Nonlinear FE approach for design by analysis of valves:

advantages for optimization and cost reduction

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Introduction

- The use of **FEA** in the valve's design workflow is necessary to be **COMPETITIVE ON THE MARKET**

- Advantages of design by analysis (***DBA***) for engineered valves:
  - Deep knowledge of the valve behaviour (***DIGITAL TWIN***)
  - Compliance with international code prescriptions (e.g. *ASME VIII div.2*)
  - Large range of operative scenarios analysed
  - Optimization of the valve geometry for cost reduction
  - Weight reduction
  - *RCA* in case of unexpected failures/low performances

Scope of the work

- Highlight the **weakness of “elastic route”** for valve assessment
- Describe the **non-linear approaches** available in design codes (e.g. ASME VIII div.2)
- Point out the **advantages of non-linear approaches** with practical examples:
    - *Robustness / safety of the design*
    - *Design optimization and cost reduction*
    - *Assessment for serviceability*
- Introduce **Fatigue** assessments / **ECA**

The *“elastic route”*

Limitations and disadvantages on the applications to valve’s design

Elastic analysis: methodology

- **Protection against plastic collapse** *(ASME VIII div.2)*

FEA

- Linear elastic material
- Design conditions

STRESS CATEGORIES

- Primary membrane
- Primary membrane + bending

STRESS CHECK

- Allowable stress

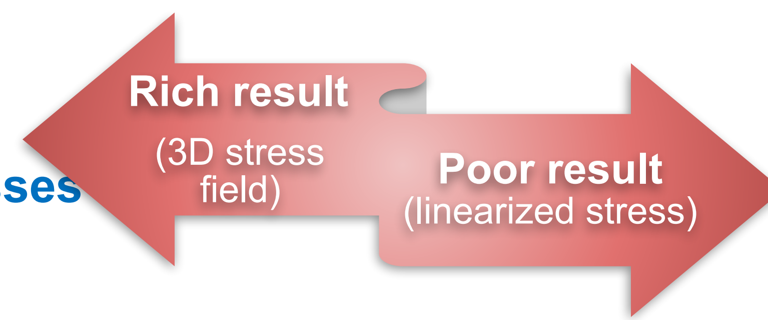
Elastic analysis: weakness

- Limitations on the application of the elastic approach:

Difficulties on the assessment of complex geometries	Arbitrary interpretation of the results
Not applicable to high pressure valves	Optimization process difficult to implement

Elastic analysis: limitations

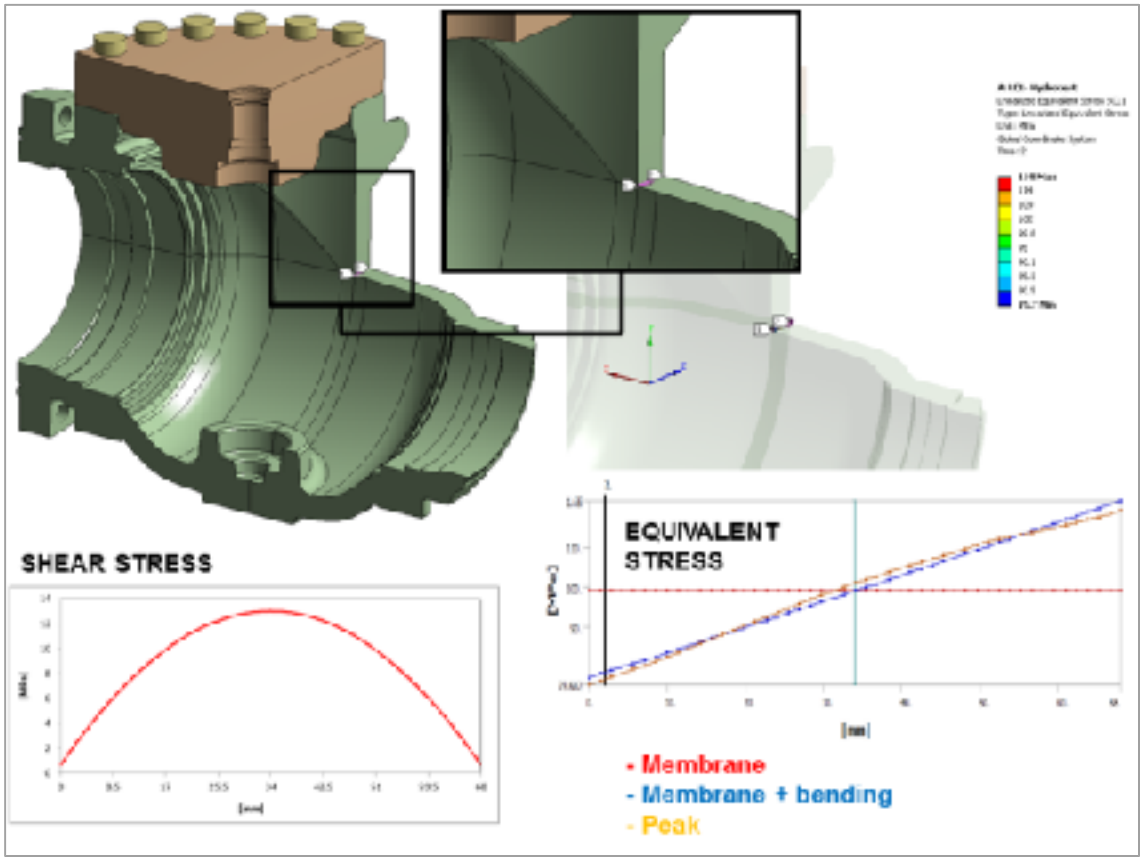
- The <u>categorization of stress</u>:
  - Elastic analysis is based on the definition of **stress categories**:
    - <u>Primary membrane stress (*Pm*)</u>: *equivalent stress average across the thickness related to equilibrium excluding structural discontinuities*
    - <u>Primary Membrane Plus Primary Bending (*Pm + Pb*)</u>: *equivalent stress, derived from the highest value across the thickness, of the linearized primary membrane plus primary bending stresses related to equilibrium excluding structural discontinuities*
  - FE stress results must be **linearized**:



  - **Secondary stresses** ust be <u>**excluded**</u>

Elastic analysis: case study

- *Example of correct stress linearization in a valve body*



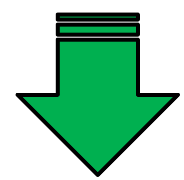
Suitable SCL:

