ANDREW FRANCIS & ASSOCIATES LTD

AFAA

Safety Justification for Operation of Onshore Gas Pipelines & Above Ground Installations at Design Factors up to 0.8

Presentation to Office of Pipeline Safety, Public Hearing
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Overview

- UK Uprating Chronology
- Uprating Methodology To Date
- Pipeline Integrity Issues
- AGI Integrity Issues
- Failure Causes (Threats)
- Criteria
- Conclusions

UK Uprating Chronology

- HSE (UK regulator) agreed in principle to increased design factor if supported by Structural Reliability Analysis (SRA) and associated assessment of Risk

- Safety assessor to compile list of threats

- Analysis showed mechanical damage to be dominant failure mode

- Increasing the design factor generally had little effect on the failure frequency and basis for increasing maximum allowable value to 0.8 was established in principle

UK Uprating Chronology

- Localised populated areas (HCAs) subjected to Quantified Risk Assessment (QRA) based on SRA results

- Increase in risk due to two factors:
  - (Small) increase in failure frequency
  - Increased hazard range

- Mitigation (e.g. use of protective concrete slabs) sometimes advised

UK Uprating Chronology

- Design code IGE/TD/1 amended to allow operation at 0.8SMYS if justified using SRA and QRA

UK Uprating Chronology

- Basic SRA established uprating principle
- Method continued to evolve through:
  - Liaison with regulator
  - More extensive consideration of failure modes
    - Some failure modes (e.g. SCC, fittings, vibration, ground movement) previously addressed only qualitatively
  - More attention to detail
  - Refinement of techniques

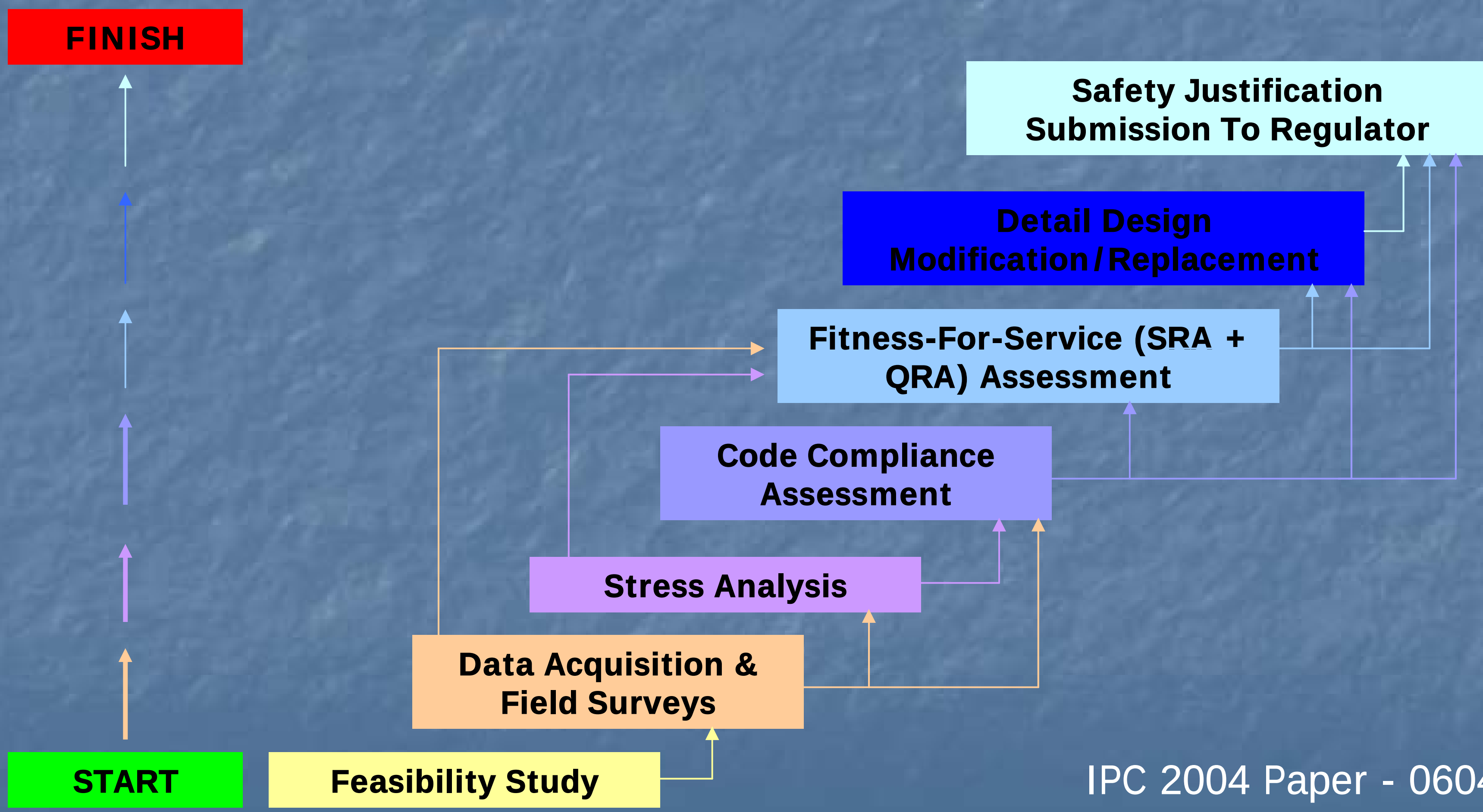
UK Uprating Chronology

- Focus moved away from design factor per se and moved towards:
- Integrity and Risk Management Plan taking account of effects of:
  - Increase in pressure
  - Increase in capacity and mass flow rate
  - Increase in temperature
  - Increase in magnitude of pressure and temperature cycles
  - Increase in hazard ranges

