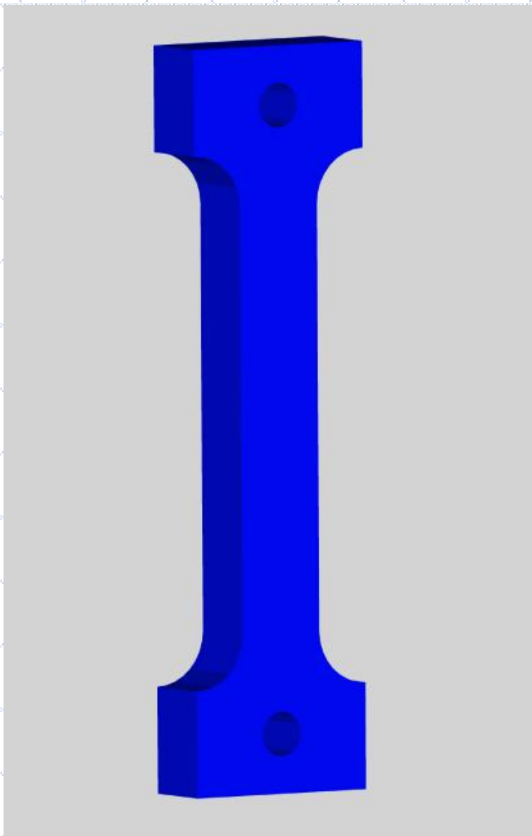
Fracture Assessment Using API 579 L2

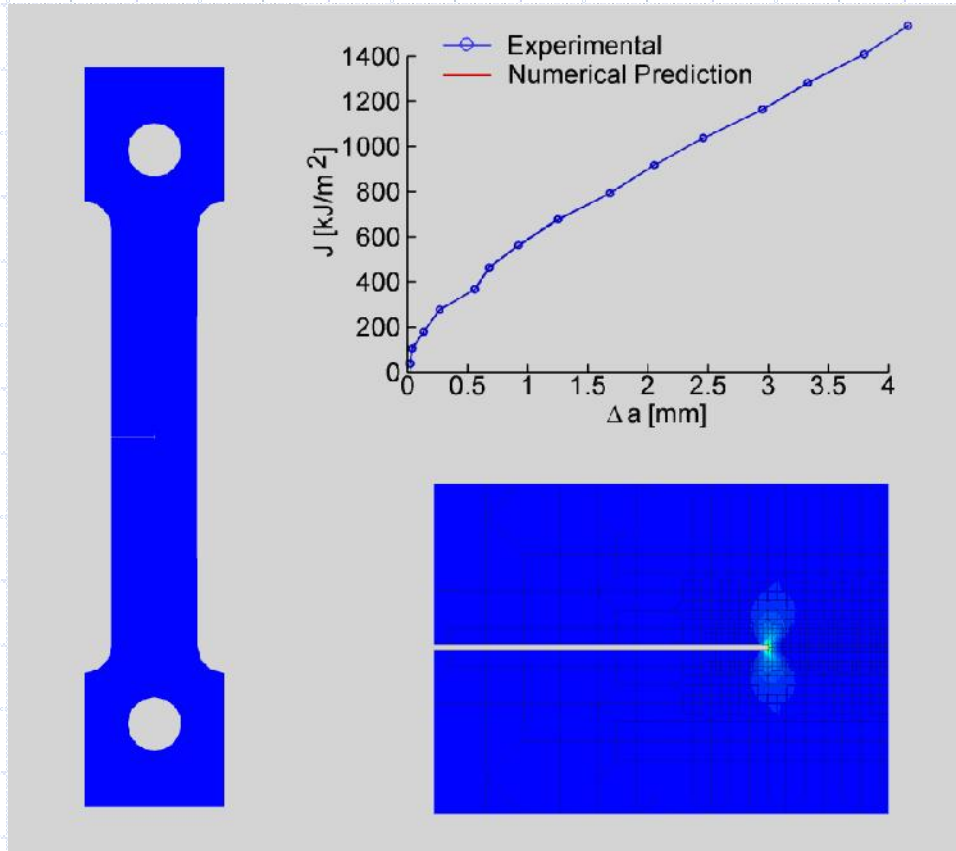


On-Going Research

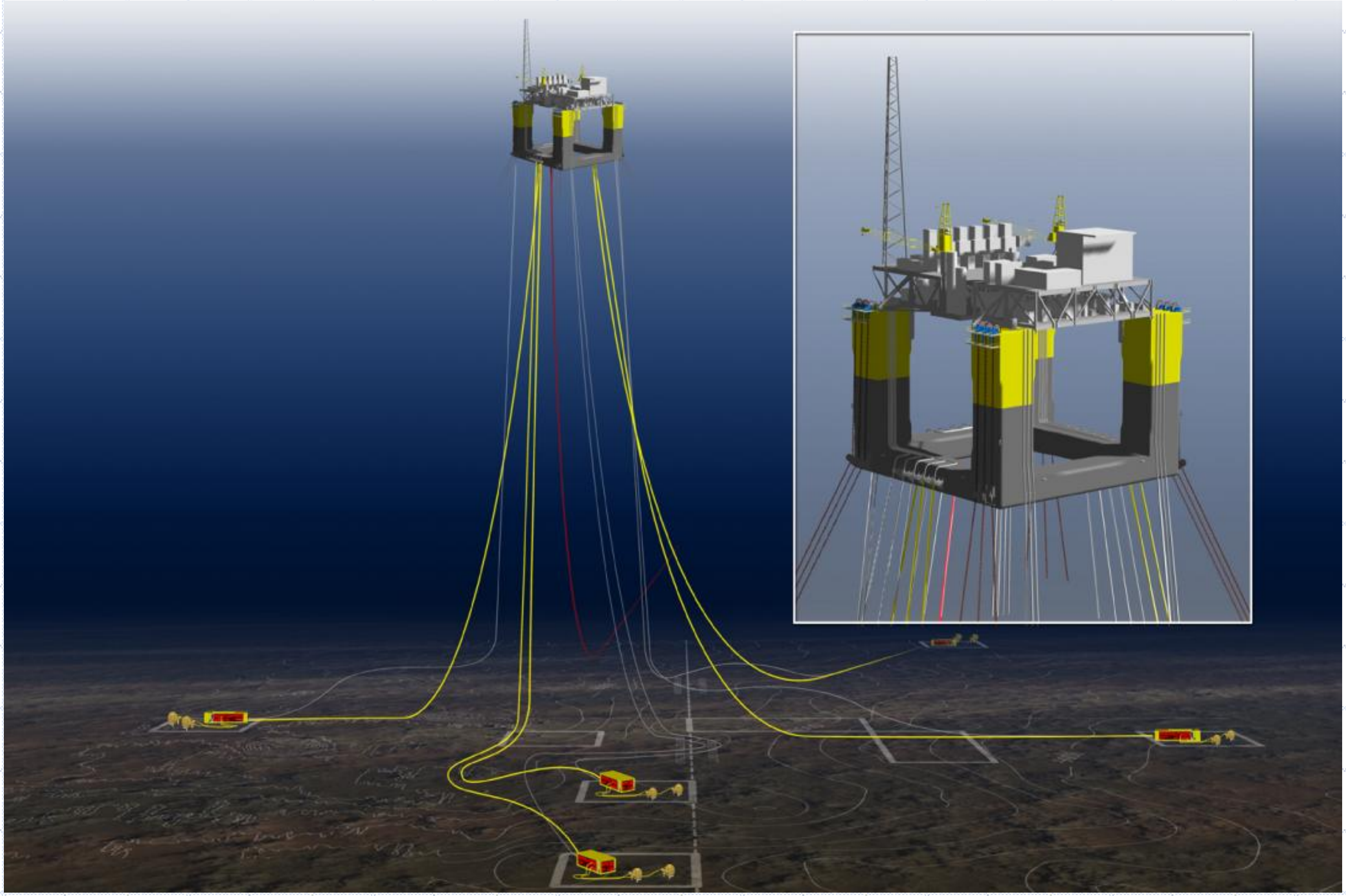
- *Development of Test Procedures for Constraint-Designed SE(T) Specimens*
- *FFS Procedures and Biaxial Loading Effects on Reeled Risers*
- *Structural Integrity Assessments of Lined Pipes for Reeling*
- *Fatigue and Toughness Behavior of Girth Welds of Lined Pipes under H_2 Environment*