✓ Far from discontinuities

✓ Normal to cross section through the thickness

✓ Monotonic distribution of hoop stress

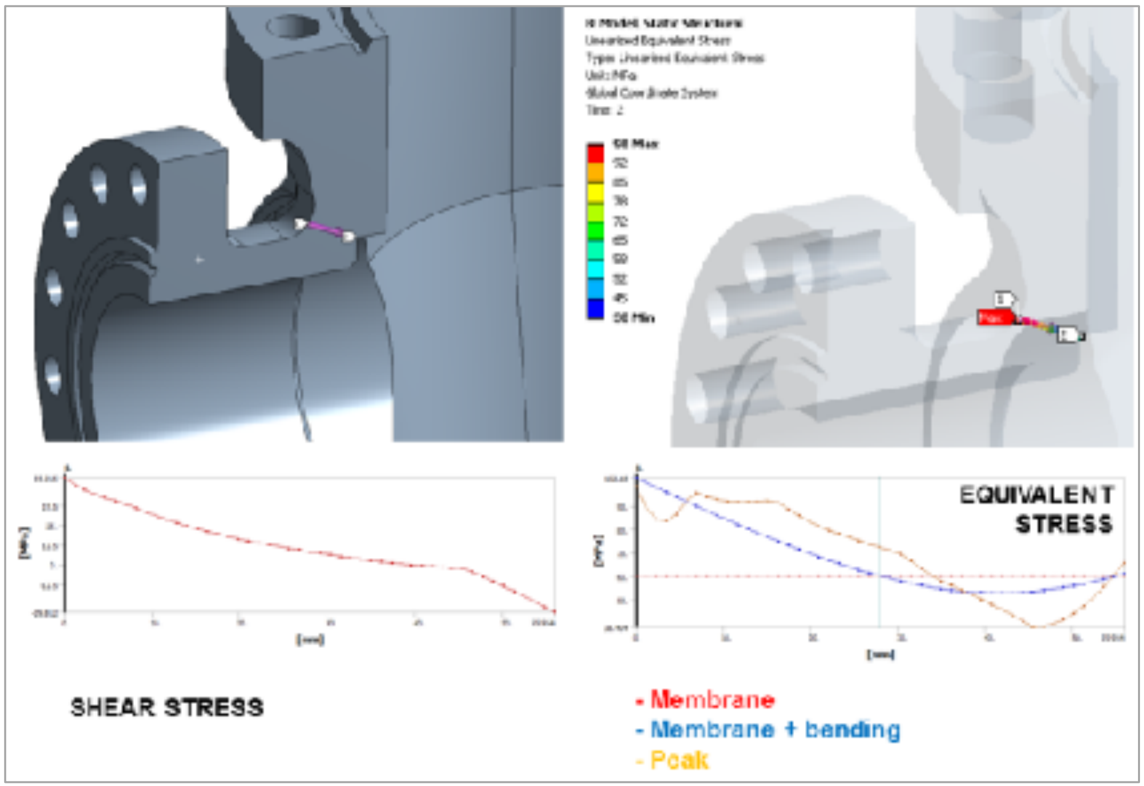
✓ Parabolic distribution of shear stress



CORRECT LINEARIZED STRESS

Elastic analysis: case study

- *Example of non correct stress linearization in a valve body*



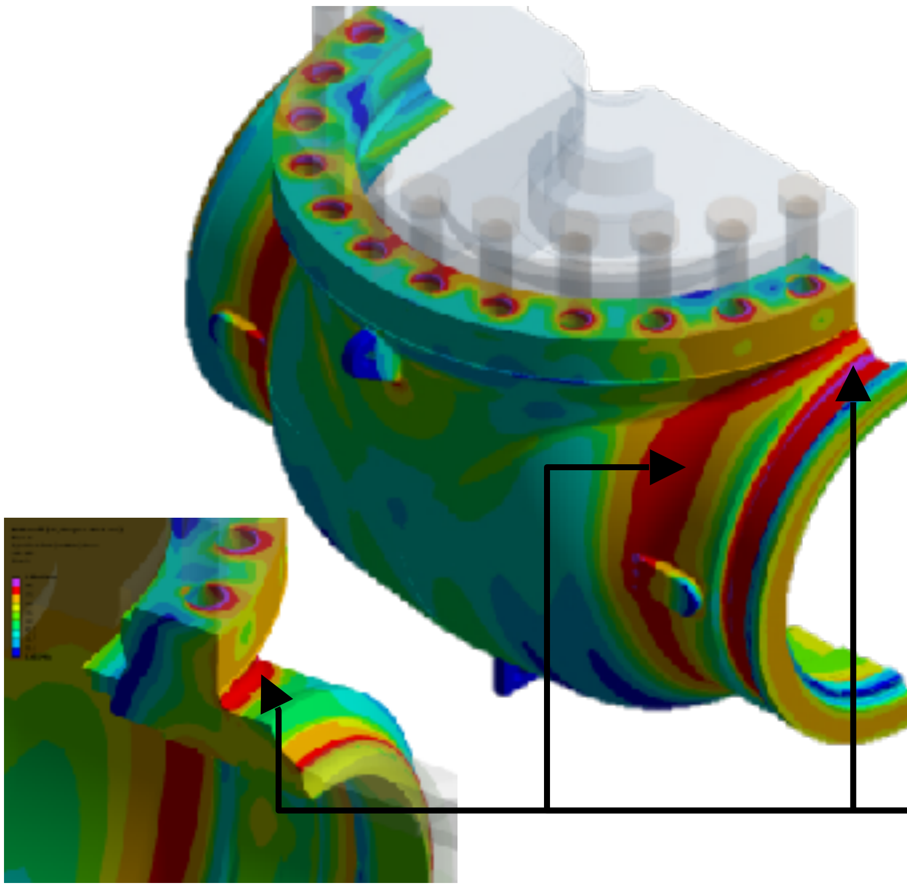
Non suitable SCL:

- ✓ In correspondence of structural discontinuities
- ✓ Diagonally respect to cross section normal
- ✓ Nonlinear distribution of hoop stress
- ✓ Non-parabolic distribution of shear stress

NON CORRECT LINEARIZED STRESS

Elastic analysis: case study

- *Example of secondary stress in a valve body*



- Areas with stress level over *1.5* S_m *(allowable for membrane + bending primary stress)*
- Presence of gross/local structural discontinuity
- Bending stress due to forced compatibility

SECONDARY STRESS

Elastic analysis: summary of limitations

- Limitations of protection against plastic collapse with linear approach:
  - Applicable only for at **primary stress** regions
  - **Linearization** of stress must be done
  - **Arbitrary selection** of stress classifications
  - Gross/local structural **discontinuities cannot be assessed**
  - Not applicable for **high pressure** valve (*R/t* < *4*)
  - Conservative approach: **optimization difficult** to be performed