UK Uprating Chronology

- Lead taken from USA
- Comprehensive identification of threats
- Performance based approach using
  - SRA to identify ILI re-inspection intervals, risk based inspection of girth and fitting welds, DA excavations, SCC predictions
  - SRA and QRA to identify level of mitigation that might be required in populated areas (HCAs)

Uprating Methodology To Date



IPC 2004 Paper - 0604

Code Compliance

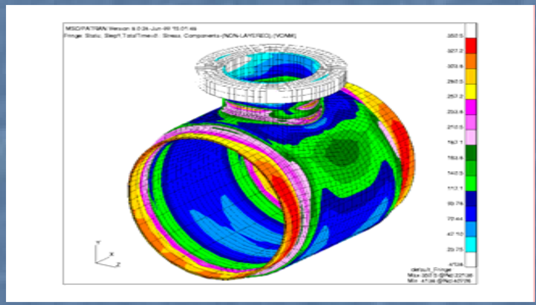
- Code compliance checks required to determine all aspects of non-code compliance
- Typical non-compliances
  - Design factor
  - Low toughness
  - High thermal loadings (increased total stress)
  - Increased hazard ranges
  - Hydrotest pressure margin erosion
  - Fitting design
  - Fatigue usage
- Non-compliances addressed by explicitly considering all possible failure modes – ‘holistic’ approach
- Fitness-for-service Assessment using Structural Reliability Analysis
  - Pipeline integrity issues
  - Above Ground Installation issues

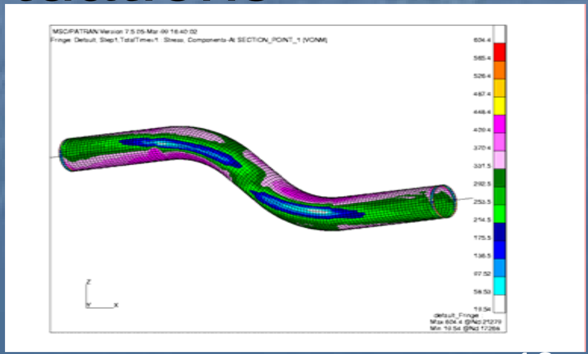
Why SRA?

- What defects survived original hydrotest and past operation could cause failure at higher pressure
- Significant material variability for old pipelines
- Significant geometric variability of fittings
- Poor ILI reliability in detecting small defects
- More appropriate method to include sizing errors
- Ability to model variation in loading
- Appropriate modelling of fatigue and corrosion growth rates
- Modelling of uncertainties in a systematic manner within the limit states was key to uprating

Pipeline Integrity Issues

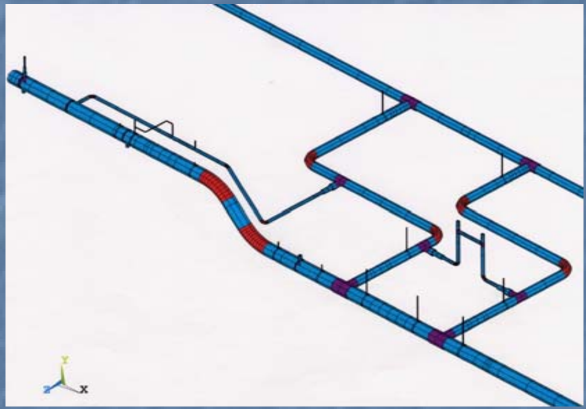
- Straight sections
  - Pressure and pressure fluctuations
- Bends and fittings
  - Pressure and pressure fluctuations
  - Temperature and temperature fluctuations
    - Pipeline flexibility and stress analysis