Constraint-Designed Test Specimens





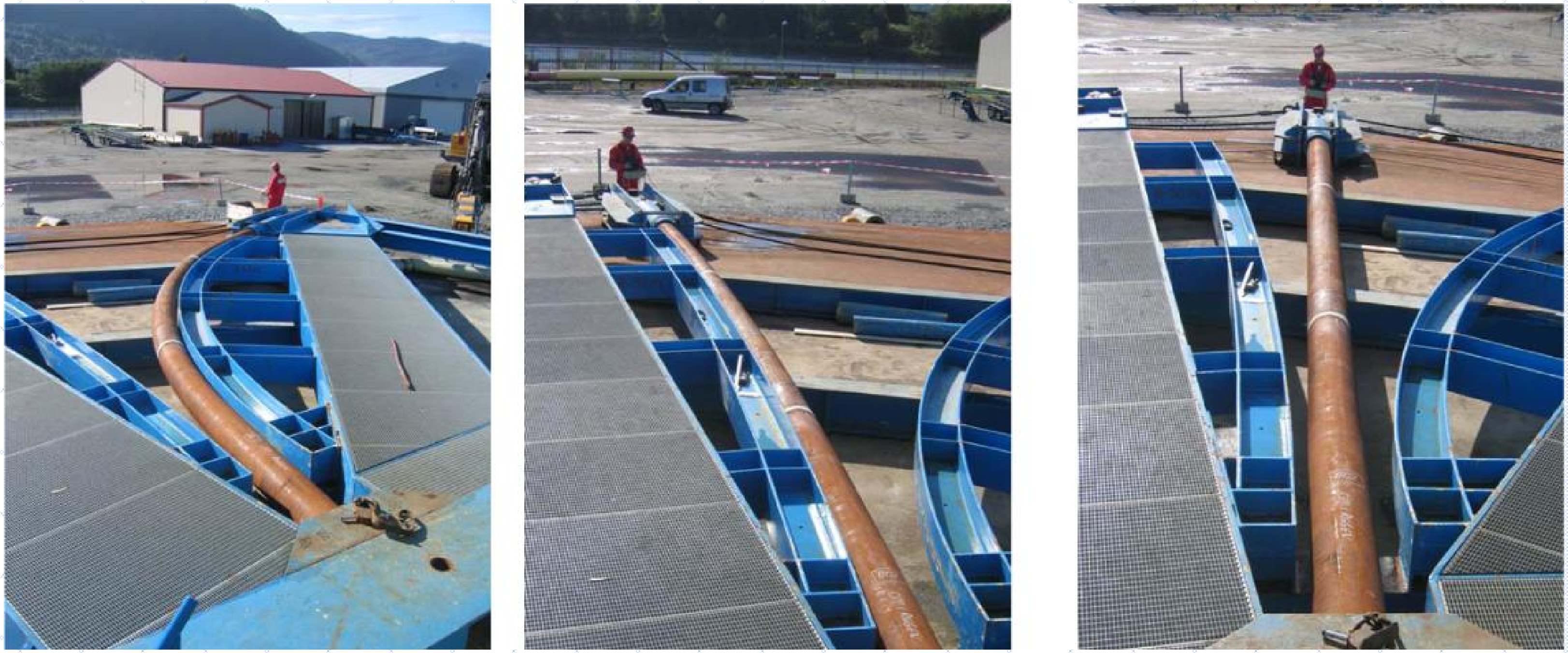
Pipeline and Riser Installation



Riser Installation by Reeling

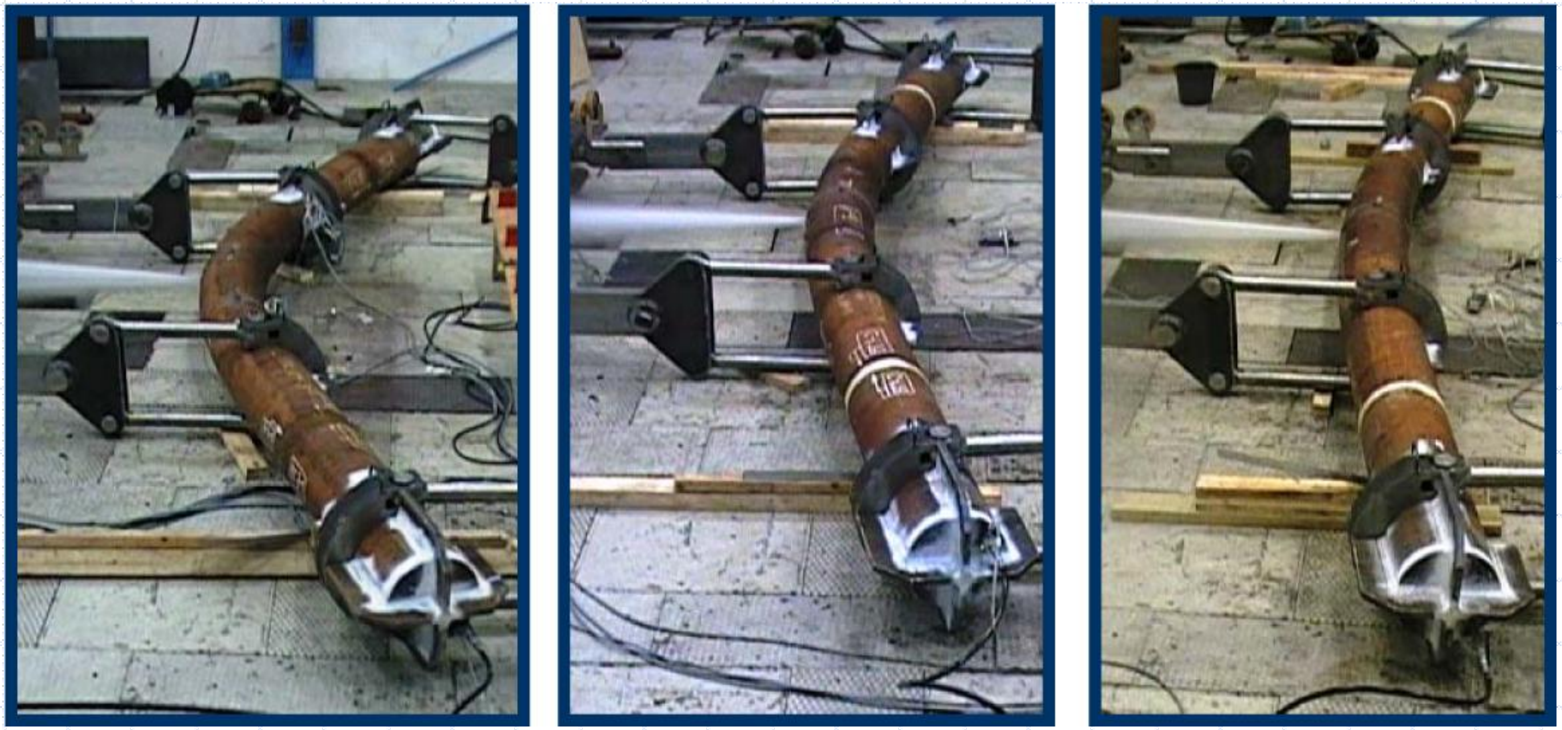
