OFFSHORE PIPELINE DAY

Fitness-for-service (FFS) and engineering critical assessment (ECA) of pipelines and offshore structures

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INTRODUCTION
What is FFS?

- FFS / ECA is multi-disciplinary analysis to determine if equipment can remain in operation
  - Material damage mechanisms and behavior
  - Stress analysis - often FEA
  - NDE to locate, size, and characterize flaws
  - Material properties, especially environmental effects - corrosion and temperature
  - Statistical data analysis
- FFS Assessment Requires Knowledge and Information
  - Historical records and future forecast of operating conditions
  - Interaction With Operations Personnel
- Results of FFS products are
  - Determination to Run, Alter, Repair, Monitor, or Replace
  - Guidance on Inspection Interval

Why is FFS Required?

- During construction or in-service - material properties or flaws may be identified which do not meet strict code requirements
  - FFS or ECA can be applied to:
    - Assess acceptability for continued operation
    - Determine safety and integrity of operating damaged or aging facilities
    - Justify life extension
    - Assess change in operation
- Addresses Flaws commonly found in onshore / offshore pipelines and equipment
  - Cracking, corrosion, buckling, mechanical damage, HIC, creep, weld anomalies, etc.
  - Focus on Cracking, Corrosion, Mechanical Damage
- Assess flaws found by more rigorous inspections than performed during original construction
- Design and construction codes may be arbitrary and overly conservative
  - Often based more on workmanship than integrity

Standards

STANDARDS

Several Standards and RPs that describe FFS and ECA approaches:

- BS 7910: Guide on the methods for assessing the acceptability of flaws in metallic structures
- API 579-1/ ASME FFS-1 Fitness-for-Service, June 2016
- DNVGL-RP-F101 Corroded pipelines
- DNVGL-RP-F108 Assessment of flaws in pipeline and riser girth welds, October 2017
- DNVGL-ST-F101 Submarine pipeline systems, October 2017.

FFS Assessment Levels

Each Part of Standard Provides Three Levels of Assessment

- **Level 1**: conservative screening criteria for use with minimum amount of data
- **Level 2**: more detailed and precise than Level 1; more detailed calculations by plant engineer or other engineering specialist
- **Level 3**: most detailed and more precise than Level 2; stress and material damage analyses by team of experienced engineering specialists

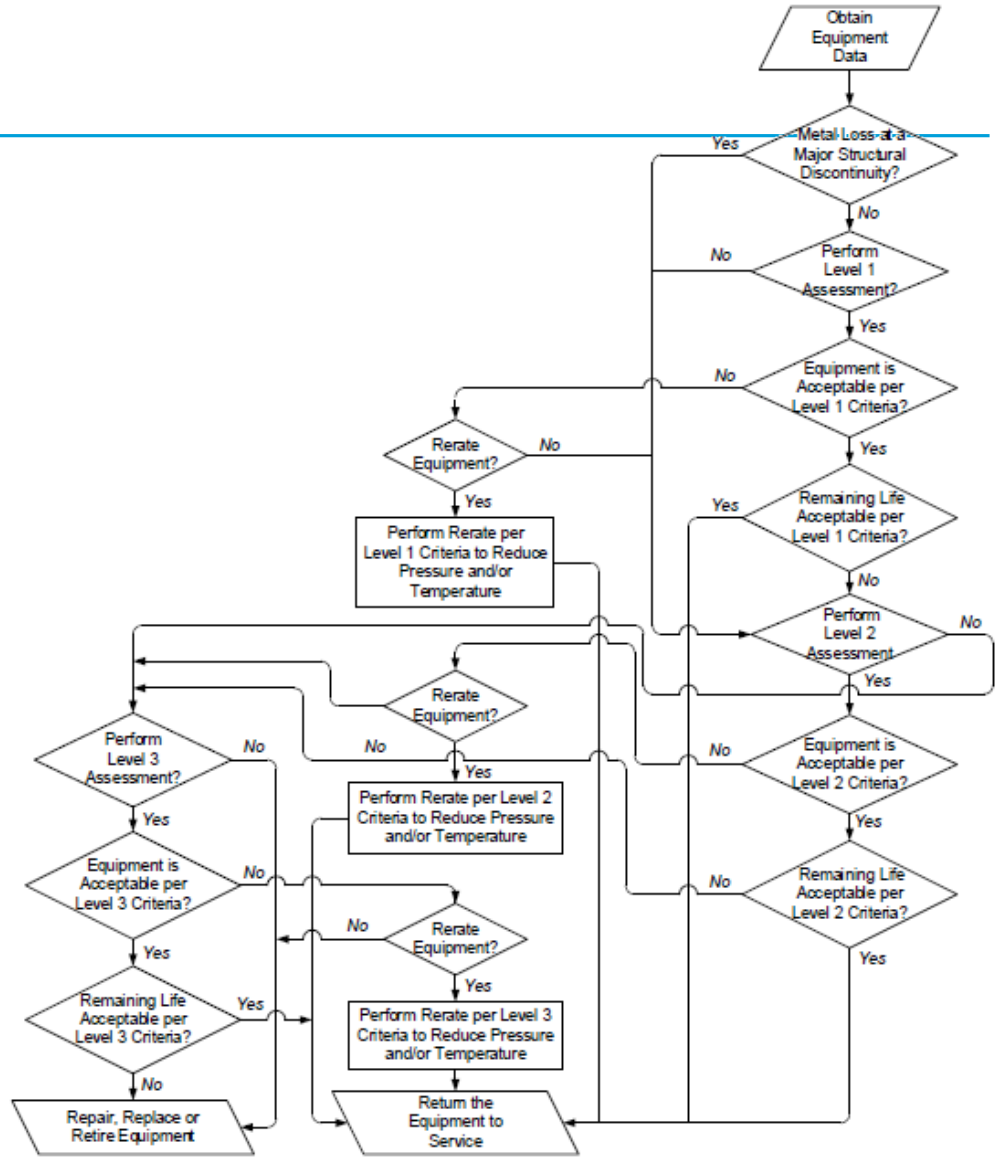

Figure 4.1 – Overview of the Assessment Procedures to Evaluate a Component with General Metal Loss

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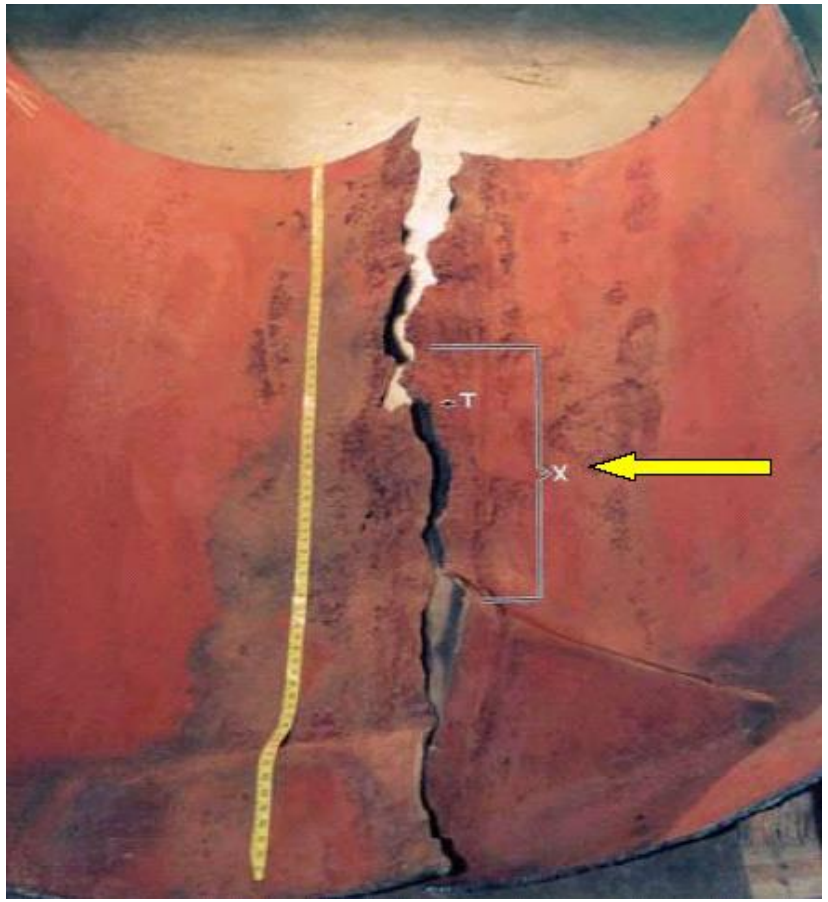
Pipeline Failures at Area of Local Corrosion