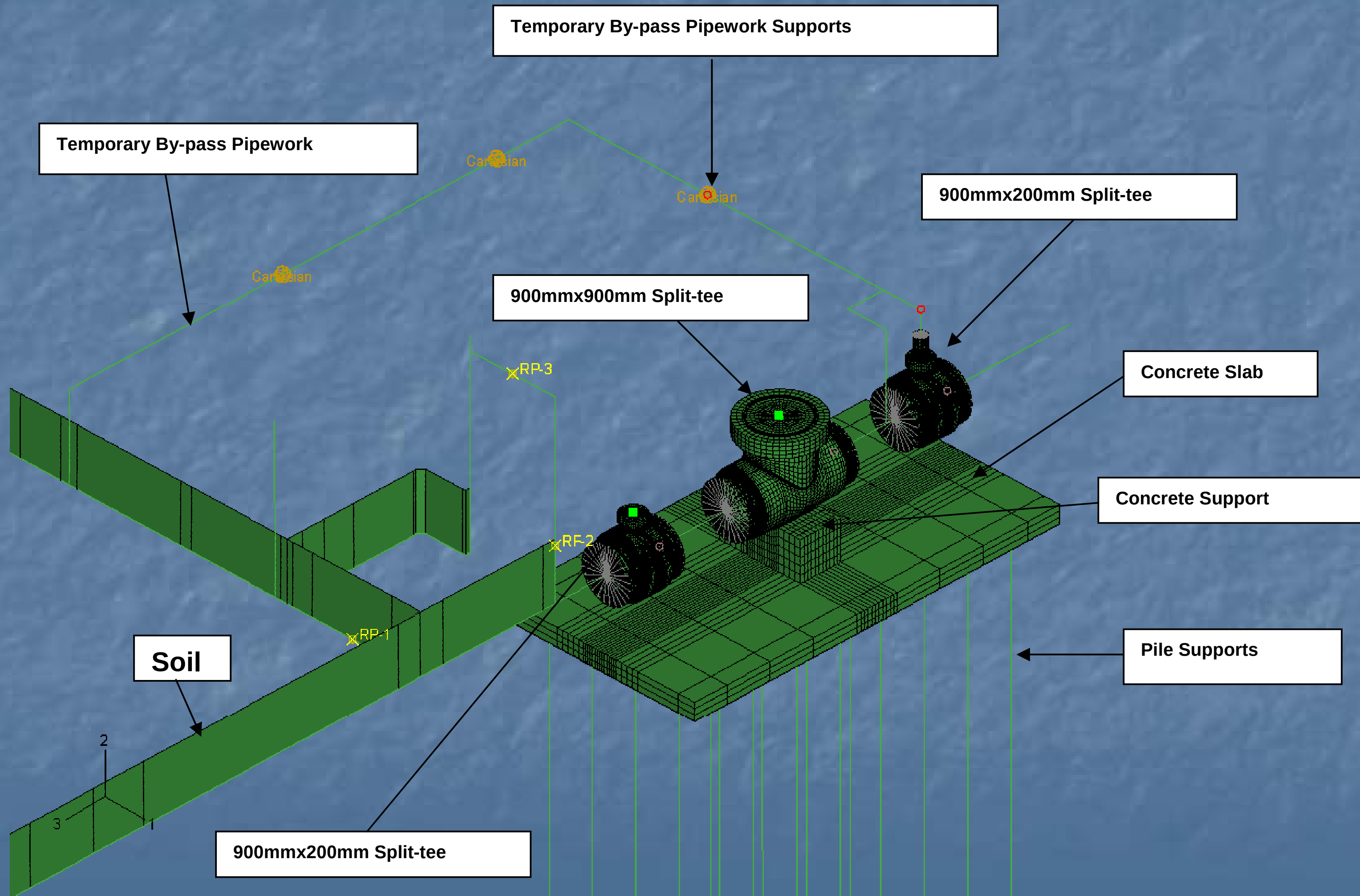


AGI Integrity Issues

- Main above and below ground pipework including bends and fittings
  - Pressure and pressure fluctuations
  - Temperature and temperature fluctuations
    - AGI flexibility and stress analysis
- Small bore pipework
  - Mass flow rate
    - Vibration



AGI Integrity Issues



AGI Integrity Issues

- Process equipment - boilers, heat exchangers, filters, valves, valve actuators, meters etc
  - Equipment class rating (Class 600)
  - System loads on nozzles
  - Fatigue
  - Re-hydrotest
  - Actuator stem torques
  - Instrumentation re-calibration

Failure Causes (Threats)

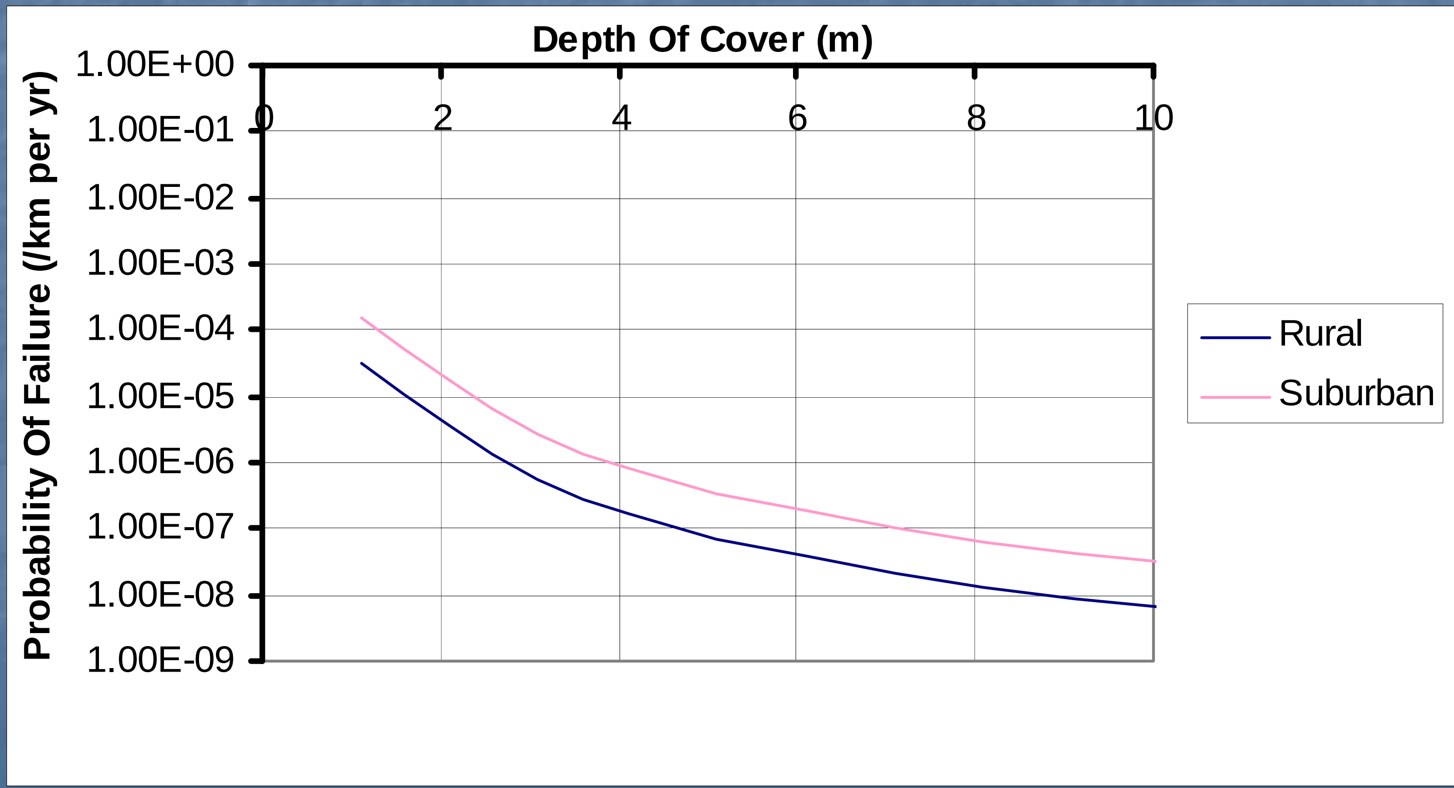
- Mechanical damage
  - Loads
    - Pressure
    - Gouge depth, length
    - Dent depth
  - Resistance
    - Wall thickness
    - Yield strength, Ultimate tensile strength
    - Fracture toughness
  - Mitigation
    - Surveillance
    - Depth of cover
    - Concrete slabs