FFS Procedures for Reeled Risers

Pipe Reeling Behavior



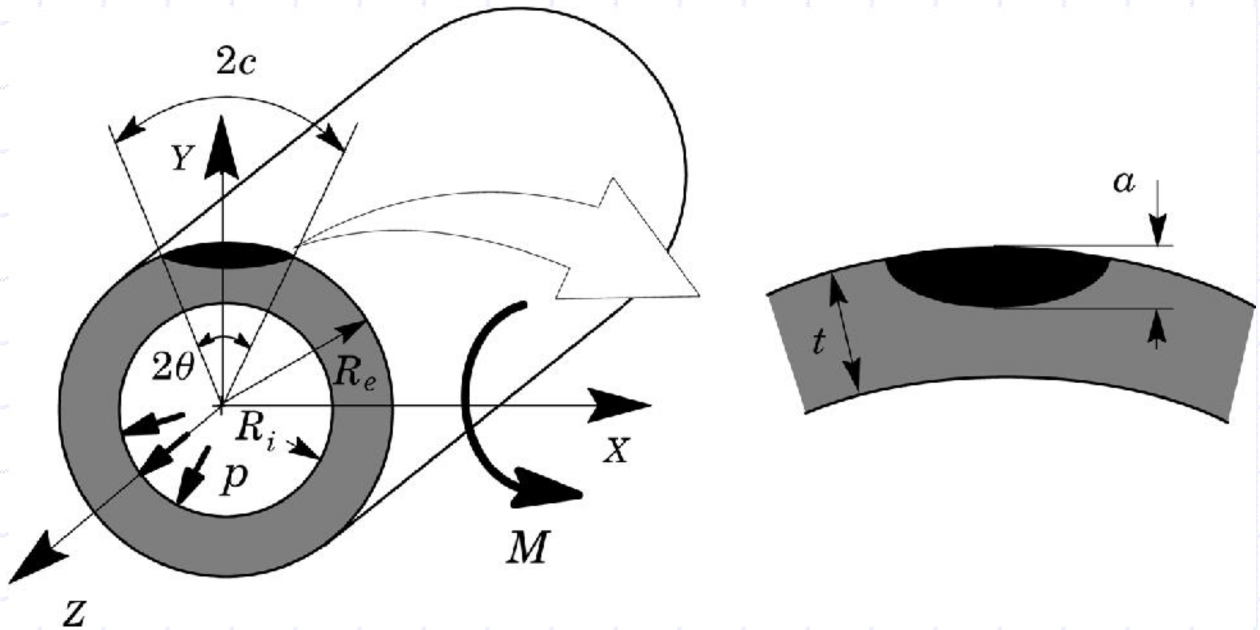
(From SINTEF Materials Laboratory)

Pipe Reeling Behavior



(From SINTEF Materials Laboratory)