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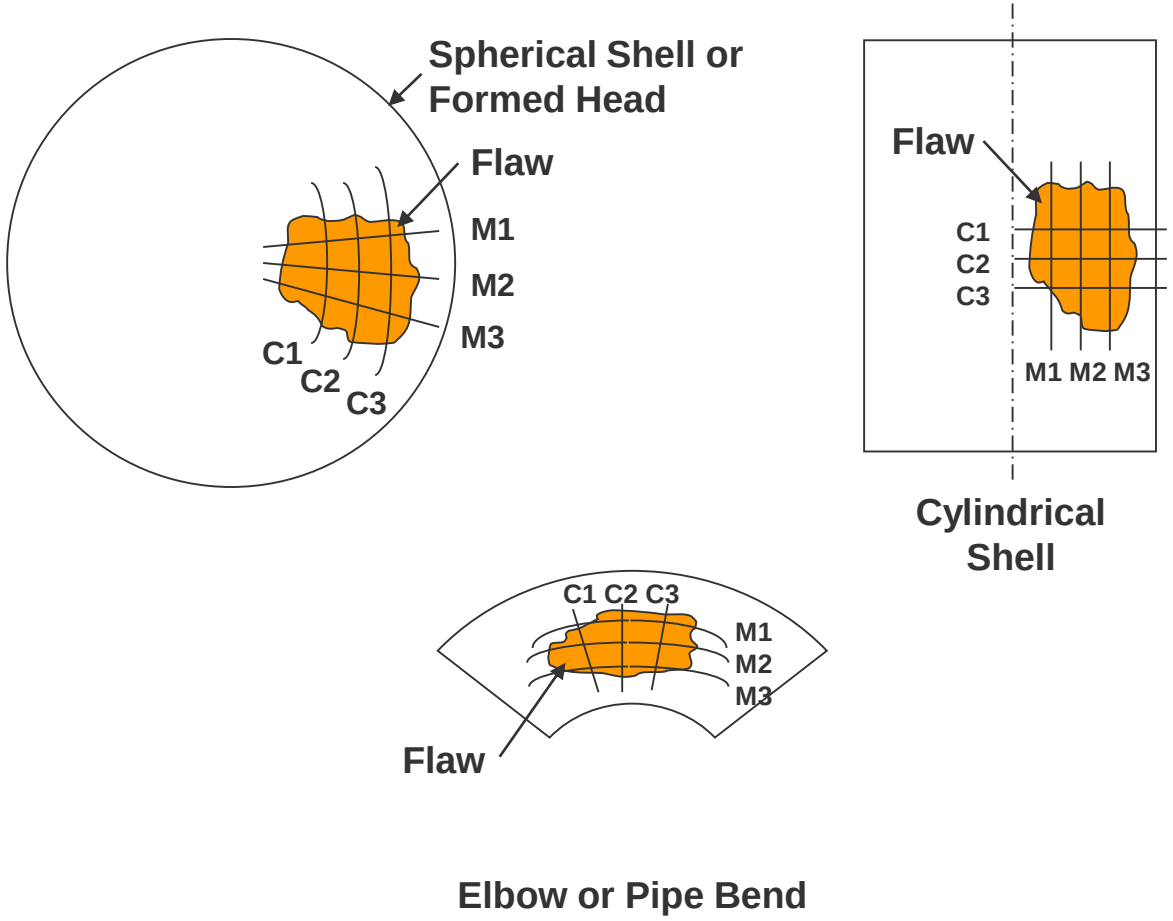
Parts 4 & 5: Assessment of Metal Loss

Assessment of Local and General ML

- Make wall thickness measurements
- Use criteria for thickness averaging
- Step-by-step recipes for levels 1 and 2
- Level 3 for complex regions of metal loss or component details using detailed FEA
- RSF used to qualify or rerate component
- Remaining life assessment
  - Minimum allowable thickness approach
  - MAWP approach



Inspection Planes for Thickness Profile

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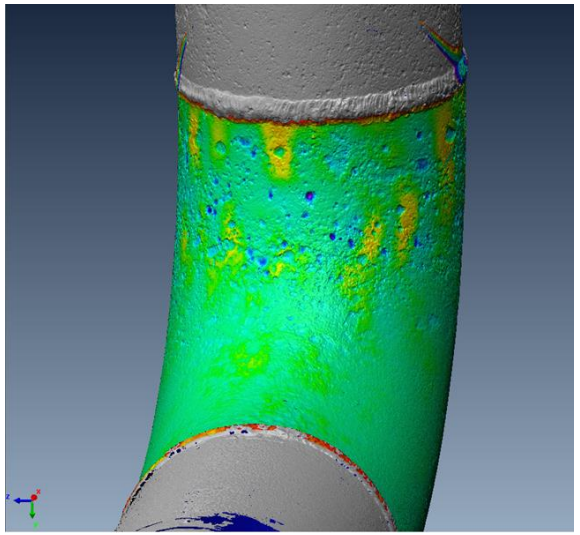
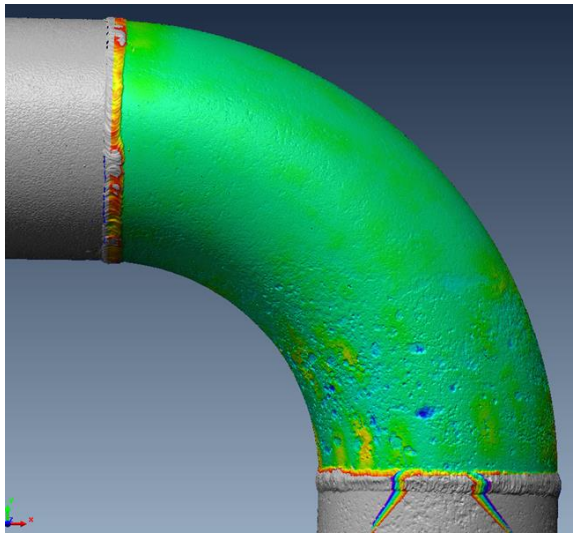
Applicability and Limitations

- Level 1 and 2 apply only when
  - Simple loading (internal / external pressure)
  - Smooth contours w/o notches (negligible stress concentrations)
  - Separated from structural discontinuity (weld, nozzle, branch, fitting, etc.)
  - Not in cyclic service

- Level 3 :
  - Complex loading or geometry
  - Localized stress concentrations
  - Failure pressure defined from FEA
  - E.g. BS7910 defines where von Misses = UTS





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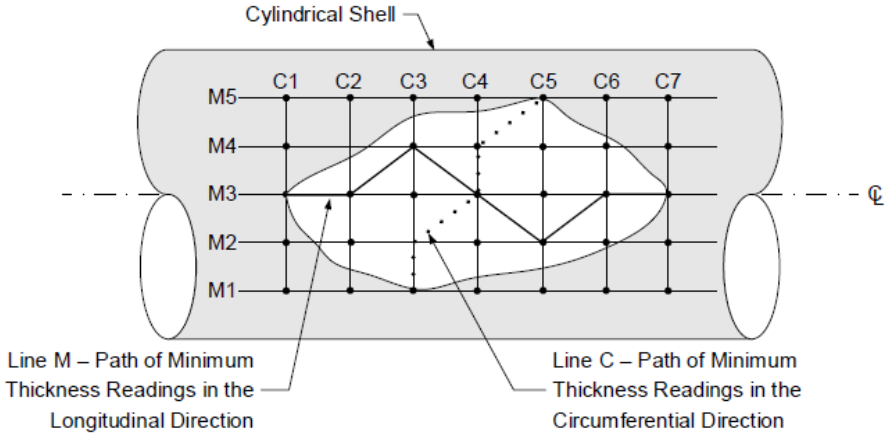
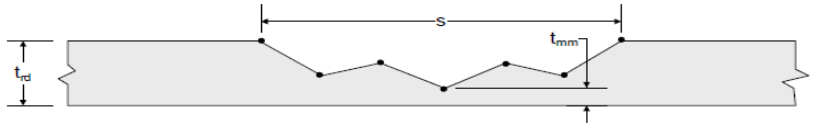
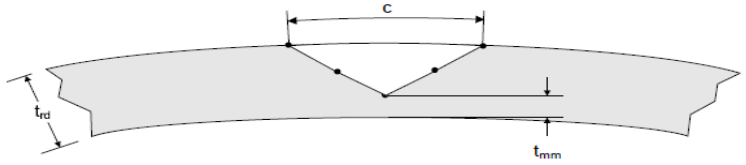
Level 1, 2, 3 – Corrosion Analysis