The non-linear approach

Advantages on the applications to valve's design

Linear vs. nonlinear approach

Elastic analysis

- Primary stress only
- Onerous postprocessing
- Arbitrary selection of results
- Not applicable to high pressure valves

Model easy to be implemented

Fast solution of FE model

Non-linear analysis

- Global assessment (primary & secondary stresses)
- Non arbitrary selection of results (robust method)
- Generally applicable (high pressure valves)
- Realistic stress/strain status
- Useful for valve optimization process

Model development more complex

Computationally onerous (longer time for solution)

Linear vs. nonlinear approach

Linear approach

- Allowable stress design method
- Design loads only
- Evaluation of stress state
- Safety factor on stress limit
- Plasticization not allowed
- No serviceability criteria

Non-linear approach

- Limit state design method
- Load combinations with load factors
- Plasticization allowed
- Evaluation of global stability

  (Check respect to global collapse – Ultimate limit state)
- Serviceability criteria available

  (Service limit state)

Nonlinear analysis: methodology

- **Protection against plastic collapse** *(ASME VIII div.2)*

FE model
- Perfectly plastic material (limit load)
- Multilinear plasticity (elastic –plastic analysis)

Nonlinear analysis
- Progressive application of factorized load
- Convergence criteria

Assessment
- Acceptance criteria based on convergence of the analysis

Nonlinear analysis: load factorization

Limit load analysis

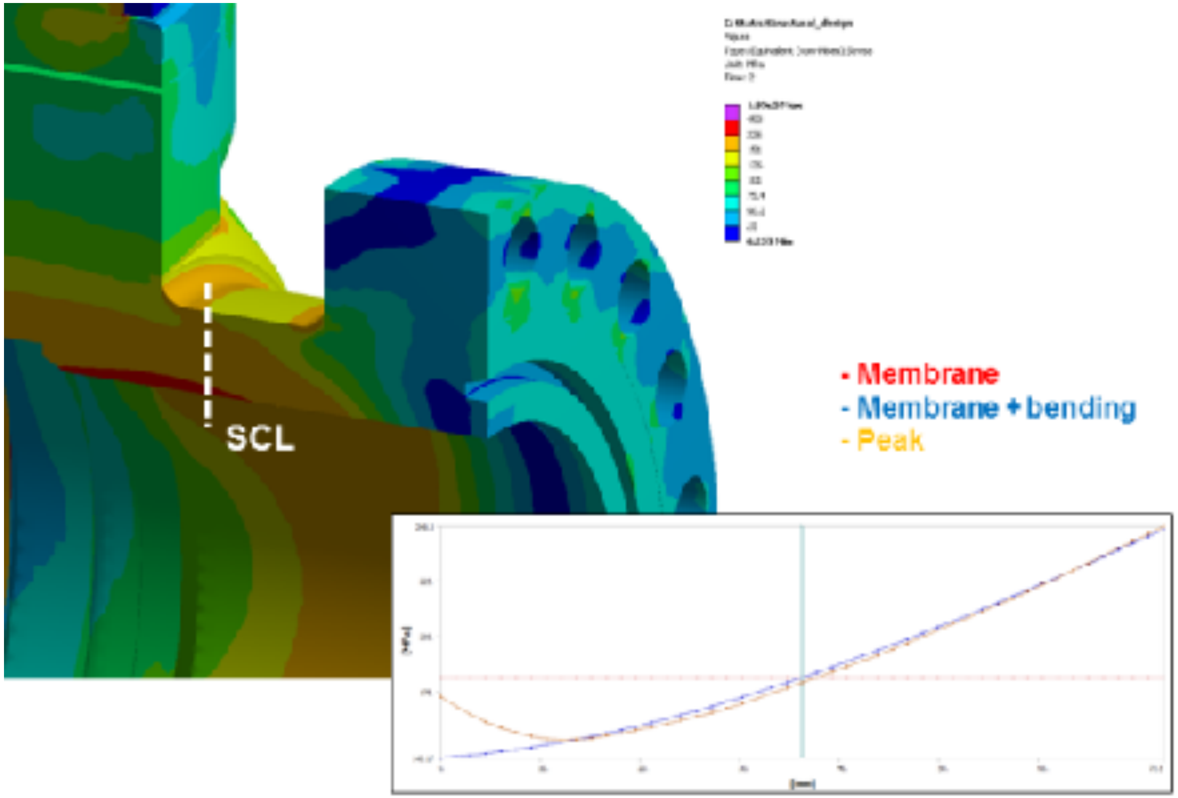
Criteria	Factored load combinations
Design conditions	
Global	$1.5\ (P + P_s + D)$
	$1.3\ (P + P_s + D + T) + 1.7L + 0.54S_S$
	$1.3\ (P + P_s + D) + 1.7S_S + (1.1L \text{ or } 0.54W)$
	$1.3\ (P + P_s + D) + 1.1W + 1.1L + 0.54S_S$
	$1.3\ (P + P_s + D) + 1.1E + 1.1L + 0.21S_S$

Elastic-plastic analysis

Criteria	Factored load combinations
Design conditions	
Global	$2.4\ (P + P_s + D)$
	$2.1\ (P + P_s + D + T) + 2.7L + 0.86S_S$
	$2.1\ (P + P_s + D) + 2.7S_S + (1.7L \text{ or } 0.86W)$
	$2.1\ (P + P_s + D) + 1.7W + 1.7L + 0.86S_S$
	$2.1\ (P + P_s + D) + 1.7E + 1.7L + 0.34S_S$
Local	$1.7\ (P + Ps + D)$
Service	*Per User's Design Specification at operating*

Nonlinear analysis: case study

- **24in 1500#** top entry valve **Norsok** compact flange – [Linear analysis]