FFS Procedures for Reeled Risers



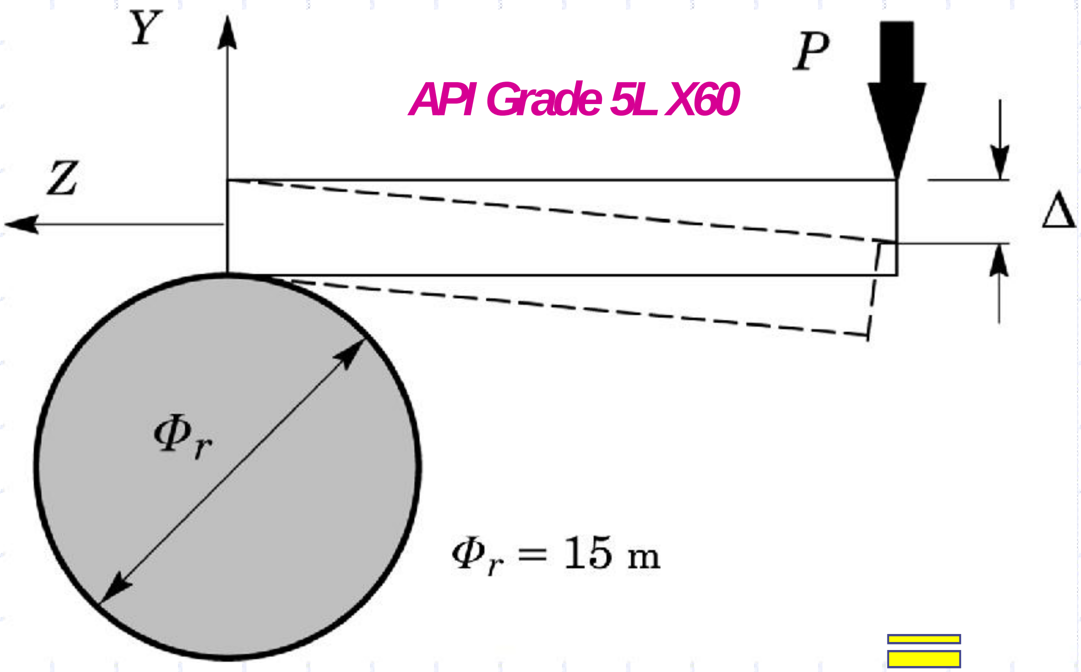
$$J_p = \alpha \epsilon_{ys} \sigma_{ys} b h_1 (a/t, D_e/t, \theta, n) \left[\frac{M}{M_0} \right]^{n+1}$$