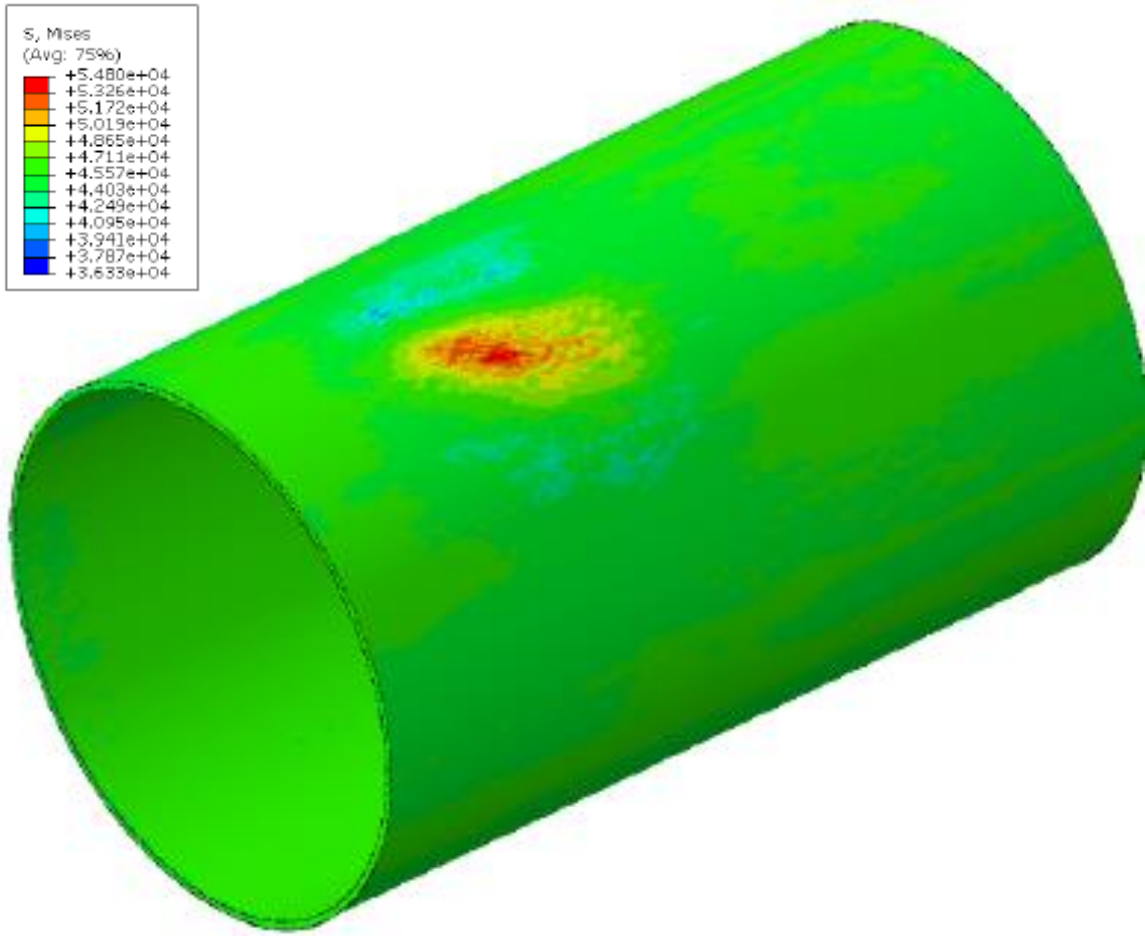


CTP for Longitudinal Plane



CTP for Circumferential Plane

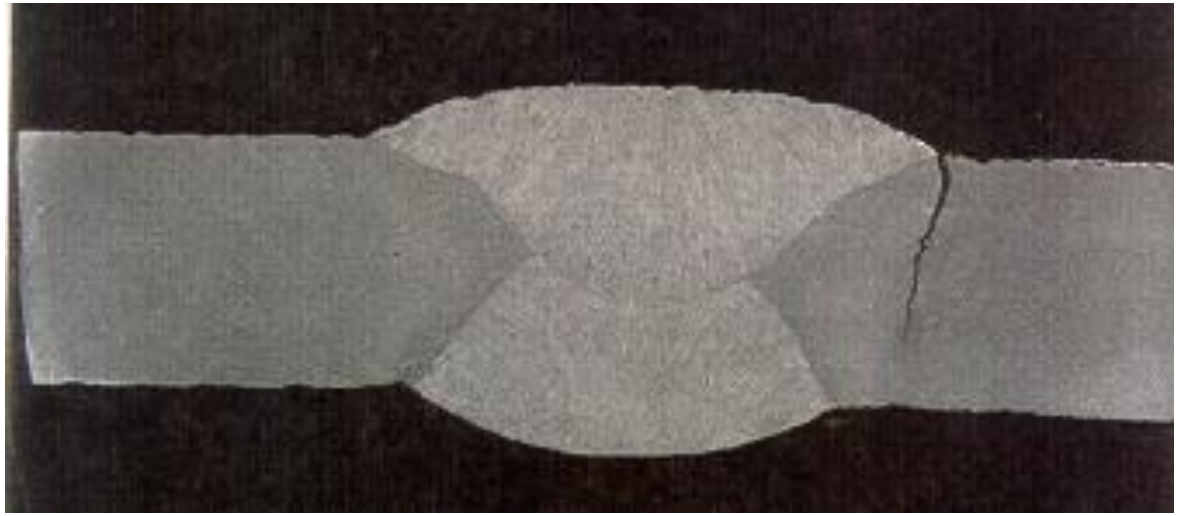
Level 1,2: Calculate MAWP using t_{mm} or CTP



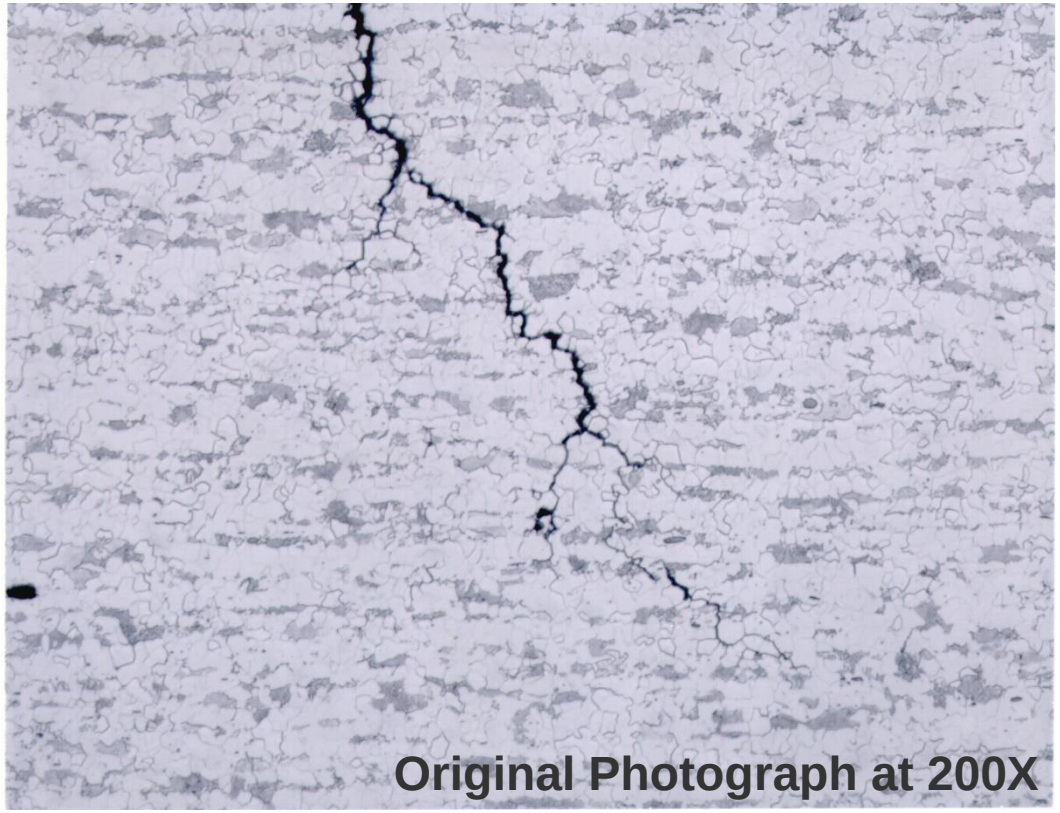
Level 3: NL FEA results of scanned ML at calculated burst pressure

Crack-like Flaws in Pipelines and Equipment

Fatigue Crack at Weld Toe



Intergranular SCC in Steel Pipe



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Part 9: Assessment of Crack-Like Flaws

- Assessment Procedures Are Based on Failure Assessment Diagram (FAD) Method
  - Background and development in Annex 9A
- Stress Analysis Concepts Based on ASME B&PV Code, Section VIII, Division 2, Part 5
- Crack-Like Flaws Are Planar Flaws
  - Characterized by length, depth, & sharp root radius
  - Surface breaking, embedded, or through-wall
  - Includes: planar cracks, lack of fusion and lack of penetration in welds, sharp groove-like corrosion,
- Treatment of Volumetric Flaws
  - Recommendation to treat as crack-like flaws in some cases
  - Aligned porosity or inclusions, deep undercuts, root undercuts, and overlaps
  - NDE may not be sensitive enough to determine whether micro-cracks have initiated from flaw

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- Use of Procedures to Evaluate Brittle Fracture
  - Compare relative flaw tolerance or evaluate risk of brittle fracture for screening purposes
  - Postulate reference flaw with a depth equal to 25% of wall thickness and length equal to 6 times this depth