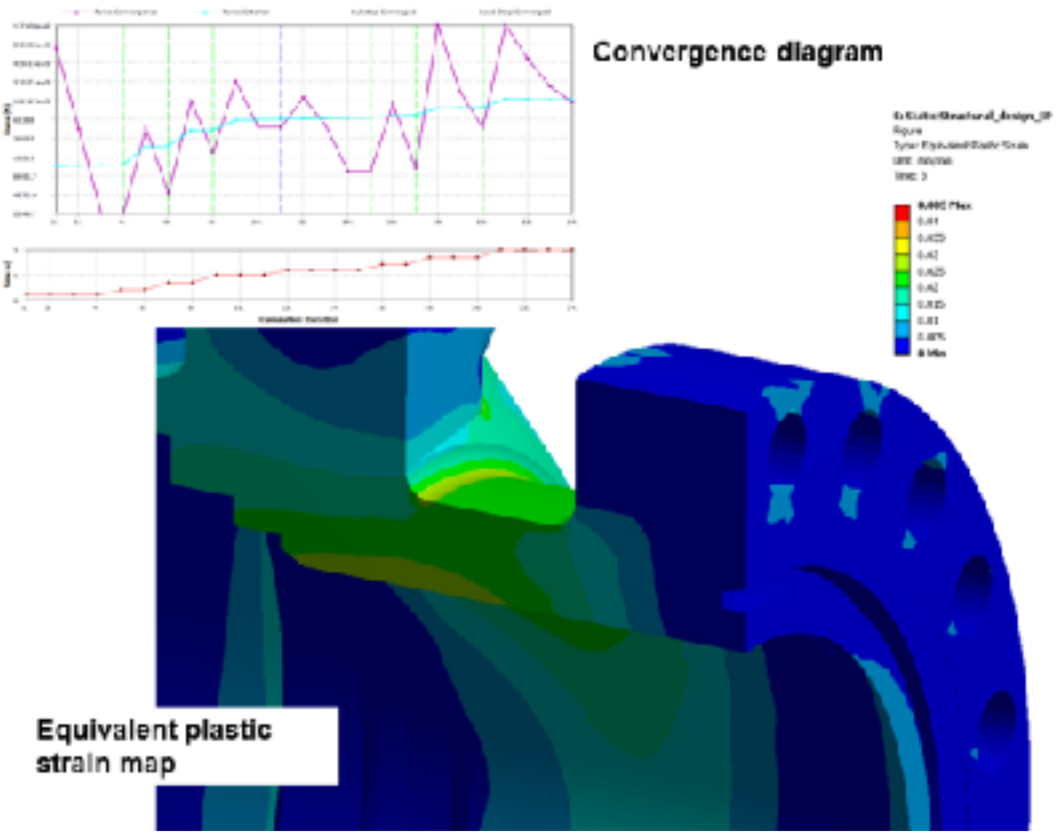


- High stress in the body/neck transition
- Area affected by secondary bending stress
- Linearized equivalent stresses higher than allowable limit

ELASTIC-PLASTIC APPROACH

Nonlinear analysis: case study

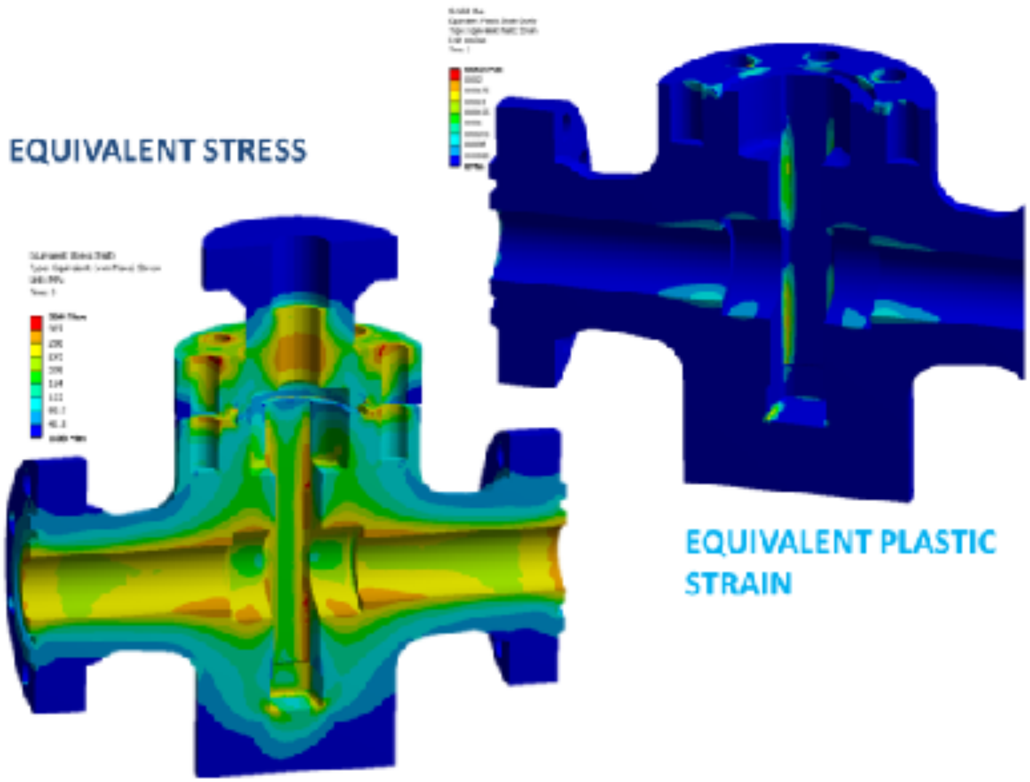
- **24in 1500#** top entry valve **Norsok** compact flange – Nonlinear analysis



- **Factorized** design load applied
- **Convergence** of analysis achieved
- **Protection against plastic collapse** satisfied
- Local **plastic deformations** at body/neck transition
- **Local failure and serviceability** to be checked

Nonlinear analysis: case study 2

- 4in 1/6 high pressure expanding gate valve (API 10000#)