Failure Causes (Threats)

- Mechanical damage
  - Data
    - Strength, toughness, wall thickness
      - Mill certificates
    - Depth of cover
      - Depth of cover survey (C-Scan survey)
    - Damage
      - Historical data base

Failure Causes (Threats)

- Mechanical damage



Failure Causes (Threats)

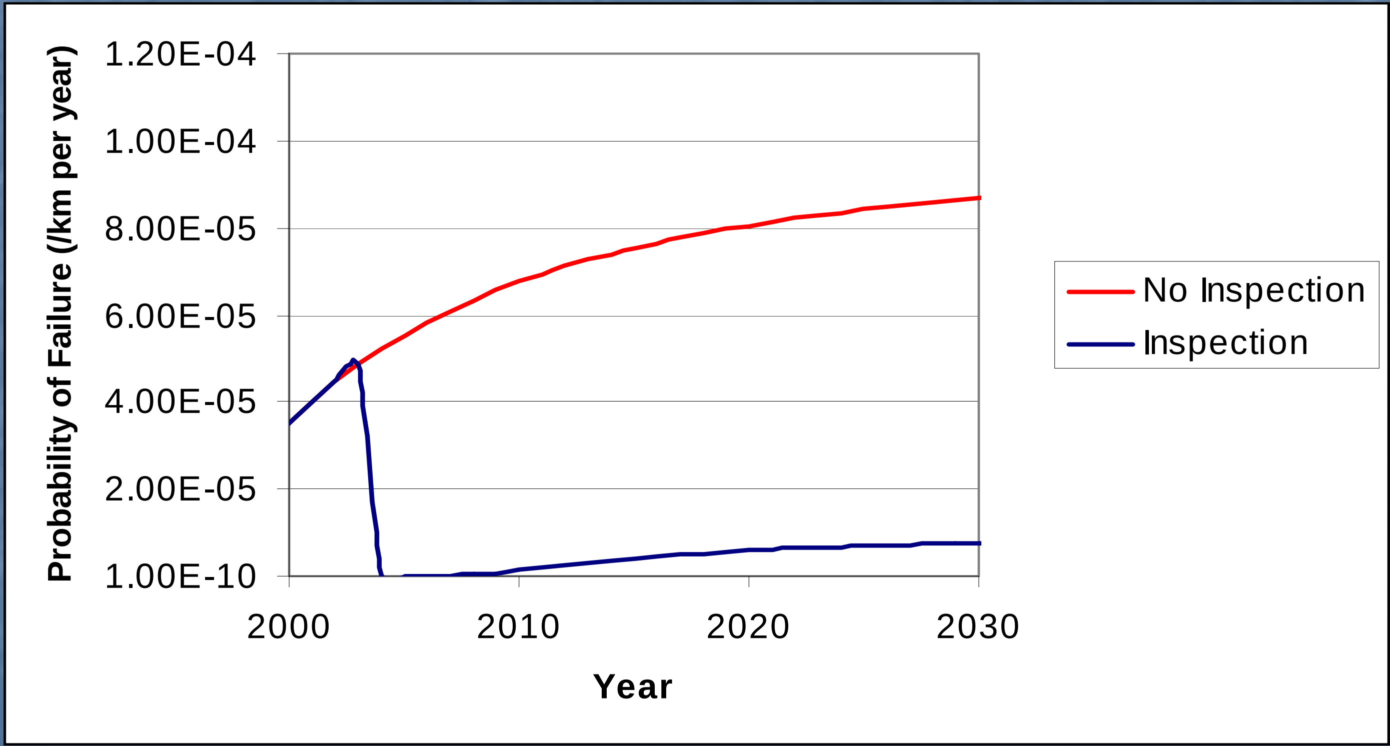
- External corrosion
  - Loads
    - Pressure
    - Treatment of thermal loads as primary loads on fittings
    - Defect depth, length
  - Resistance
    - Yield strength, Ultimate strength
    - Wall thickness
  - Mitigation
    - ILI, piggable sections
    - ECDA (DCVG, CIS, etc) unpiggable sections