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Elastic Fracture Mechanics

- Component With Crack-Like Flaw
- Elastic Stress Intensity Factor
  - $K_I = \sigma F(a/w)$
  - σ = applied stress.
  - a = crack length or depth
  - w = width
  - $F(a/w)$ = shape factor. For infinitely wide plate with a through-wall crack of length $2a$,

$$F\left(\frac{a}{w}\right) = \sqrt{\pi a}\ , \ \text{so}\ \ K_I = \sigma\sqrt{\pi a}$$

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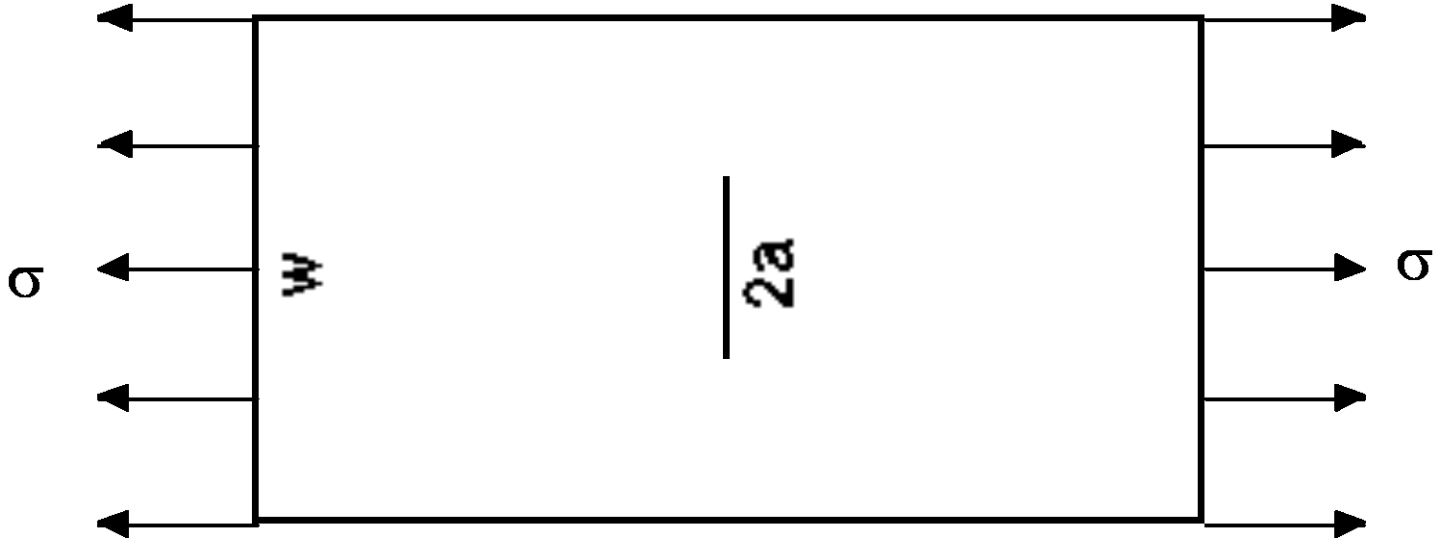
Elastic Fracture Mechanics



$$F\left(\frac{a}{w}\right) = \sqrt{\pi a} \cdot \sqrt{\sec\left(\frac{\pi a}{w}\right)}$$

- Annex 9B and handbooks have solutions for common component/crack configurations
- Use FEA software to compute *K* values

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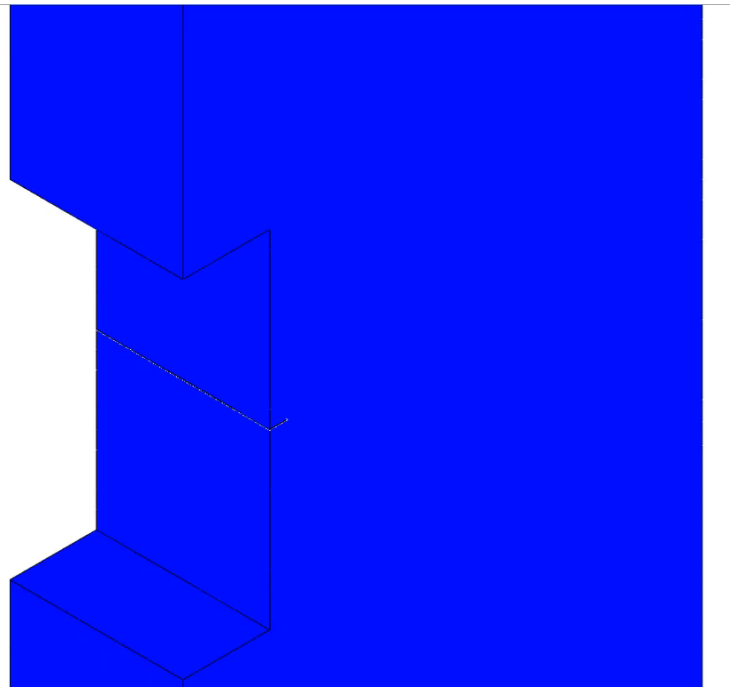
Elastic Fracture Mechanics

- Fracture Toughness
  - K_{Ic} is a material property measured in the laboratory using a cracked specimen
  - When $K_I \geq K_{Ic}$ fracture is likely to occur

- Important Factors in Analysis
  - Account for effects of residual stress (Annex 9D)
  - Apply appropriate equations for calculating K and reference stress