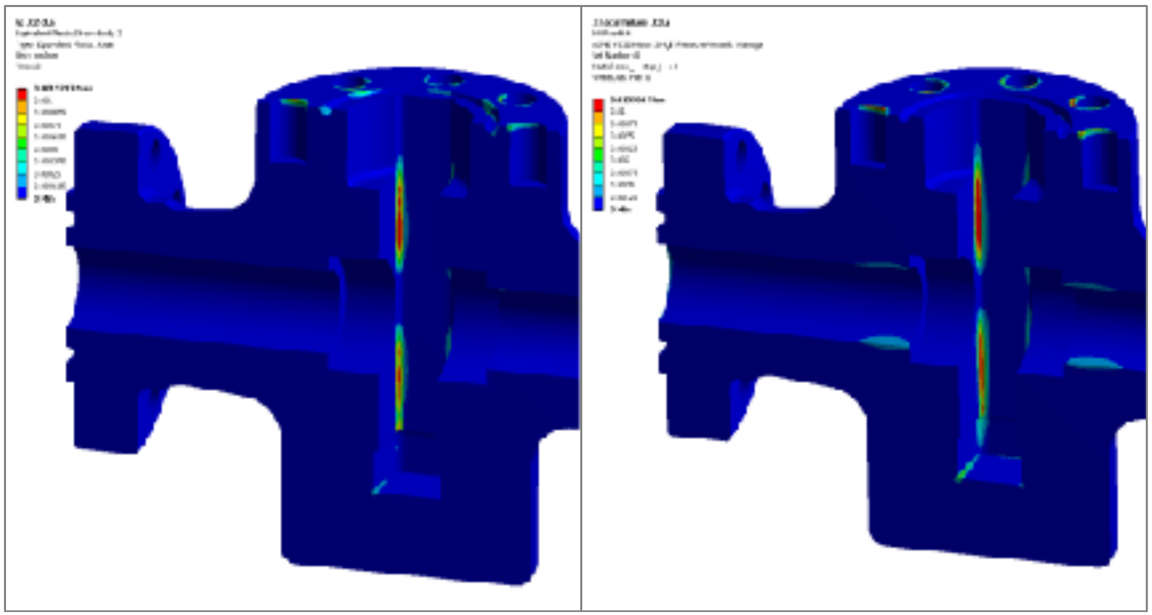


<u>Protection against plastic collapse</u>

- **Heavy wall** body (*R/t* < *4*): Nonlinear approach requested by ASME VIII div. 2
- **2.4 factor** for mechanical (pressure) loads
- **2.1 factor** for mechanical + thermal loads
- Acceptance criteria satisfied
- Need for check respect to **plastic strain** induced **damage**

Nonlinear analysis: case study 2

- 4in 1/6 high pressure expanding gate valve (API 10000#)



Protection against local failure

- **1.7 factor** for mechanical (pressure) loads
- Assessment of **total strain** (elastic + plastic)
- Calculation of **strain damage** respect to limiting triaxial strain

ACCEPTANCE CRITERIA

$$D = \frac{\varepsilon_{tot}}{\varepsilon_L} \leq 1$$

Damage

$$\varepsilon_L = \varepsilon_{Lu} \cdot \exp\left[-\left(\frac{\alpha_{sl}}{1+m_2}\right)\left(\frac{\sigma_1+\sigma_2+\sigma_3}{3\sigma_e} - \frac{1}{3}\right)\right]$$

Limiting triaxial strain

Serviceability

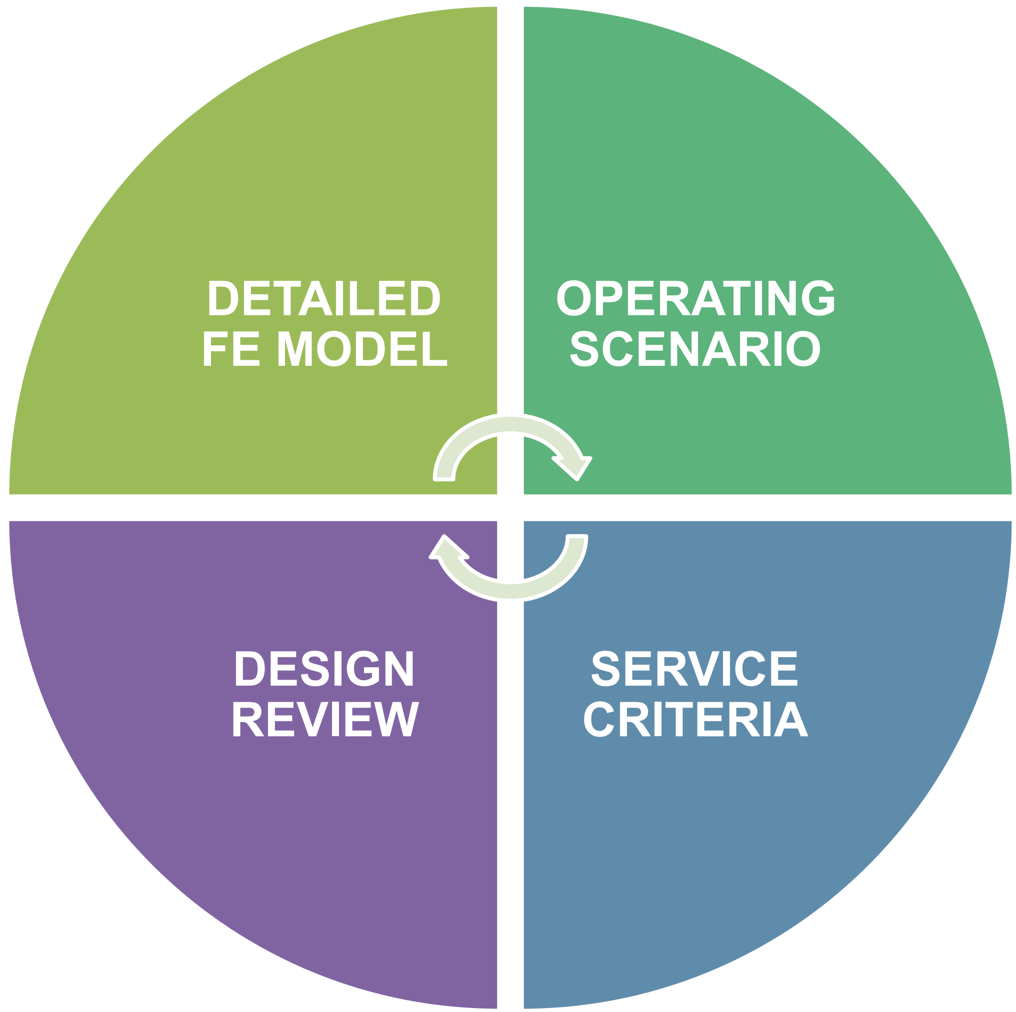
Examples of analysis of operating/ emergency scenarios for the assessment of valve functionality