FFS Procedures for Reeled Risers

- **Full Compendium of h_1 Factors Generated by Chiodo & Ruggieri in Polynomial Form for Easy Manipulation and Codification**
- **Proportionality Between *J* (CTOD) and Applied Loading is Very Good for High and Moderate Hardening (All Crack Config.) and Low Hardening (Shallow Cracks)**

Robust Procedure for Most Applications

Application to *Pipe Reeling*



$D_e = 344.5$ mm → $D_e/t = 16.7$

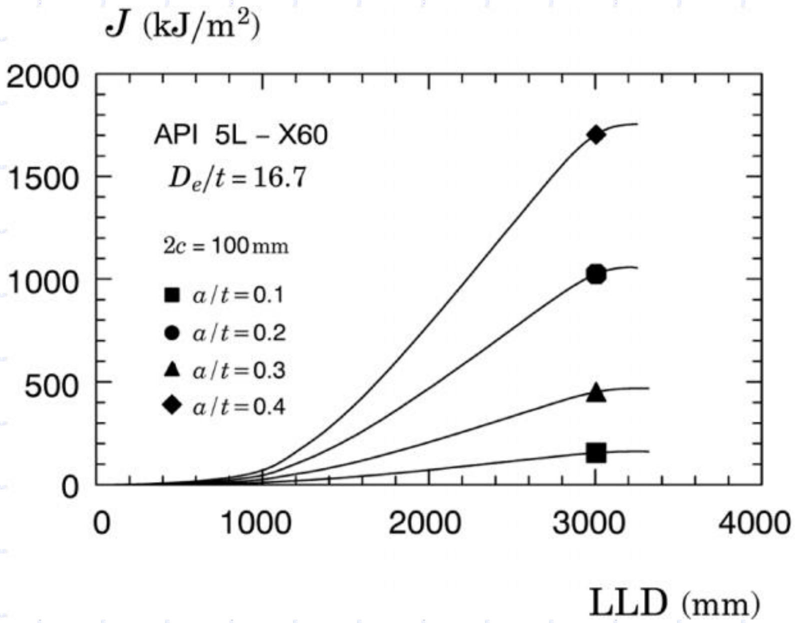
$t = 20.6$ mm

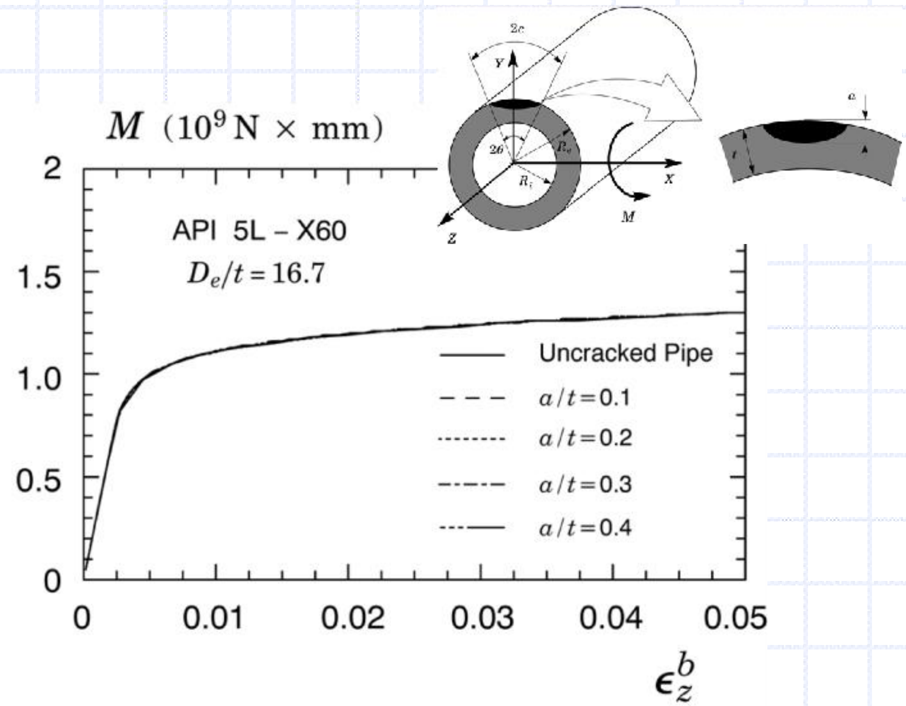
$2c = 100$ mm

$a/t = 0.1 \sim 0.4$ increments of 0.1

Estimation of J Based Upon Applied Strain (e.g., DNV-OS-F101)