- Level 3 – Detailed FEA for Calculating K and Reference Stress



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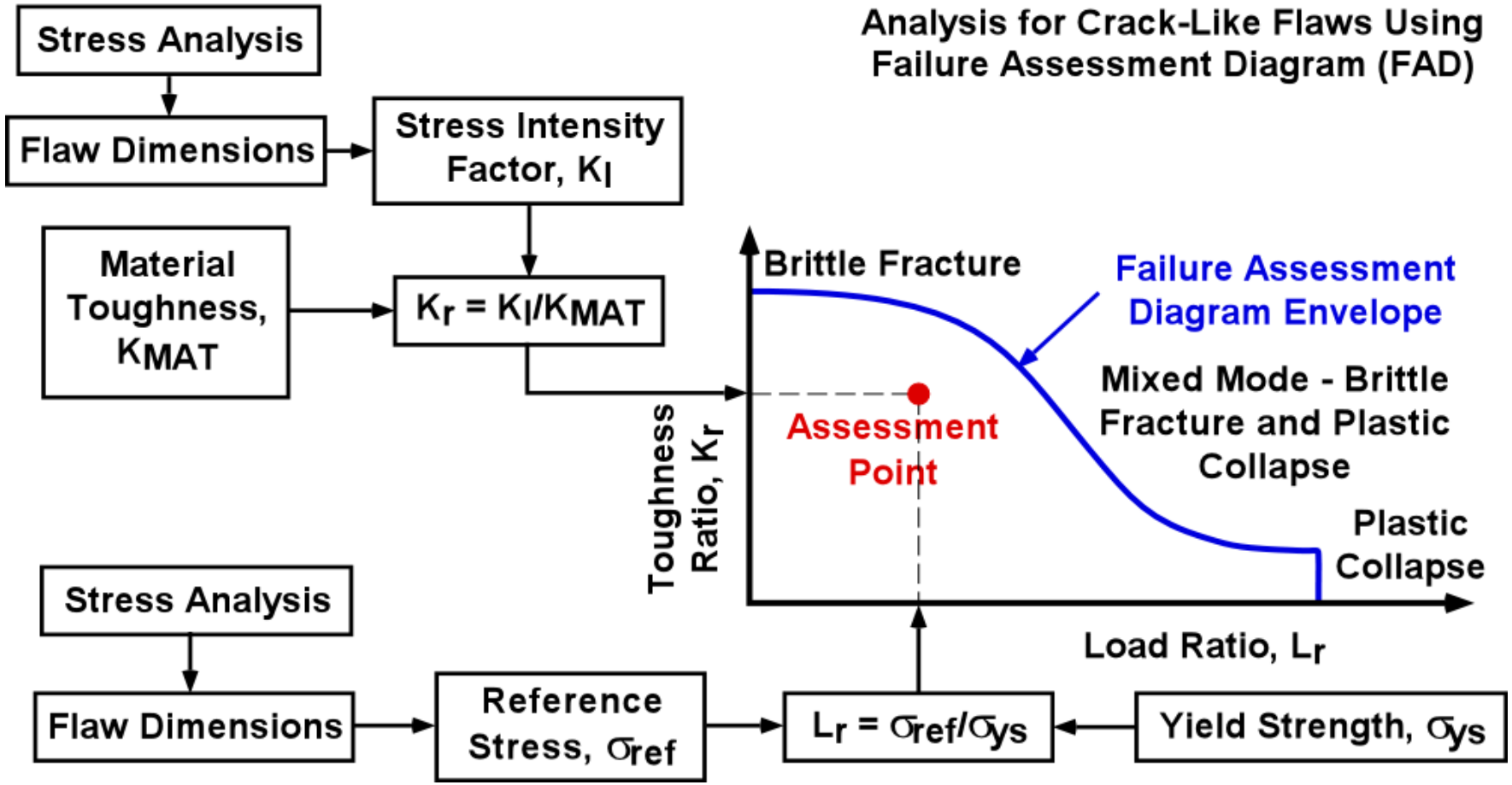
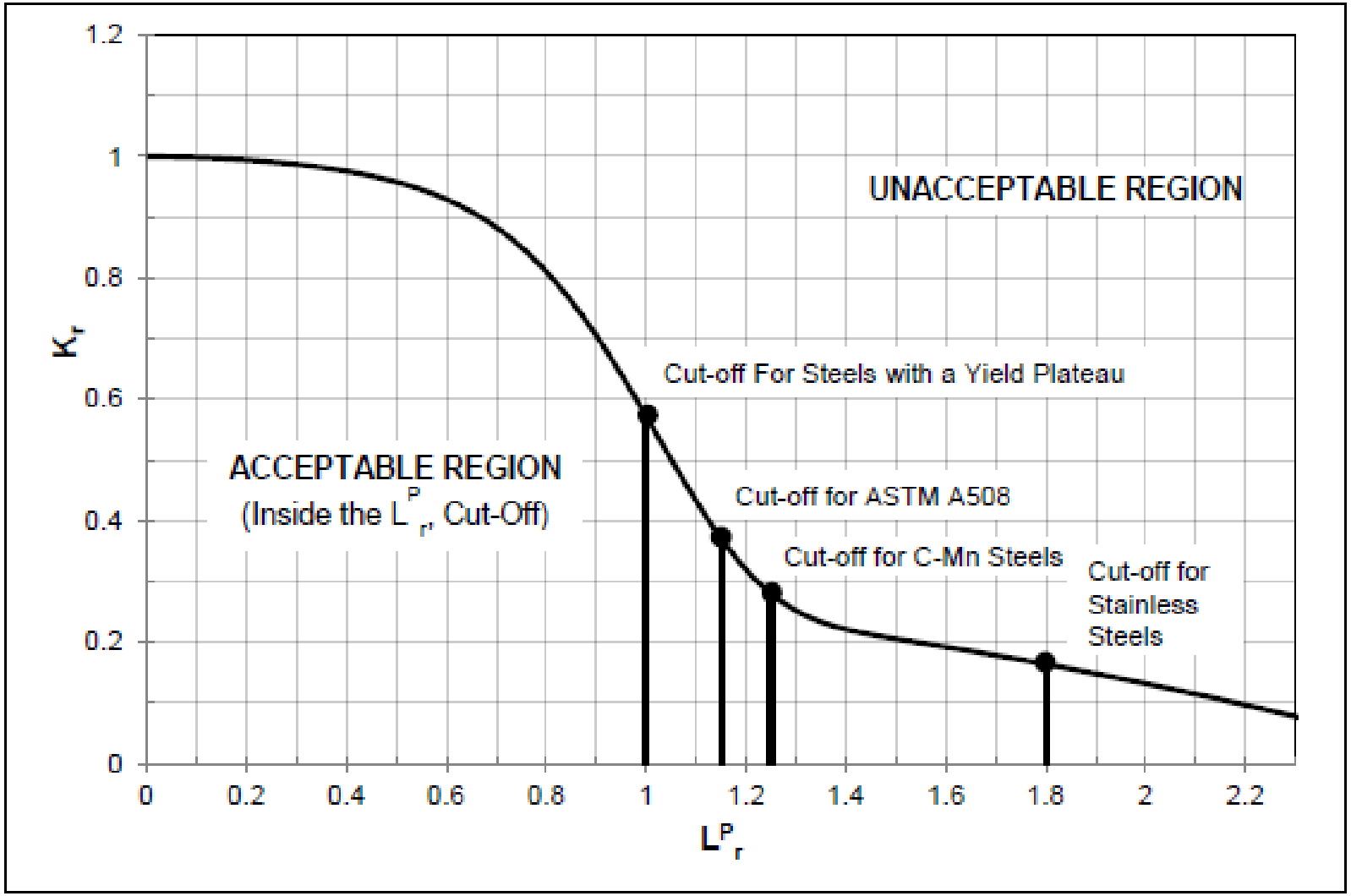
FAD for Crack-Like Flaws

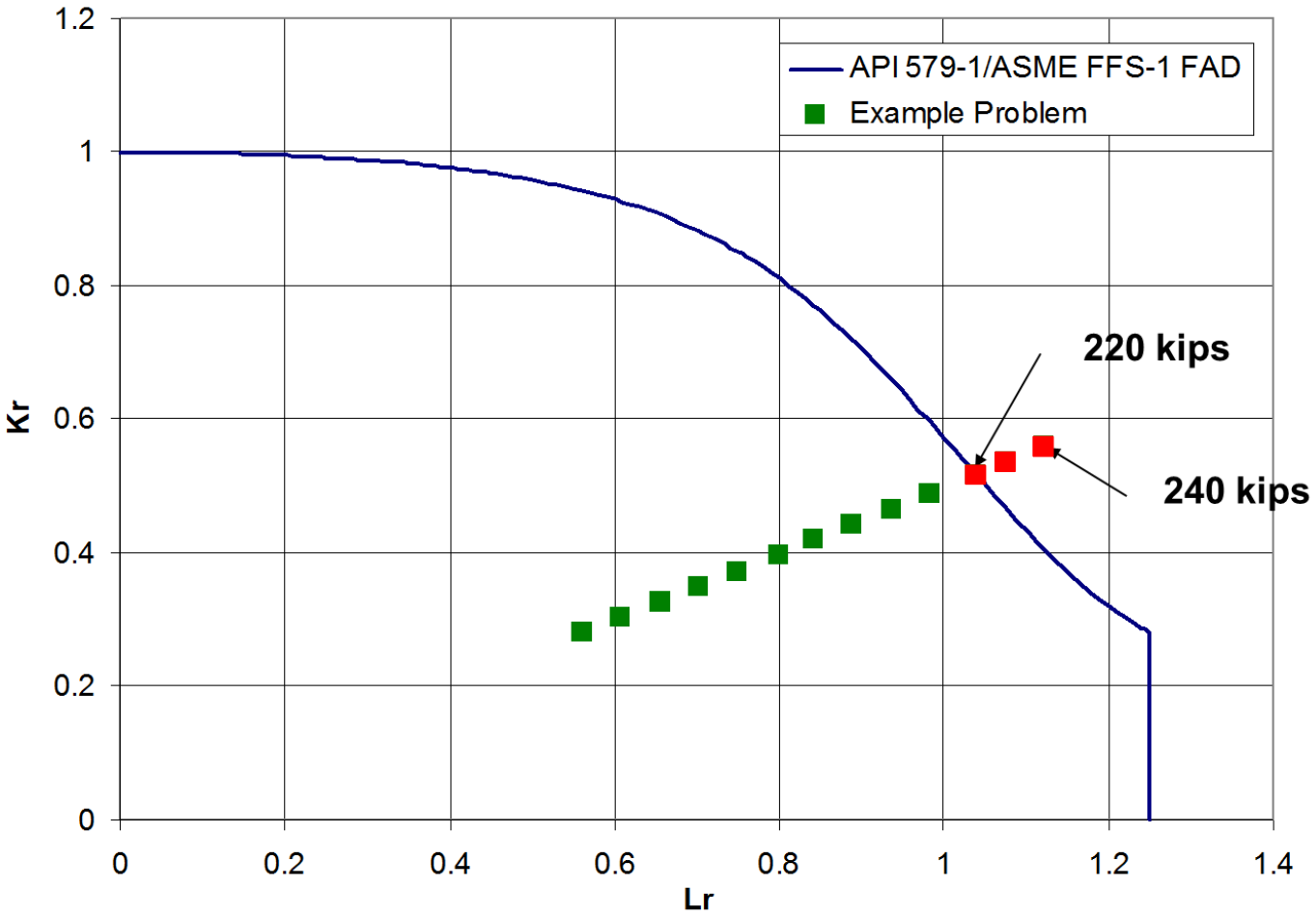


FAD for Crack-Like Flaws



Example FAD – Determining Critical Pressure

F, kip	P_m, ksi	s_{ref}, ksi	K, ksi in$^{0.5}$	L_r	K_r
120	19.2	21.33	28.53	0.561	0.285
130	20.8	23.11	30.91	0.608	0.309
140	22.4	24.89	33.29	0.655	0.333
150	24	26.67	35.67	0.702	0.357
160	25.6	28.44	38.04	0.749	0.380
171	27.36	30.40	40.66	0.800	0.407
180	28.8	32.00	42.80	0.842	0.428
190	30.4	33.78	45.18	0.889	0.452
200	32	35.56	47.55	0.936	0.476
210	33.6	37.33	49.93	0.982	0.499
220	35.2	39.11	52.31	1.029	0.523
230	36.8	40.89	54.69	1.076	0.547
240	38.4	42.67	57.07	1.123	0.571