Failure Causes (Threats)

- External corrosion
  - Data
    - Strength, wall thickness
      - Mill certificates
    - Coating Condition
      - Coating survey
    - CP Condition
      - CIS
    - Damage
      - In-line Inspection results
      - Historical database

Failure Causes (Threats)

- External corrosion



Failure Causes (Threats)

- Fatigue crack growth (seam welds)
  - Loads
    - Pressure related stress (static and fluctuating)
    - Overburden loadings (static)
    - Welding residual stress
    - Crack depth, length
  - Resistance
    - Yield strength
    - Ultimate strength
    - Fracture toughness
    - Wall thickness
  - Mitigation
    - Pressure fluctuation control
    - NDE (Radiography, MPI, UT)

Failure Causes (Threats)

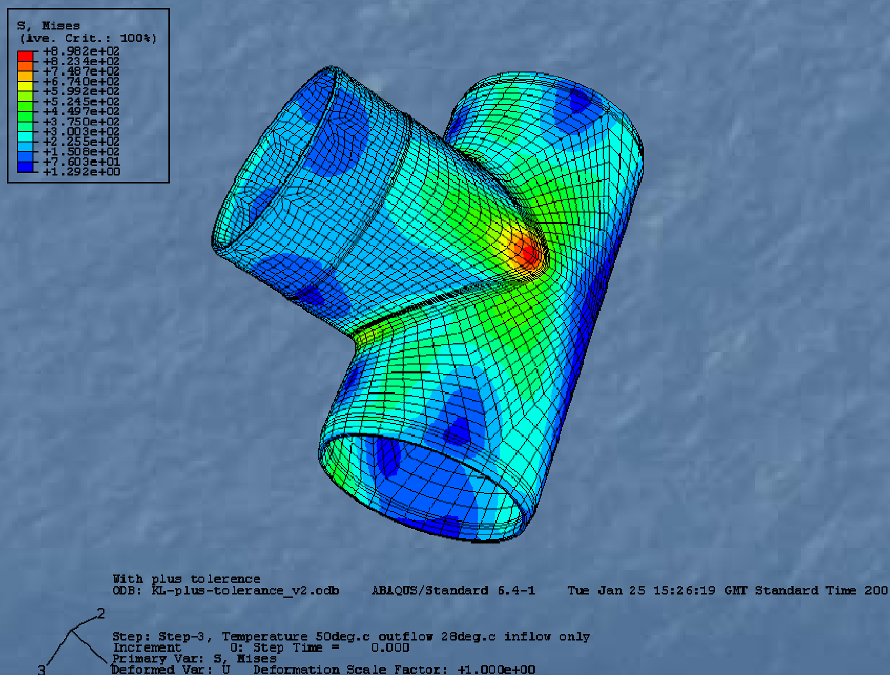
- Fatigue crack growth (girth and golden welds)
  - Types
    - Normal tie-in
    - Golden welds (welds with no hydrotest)
  - Loads
    - Pressure related stress (static and fluctuating)
    - Thermal stresses (static and fluctuating)
    - Overburden loads (static)
    - Welding residual stress
    - Crack depth, length
  - Resistance
    - Yield strength, Ultimate strength
    - Fracture toughness
    - Wall thickness
  - Mitigation
    - Pressure fluctuation control
    - NDE (Radiography, MPI, UT)

Failure Causes (Threats)

- Fatigue crack growth (seam, girth and golden welds)
  - Data
    - Strength, toughness, wall thickness
      - Mill certificates
    - Loads
      - Stress analysis results
    - Damage
      - NDE results
      - Historical database

Failure Causes (Threats)

- Fatigue crack growth (seam, girth, golden welds)



Failure Causes (Threats)