J vs. Global Response



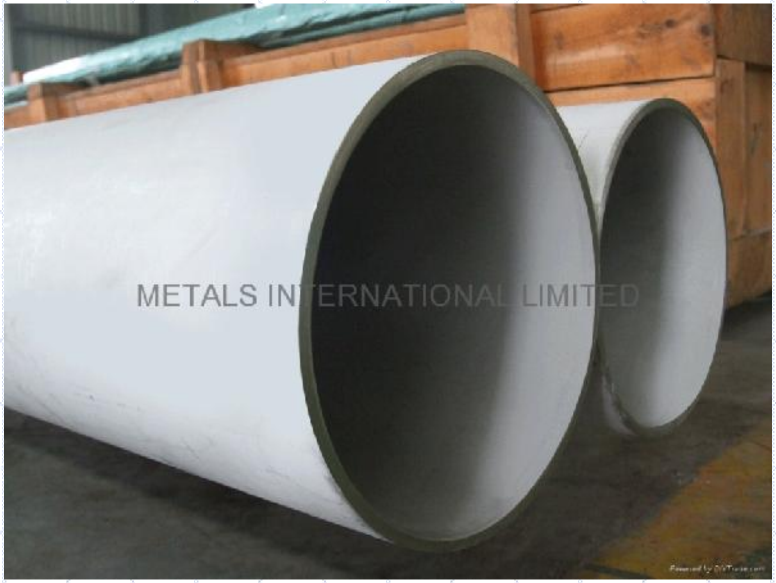


$$\epsilon_z^b = \frac{D_e}{2R_b + D_e} \quad \Rightarrow \quad \epsilon_{z,max}^b = 0.0225$$

Estimation of Maximum Crack Driving Forces in Pipe Reeling

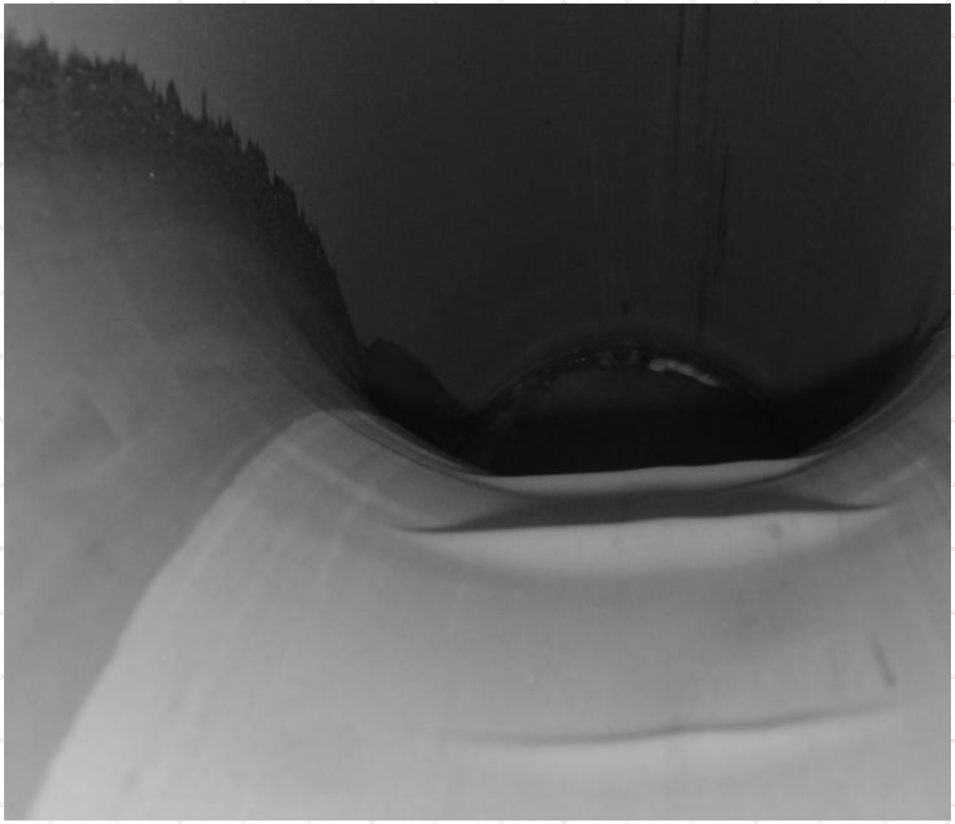
Pipe Configuration a/t	J_{reel} $(\mathrm{kJ/m^2})$	J_{pred} $(\mathrm{kJ/m^2})$	J_{reel}/J_{pred}
0.1	161.0	167.1	0.96
0.2	467.0	463.7	1.01
0.3	1055.0	1022.9	1.03
0.4	1755.0	1682.2	1.04