INDUSTRIALVALVESUMMIT

Operating conditions

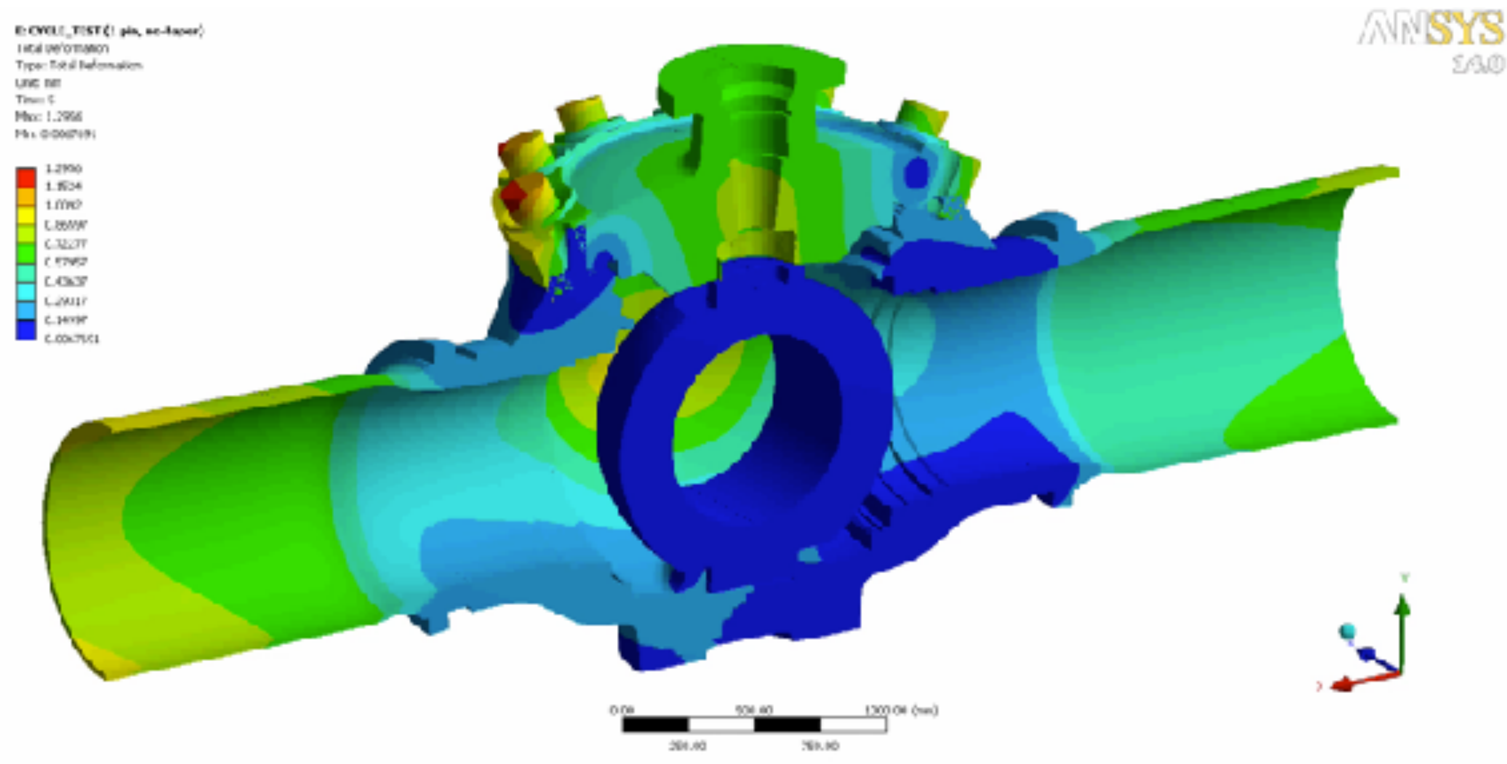
- **Serviceability check**

DIGITAL TWIN



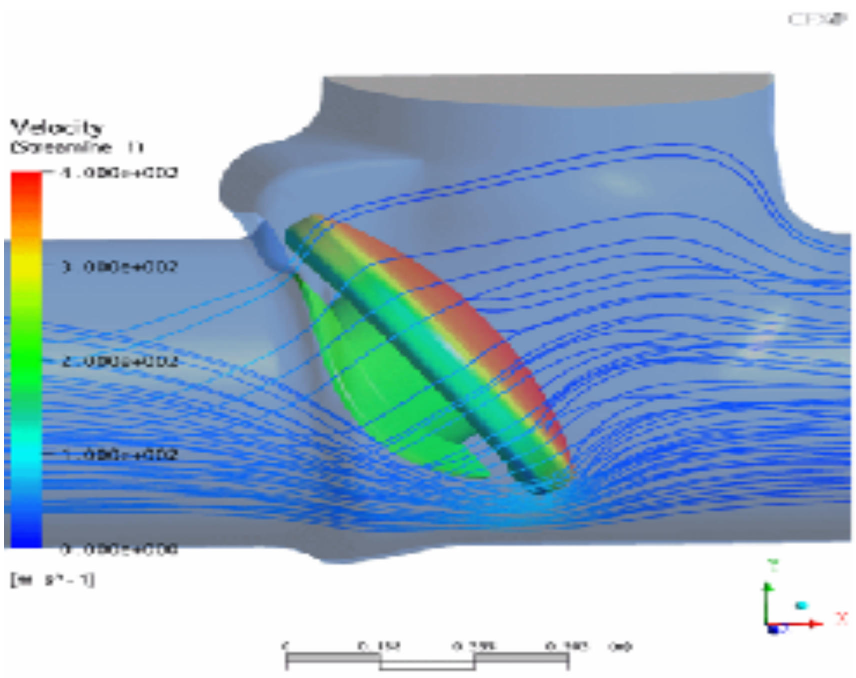
Serviceability check: case study

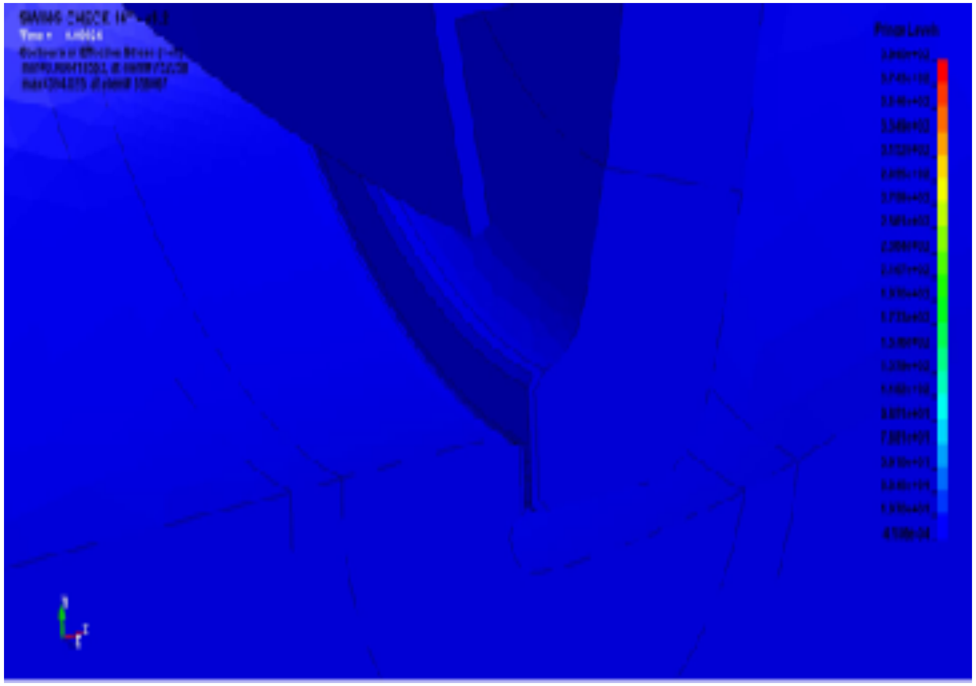
- Simulation of testing procedures (24in 900# top entry ball valve)