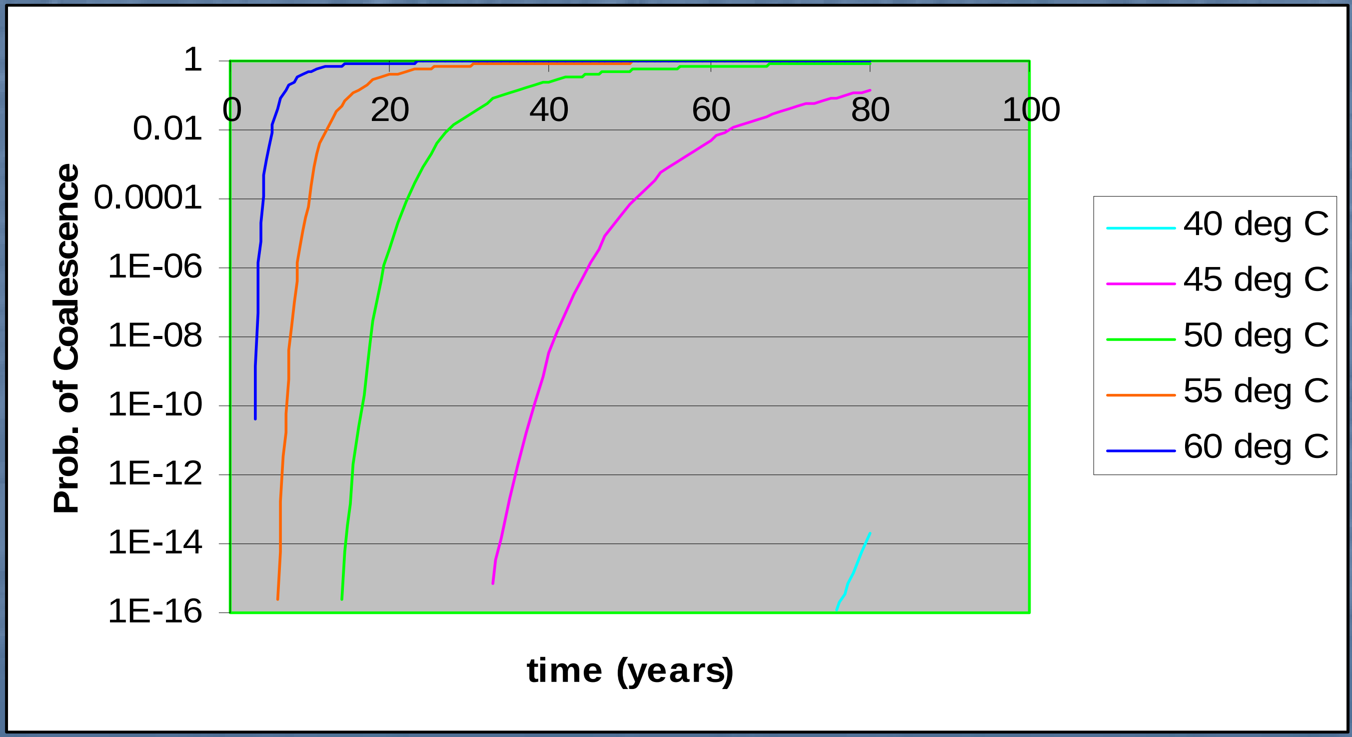
- Stress corrosion cracking
  - Loads
    - Pressure related stress (static and fluctuating)
    - Thermal stresses (static and fluctuating)
    - Crack depth, length
  - Resistance
    - Yield strength, Ultimate strength
    - Fracture toughness
  - Mitigation
    - Temperature control
    - CIS
    - Pressure cycling control

Failure Causes (Threats)

- Stress corrosion cracking
  - Data
    - Temperature control
    - CIS
    - Pressure cycling

Failure Causes (Threats)

- Stress corrosion cracking



Failure Causes (Threats)

- Incremental plastic collapse (ratchetting) of fittings
  - Loads
    - Pressure related stress (static and fluctuating)
    - Thermal stresses (static and fluctuating)
  - Resistance
    - Yield strength
    - Ultimate strength
  - Mitigation
    - Temperature cycle control
    - No of pressure and temperature cycles

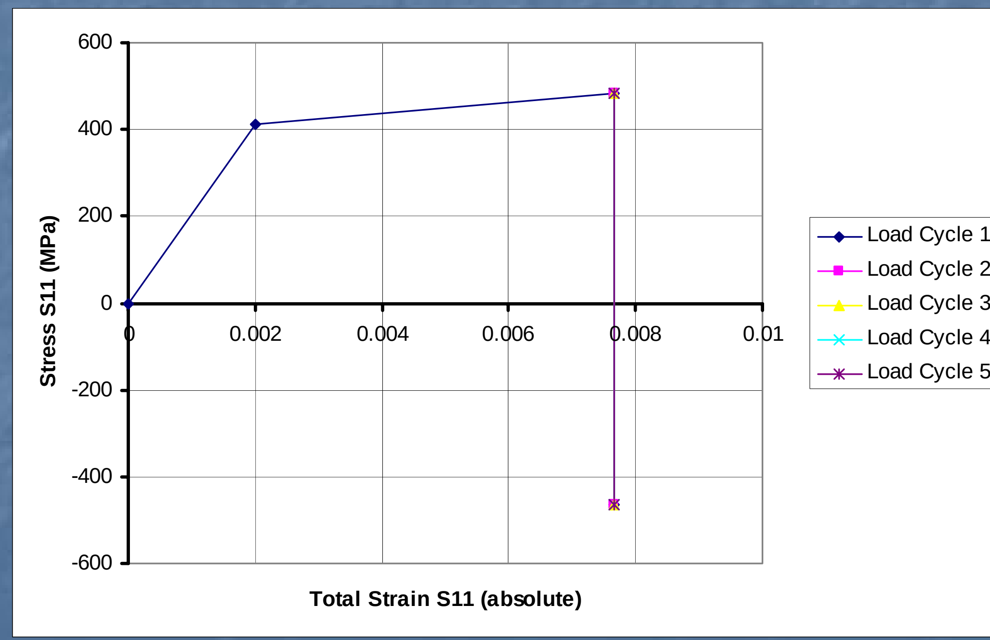
Failure Causes (Threats)

- Incremental plastic collapse (ratchetting) of fittings
  - Data
    - Temperature control
    - Fitting geometric data
      - Wall thickness
      - Crotch radii
    - Strength
      - Yield
      - UTS
      - Stress-strain curve
    - Loads
      - Stress analysis results

Failure Causes (Threats)

- Incremental plastic collapse (ratchetting) of fittings

Location of Peak Strain – Plot of Stress vs Strain Given in Figure



Failure Causes (Threats)

- Vibration
  - Components at risk
    - Small bore set-on welded fittings immediately downstream of compressor discharge or pressure reduction stations
  - Sources
    - High frequency turbulence (acoustic fatigue), pressure pulsations associated with vortex shedding
    - Resonance of small bore fittings caused by vortex shedding exciting bending modes of vibration
  - Mitigation
    - Flow control
    - Support/fitting modification