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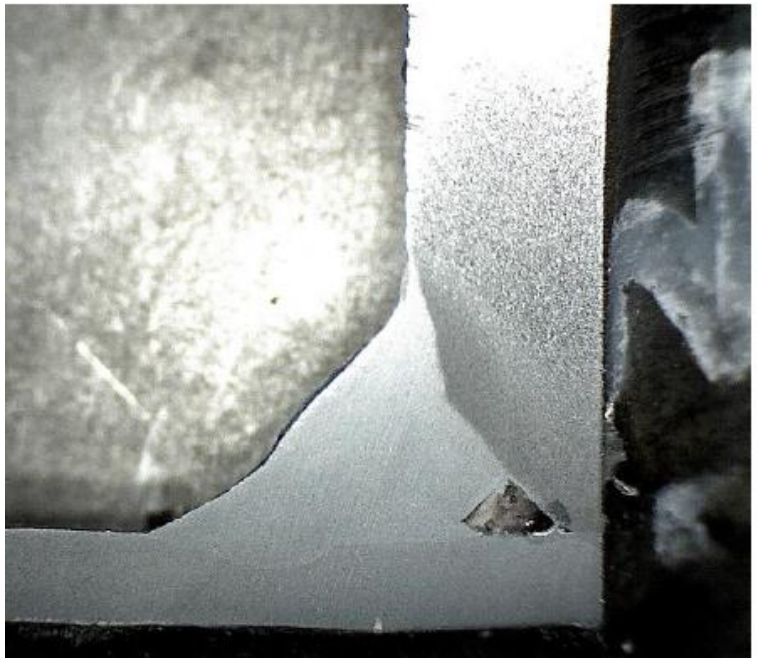
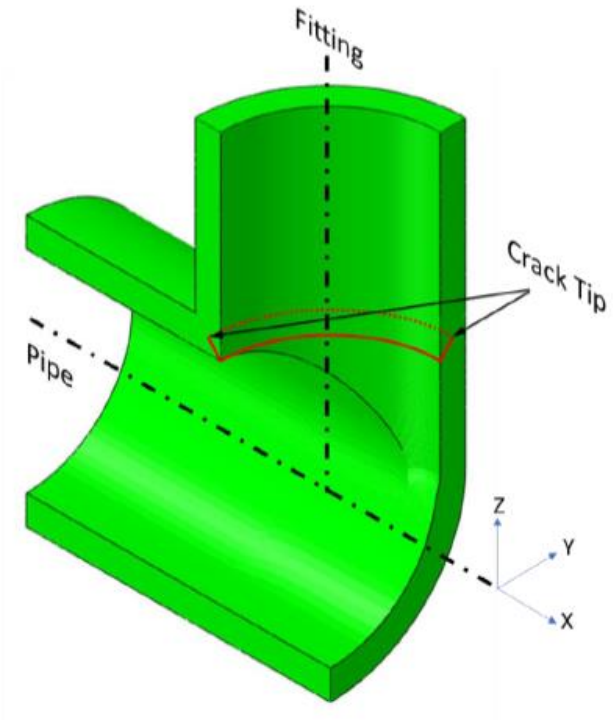
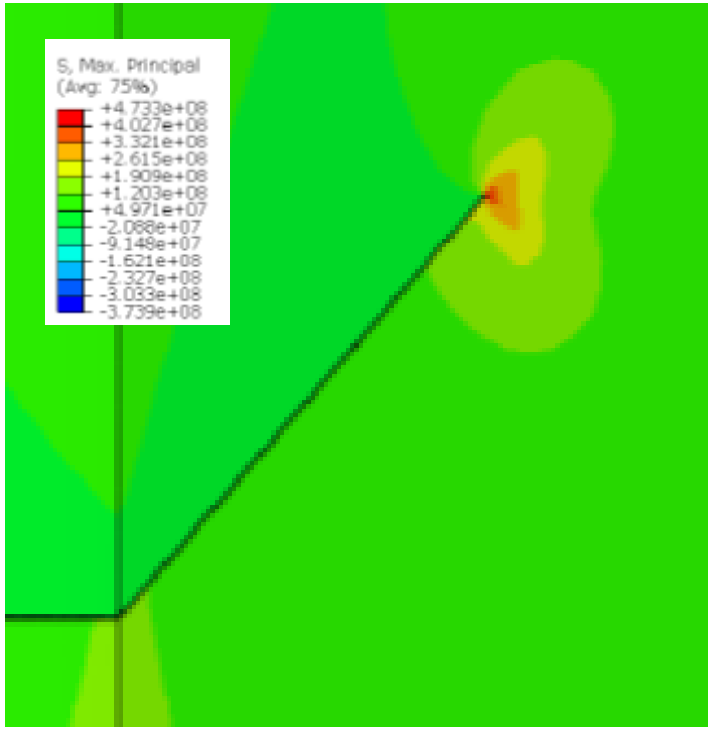
CASE 1: Weld Root Imperfections

- Analysis of weld root imperfections w/ possible cracking
- Complex stress state and flaw location required Level 3 and FEA
- Found to be acceptable – no remediation required