Serviceability check: case study 2

- Simulation of emergency closing of a swing check valve



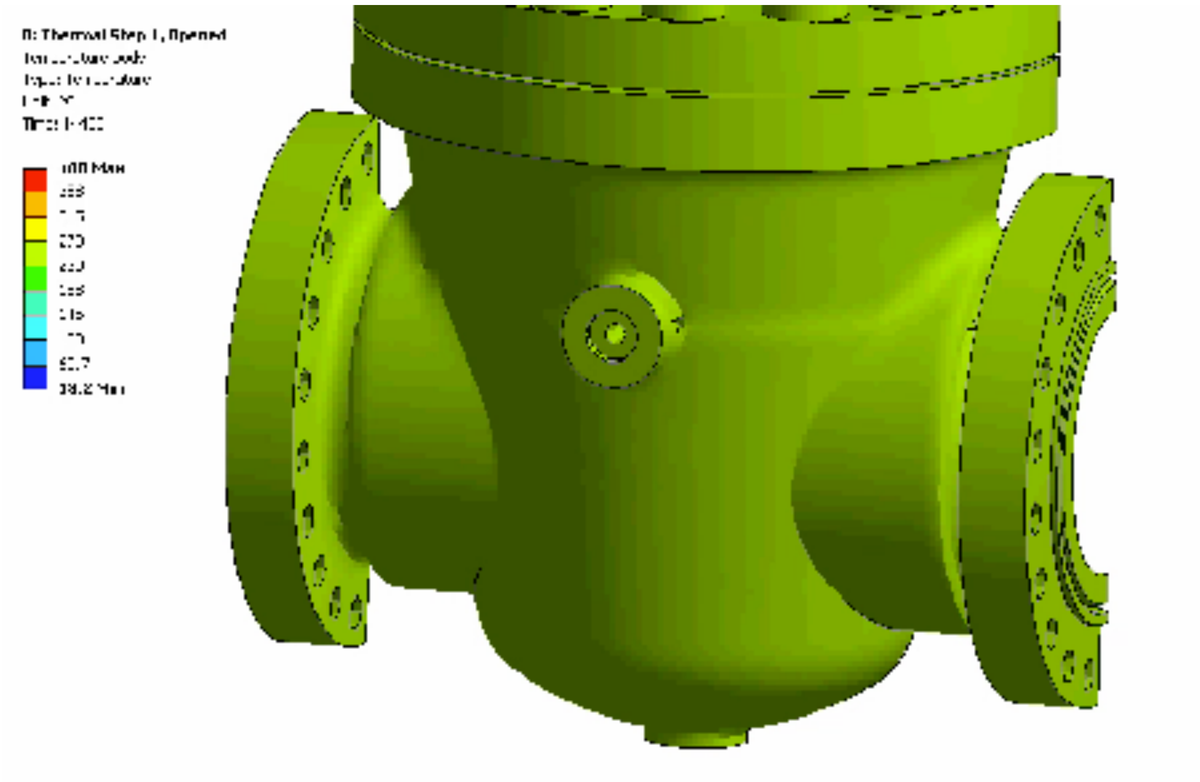


Fatigue

Examples of fatigue assessments

Fatigue assessment: case study

- Thermal fatigue, 28in API 300# plug valve for petrochemical applications

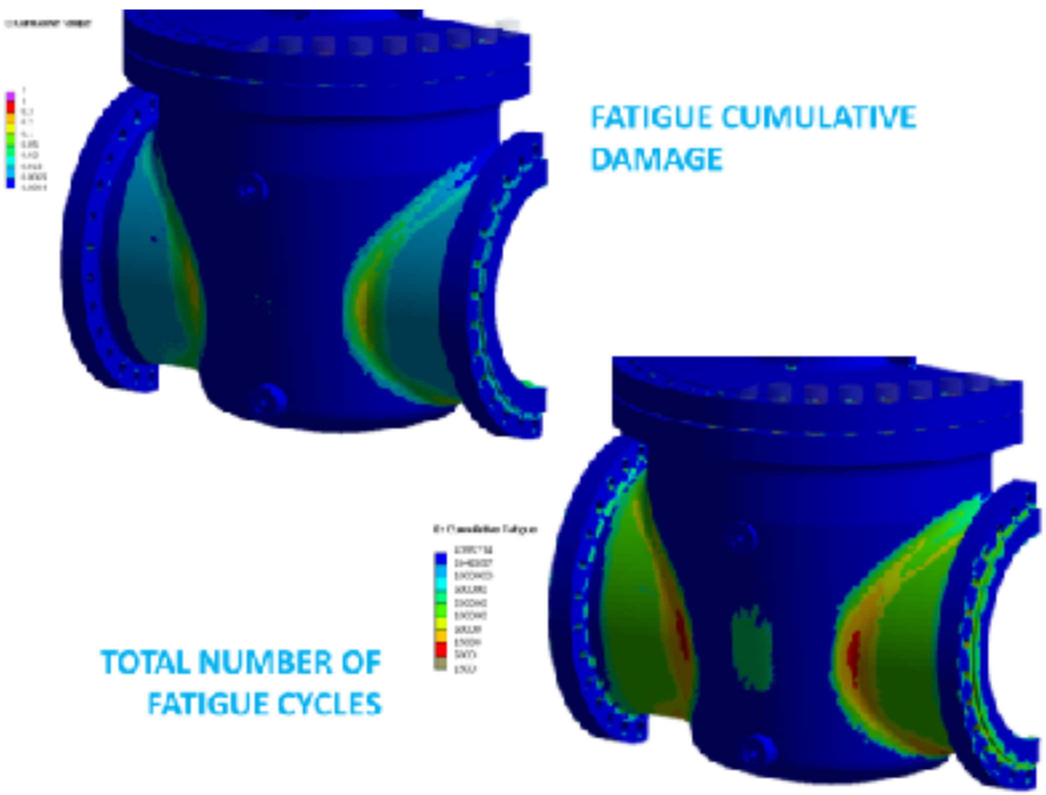


REQUESTS:

- **High temperature** gradients (150°C ÷ 500°C)
- **Cyclic operations** (heating, steam quench, cooling)
- **10 years** design life
- Critical areas for **inspections**

Fatigue assessment: case study

- Thermal fatigue, 28in API 300# plug valve for petrochemical applications



RESULTS:

- Design confirmation
- **Increased total life**
- **Increased time intervals** between inspections