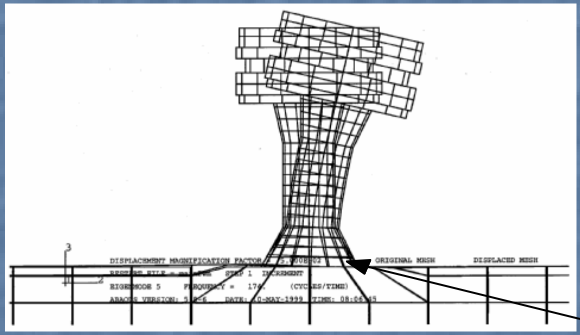
Failure Causes (Threats)

- Vibration
  - Data
    - Vibration monitoring
      - Correlation of vibration amplitude to process conditions
      - Accelerometer data
    - Fitting geometric data
      - Wall thickness
      - Crotch radii
    - Strength
    - Loads
      - Dynamic analysis results

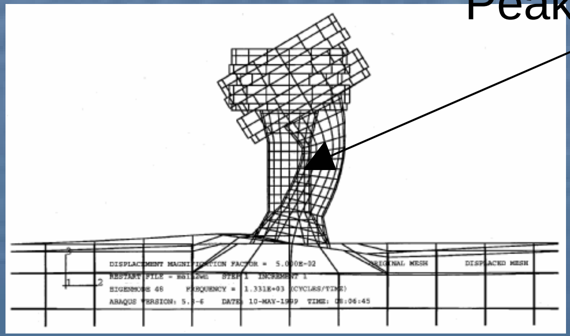
Failure Causes (Threats)

- Vibration

1st Bending Mode

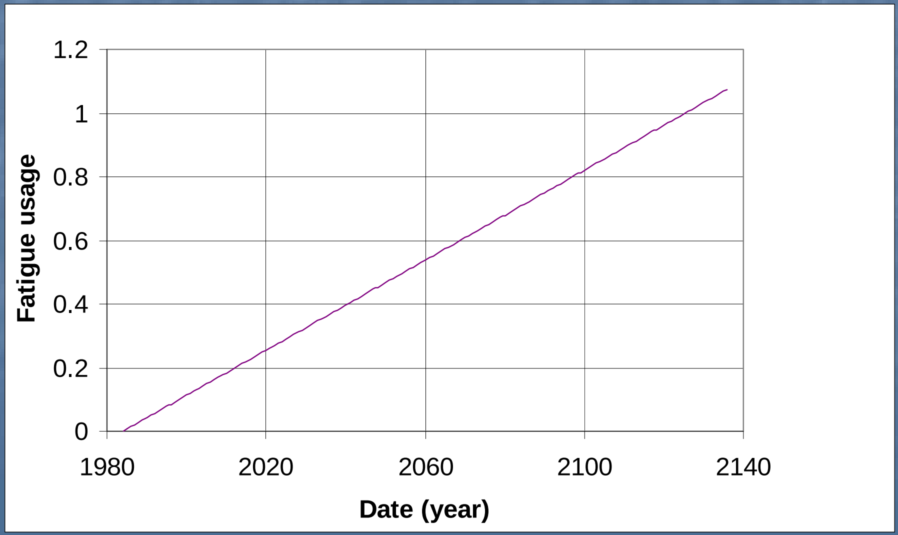


Peak Stress Locations



2nd Bending Mode

$$\frac{n_1}{N_1}+\frac{n_2}{N_2}+\frac{n_3}{N_3}+.........=\sum\frac{n_i}{N_i}\leq 1.0$$