Lined Pipes



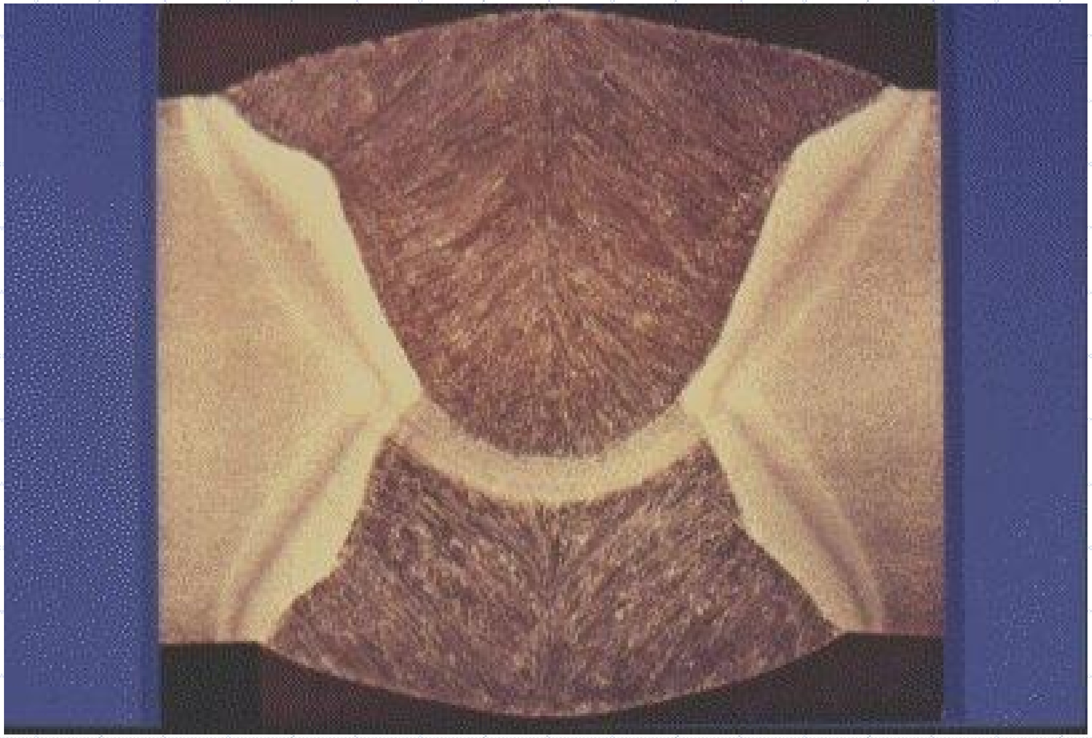
Lined pipes consist of a C-Mn pipe which has a layer of CRA in contact with the production fluid and hence, its corrosive environment. The layer of Corrosion Resistant Alloy (CRA) is applied through a mechanical bond between the CRA and the C-Mn pipe.

Key Issues



Wrinkle Formation

Key Issues



Fatigue and Fracture Behavior of Girth Welds Including Hydrogen Assisted Cracking

Summary

- **Exploitation and Production of Oil and Gas in Ultradeep and Hostile Environment Represent New and Difficult Challenges which Impact Directly the Safety and Integrity Levels of Pipelines and Risers**

- **Application of Current FFS Procedures to Newer Materials and Complex/Severe Conditions Can Not be Made by Simple *Ad-Hoc* Extension of Conventional Engineering Methodologies**

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Innovative and Yet More Rational and Reliable Approaches Must Be Developed!

THANK YOU!