REPLACEMENT COST REDUCTION

MAINTENACE COST REDUCTION

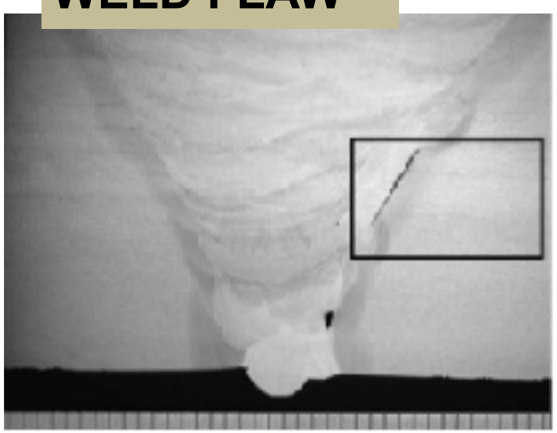
Fitness for service

ECA on welded valve

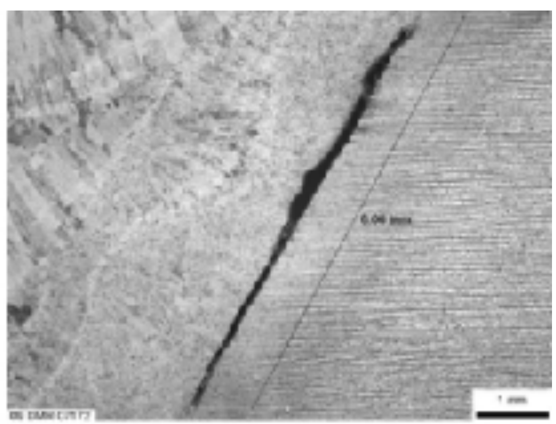
Assessment of flawed components

- Engineering critical assessment (ECA) on fully welded valves
  - *Damage tolerant approach*
  - *Fitness for service purpose: API 579/ ASME FFS-1, BS-7910*
  - *No PWHT*
  - *Fracture mechanics and NDT combination: definition of the acceptability*

WELD FLAW

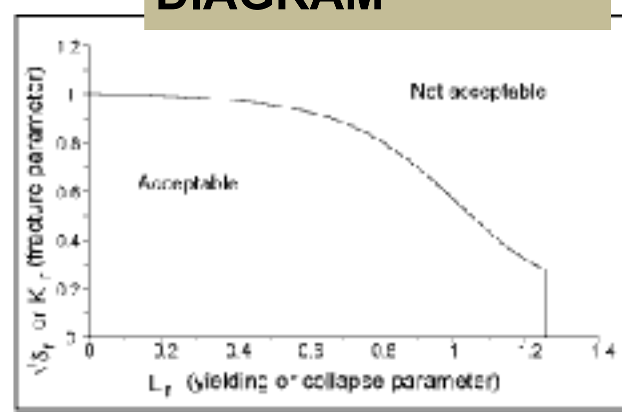


(a)



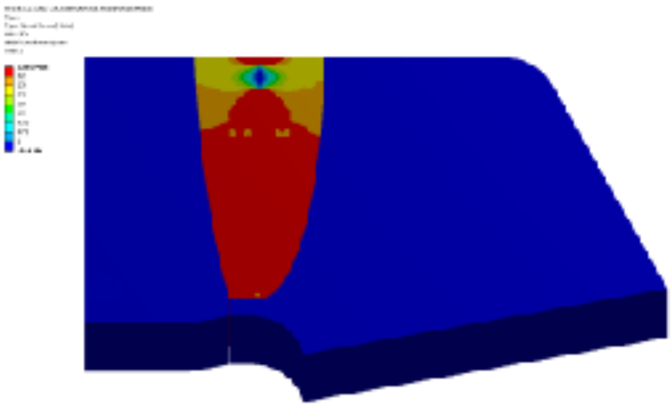
(b)

ACCEPTTABILITY DIAGRAM

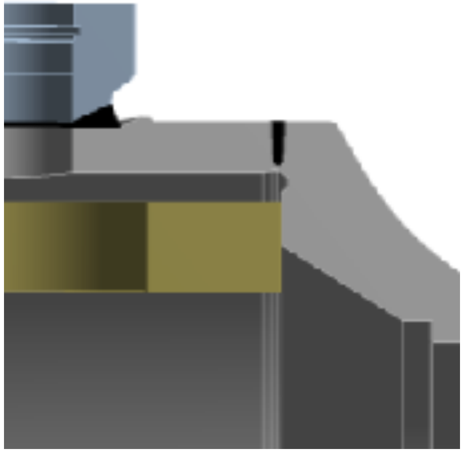


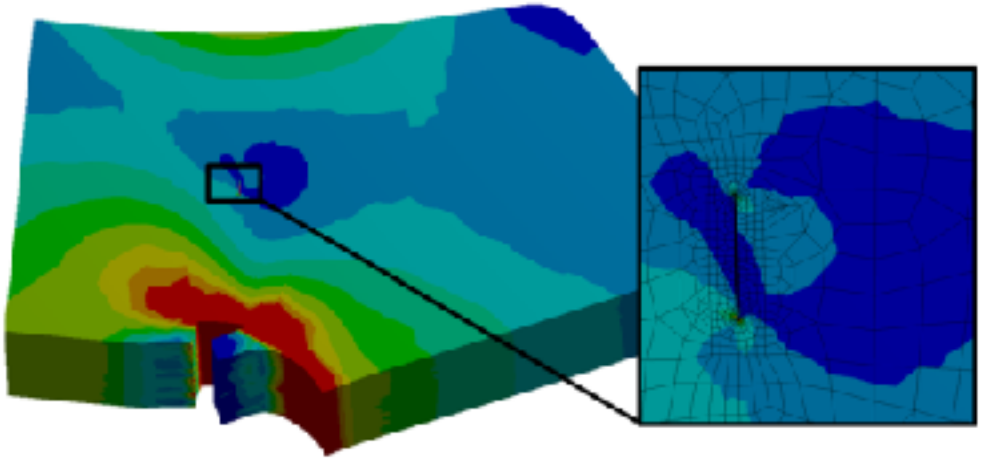
ECA analysis on fully welded valves: case study

- <u>Assessment procedure according to BS-7910</u>
  - **Fracture mechanics** body/closure weld
  - **Residual stresses** due to welding process



RESIDUAL STRESS MAP





CONCLUSIONS

- **FEA is useful to achieve robust and safe design for valves**
- **Nonlinear DBA is the most suitable approach for valve analysis**
  - Correct design check without excessive conservativism
  - Design optimization for material and weight reduction
  - Analysis of operating scenarios for serviceability check
  - Fatigue and fitness for service assessments
- **Improvement of design**
- **Production and maintenance cost reduction**

Key partner in Design Process Innovation

Stand 94
Room B