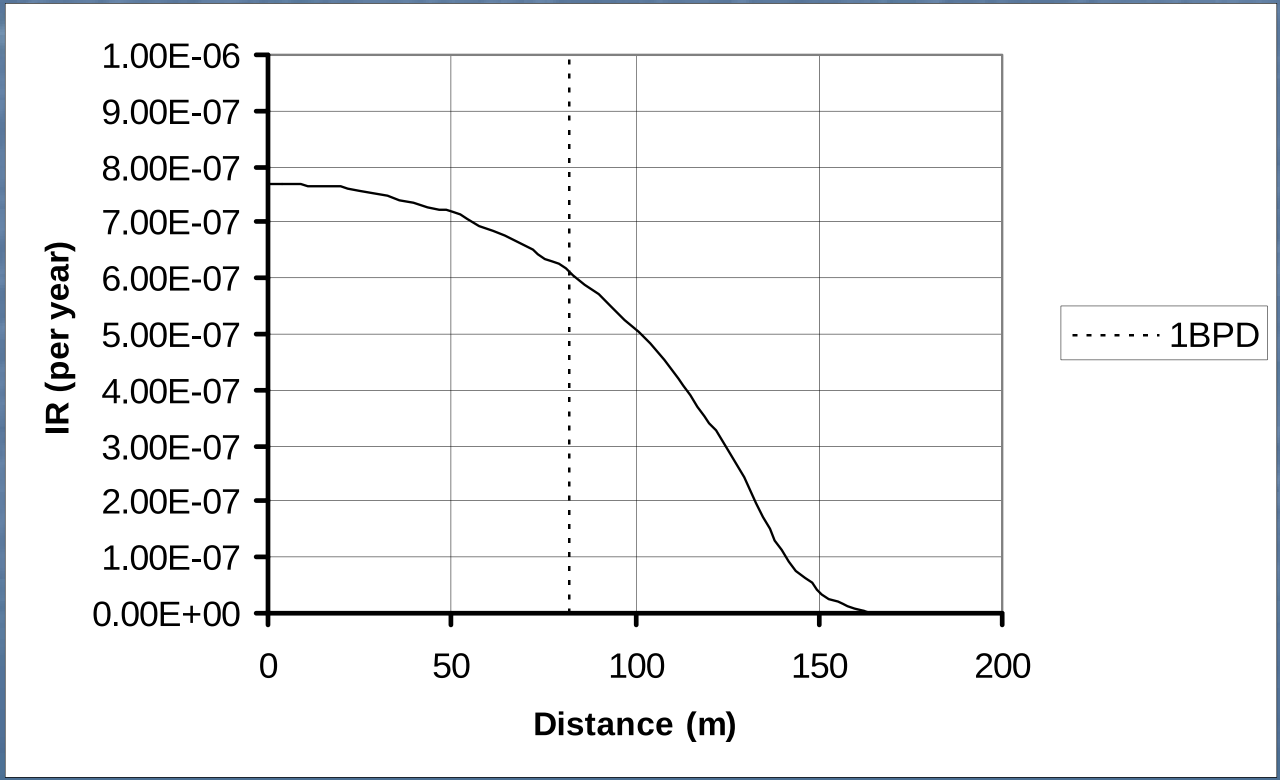
Criteria

Risk = Likelihood of failure (SRA) x Consequences

- General
  - Individual Risk
- Populated areas
  - Societal Risk

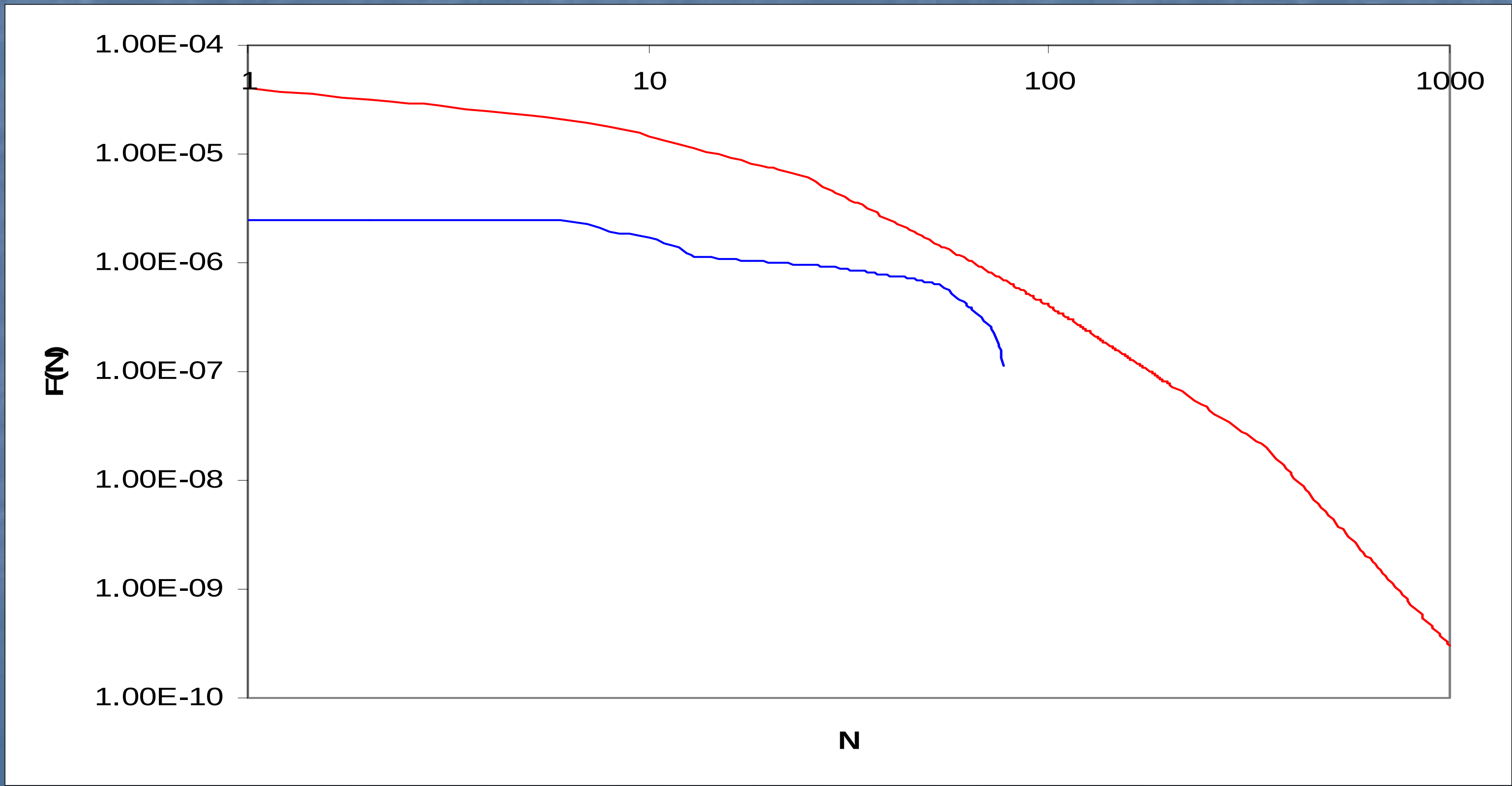
Criteria

- Individual Risk (< 1e-6)



Criteria

- Societal Risk



Conclusions

- HSE accepted SRA + QRA based approach
- Design code IGE/TD/1 revised to allow approach to be use for design factor up to 0.8
- Method has been, and is, continually evolving
- Focus moved away from design factor issue per se to integrity and risk management program