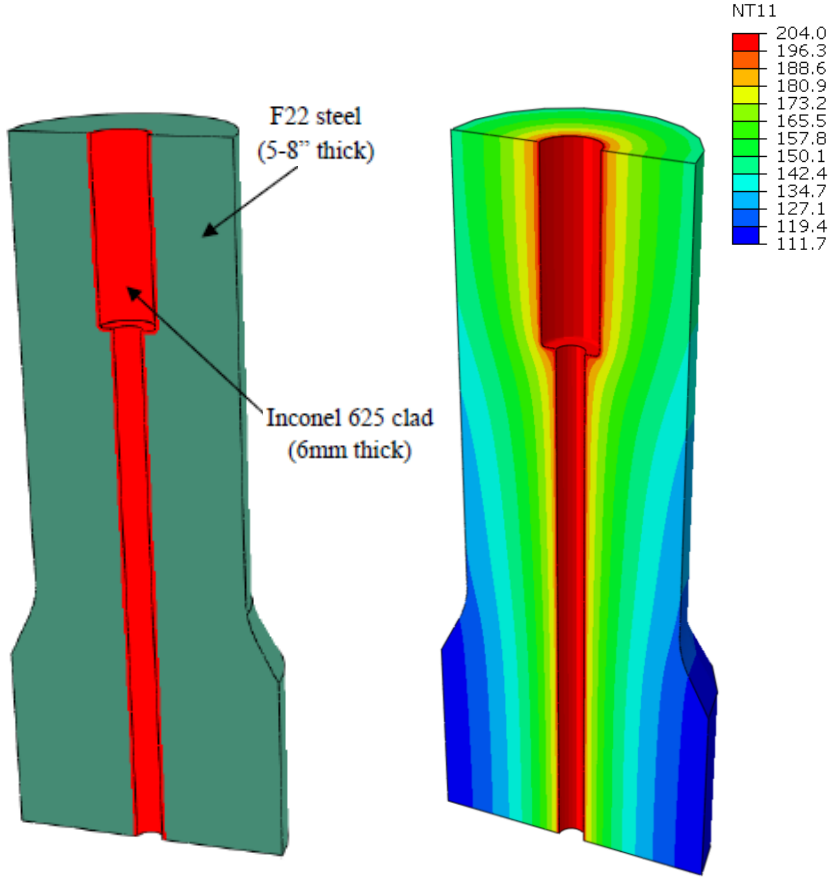






3D FE crack modelling of a weld root imperfection

CASE 2: Crack-like Flaw in Clad Subsea HPHT Equipment



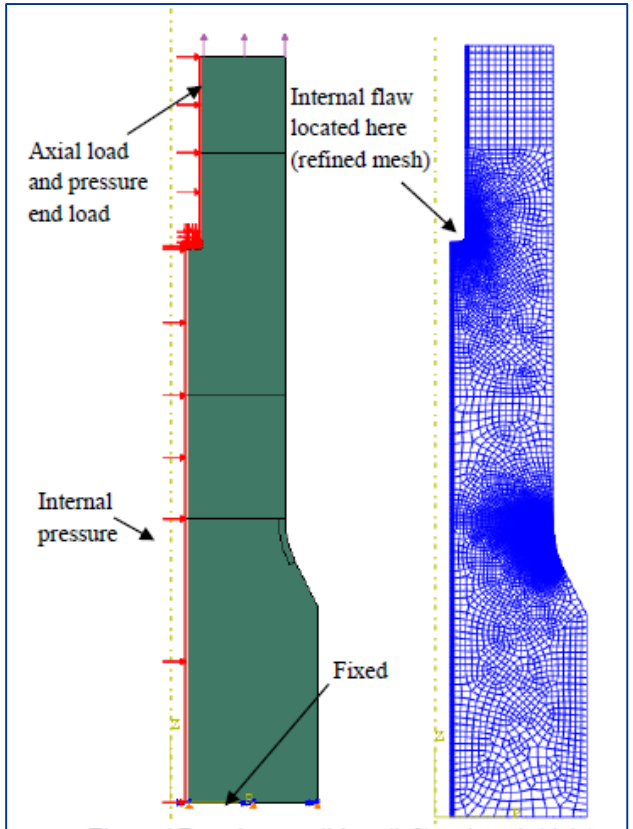
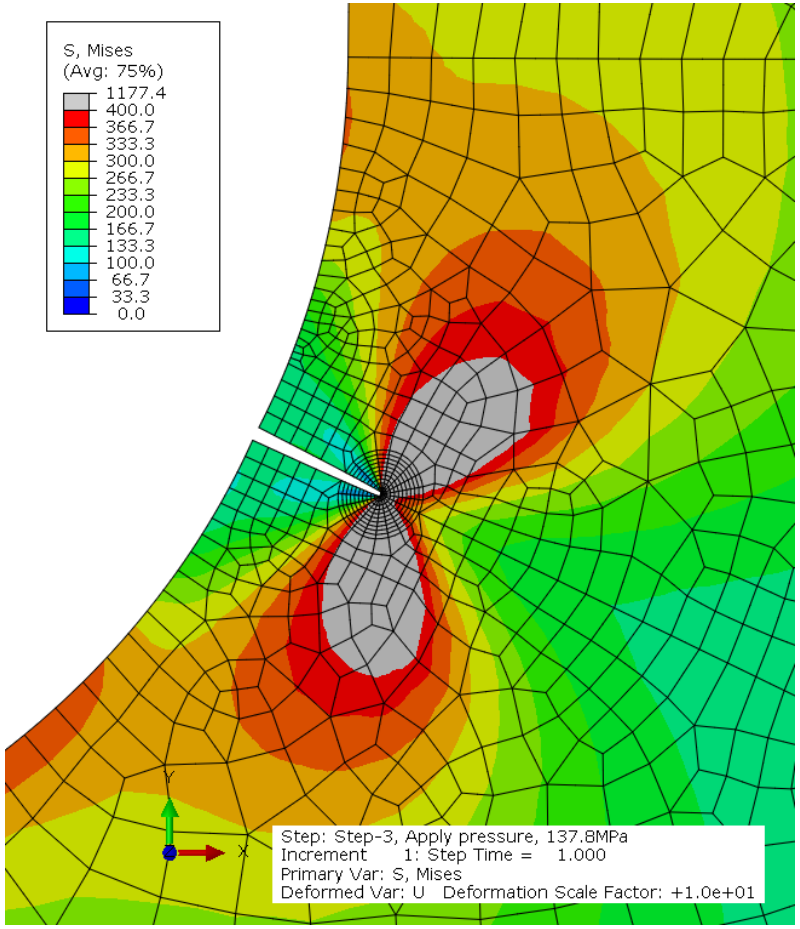
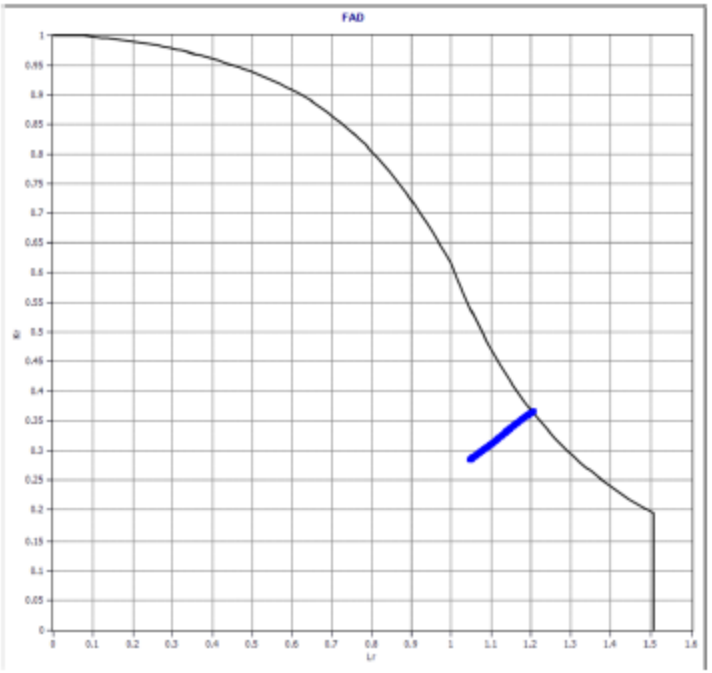


Figure 4 Boundary conditions (left) and mesh (right).

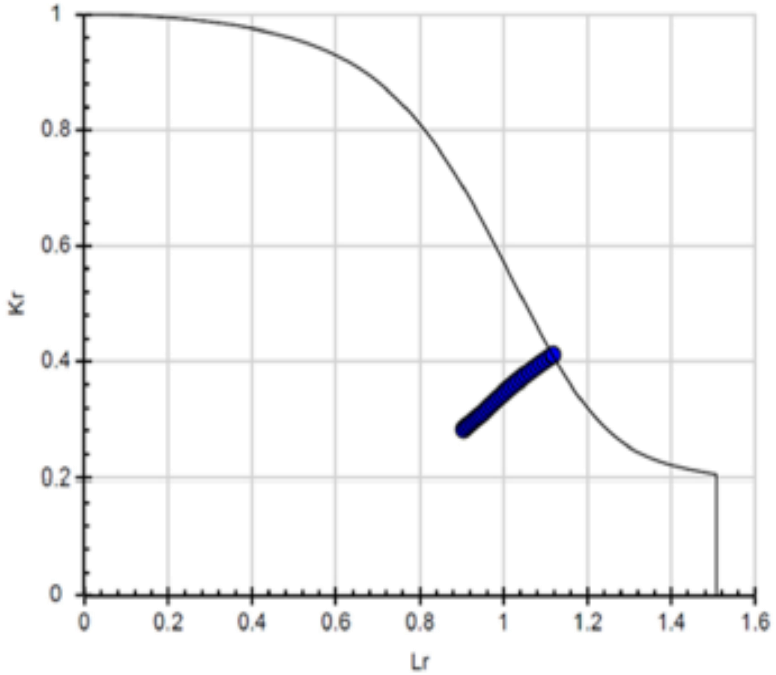


CASE 2: Results

- Solved for series of 6+ flaw depths
- Calculate stress-intensity (K_I) as a function of flaw depth
- Results using BS-7910 vs. API 579 were comparable but not identical

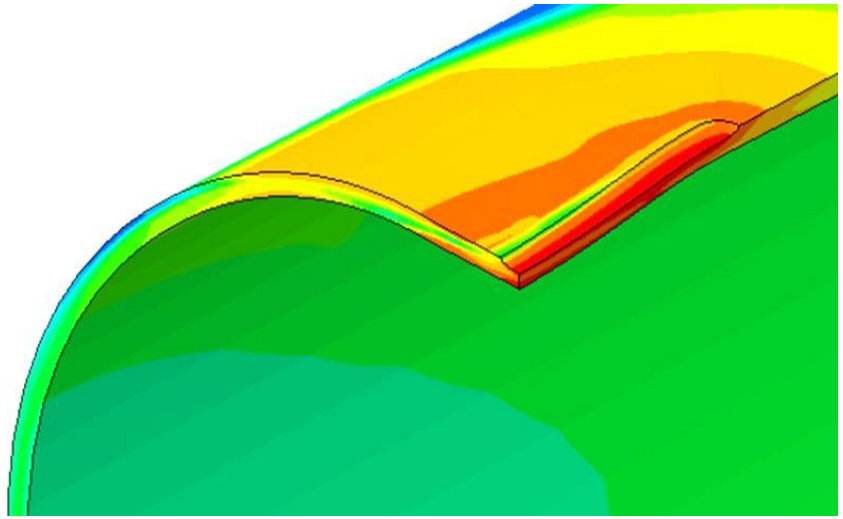


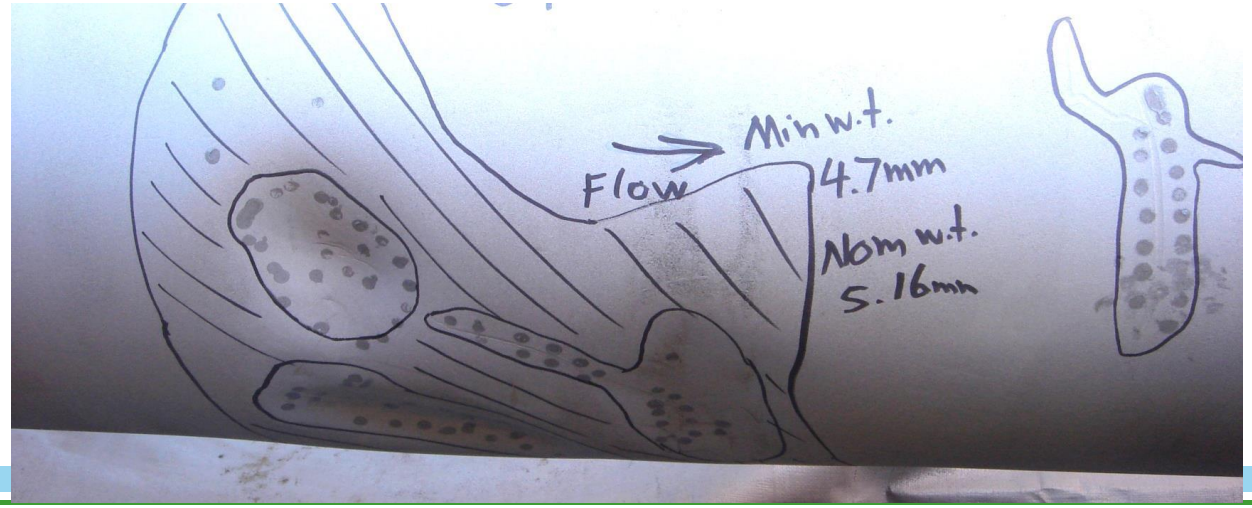
CASE 2 FAD results using BS-7910



CASE 2 FAD Results using API 579

Mechanical Damage and Other Applications





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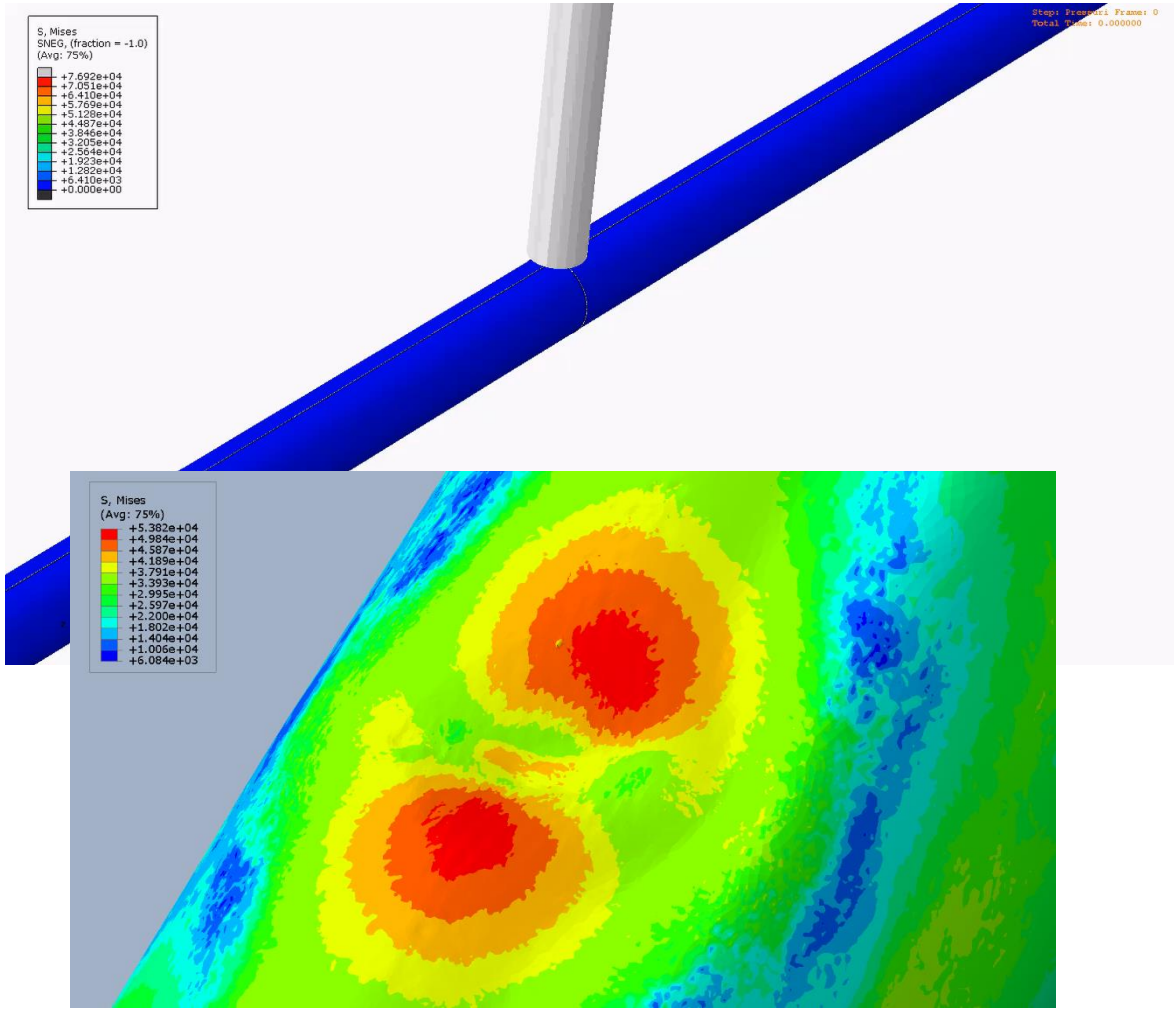
Other Applications

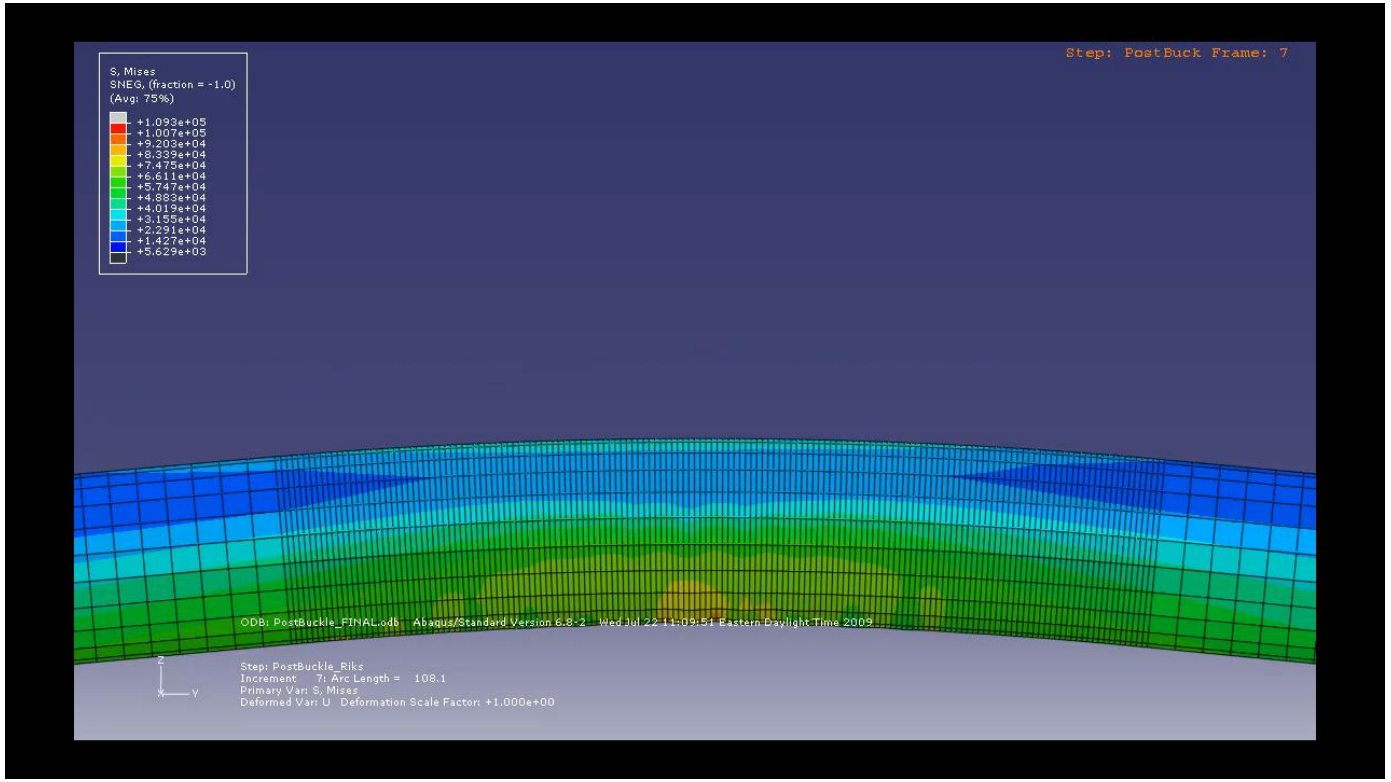
- Mechanical Damage –
  - Anchor / trawling impact
  - Debris impact,



Other Applications

- Mechanical Damage –
  - Anchor / trawling impact
  - Debris impact,

- Buckling / Wrinkling
  - Large deformation buckling
  - Concentrated to local winkle



Thank you

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