Harmonising Nuclear Codes and Standards for Mechanical Components

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4TH MDEP CONFERENCE on New Reactor Design Activities
SESSION 1: “CODES AND STANDARDS HARMONIZATION”
12-13 SEPTEMBER, LONDON
Cooperation in Reactor Design Evaluation and Licensing (CORDEL) has a mission to promote the standardization of nuclear reactor designs within a harmonized nuclear regulatory environment. Its **Mechanical Codes and Standards Task Force (MCSTF)** plays a key role in harmonisation of codes and standards.
MDEP’s Code Comparison Project
Main Reasons for Differences in the Mechanical Codes & Standards

- General Requirement Practices
  - Quality Assurance Requirements (NQA-1, ISO 9001, IAEA 50/SK)
  - Conformity Assessment (Stamping, RPE)
  - Local qualifications for welding and NDE
  - Local reference materials

- Scope of Codes
  - CSA – Candu reactors
  - AFCEN – PWR
  - ASME, JSME, KEA, and CSA – BWR, PWR, Candu

- Flexibilities allowed due to variation in country practices
  - Operational experience (prescribed in AFCEN)
  - Design and Analysis Flexibility (analysis methodology specified in AFCEN)
Sizing Related:

Russian Nominal Allowable Stress = \([\sigma]\) = Minimum \((\sigma_{UTS}/2.6,\sigma_{YS}/1.5)\)

ASME Design Stress Intensity = \(S_m\) = Minimum\((\sigma_{UTS}/3,\sigma_{YS}/1.5)\)

Pri. Membrane Russian
For NOC < [\sigma]
For AOO < 1.2 [\sigma]
For DA < 1.4 [\sigma]
Hydro Test < 1.35 [\sigma]

Pri. Membrane ASME
For Level A < \(S_m\)
For Level B < 1.1 \(S_m\)
For Level C < 1.2 \(S_m\)
For Level D < 2.4 \(S_m\) or 0.7 UTS
Hydro. Test < 0.9 \(\sigma_{YS}\)

Example presented by Dr Vaze of BARC
Estimating VVER1000 RPV Thickness

RPV Thickness Calculation using ASME NB and PNAE G 7-002-86

• Russian Nominal Allowable Stress

\[ \sigma = \text{Minimum}(\frac{539}{2.6}, \frac{441}{1.5}) = 207.3 \text{ Mpa} \]

• ASME Design Stress Intensity

\[ S_m = \text{Minimum}(\frac{539}{3}, \frac{441}{1.5}) = 179.7 \]

— ASME: Minimum thickness required = 214 mm
— PNAE: Minimum thickness required = 185 mm
— Actual thickness provided = 192.5 mm

• Although actual thickness is less than the minimum required by ASME: Is design less safe? May or may not be

Should we apply ASME equation to Russian design?
Harmonization of Safety Levels

Failure modes and the knowledge of Mechanics used are universal

But code rules differ because of :-

► Regulatory Requirements and Limitations
► Local Industry Practices
► Qualifications of welders, NDE/T personnel and professional Engineers
► QA and compliance requirements
► Scope Differences
International Harmonisation

• Applicable and internationally recognized set of Safety requirements
  • IAEA standards underpin safety in all countries
    • Higher level in standards hierarchy, not enforceable
    • Supplemented by enforceable national regulations
  • Need harmonisation of more detailed requirements
  • Need also an effort on the Industry side:
    • Codes and Standards that are recognised as equivalent by industry (necessary for acceptance being considered by regulatory bodies).
    • A harmonisation effort is required to identify differences and recognised equivalences between major codes.
International Cooperation Framework

Industry
- International (WNA: Supply Chain, Nuclear Law, Capacity Optimization; WANO)
- Regional (EPRI, INPO, FORATOM, EUR, ENISS)

Government
- NUSSC
- Probabilistic Safety Goals
- SMRs
- Knowledge Management

WNA
- CORDEL
- Safety Standards

SDOs
- ASME, AFCEN, KEPIC, JSME, NIKIET, CSA, IEC, IEEE and ISO

REGULATORS
- MDEP

International
- (OECD/NEA, OECD/IEA, ICRP, IAEA, EC)
- Regional (WENRA, ENSREG)
Promotion of Harmonization of Standards and Codes

- **Regulators**: MDEP
  - Canada, Finland, France, Indi, Japan, Russian Federation, South Africa, the UAE, The UK, the USA, China, and Sweden
  - 1 common position and four technical reports

- **Standard Development Organizations**: SDO Board
  - ASME BPVC III div.1, AFCEN (RCC-M), KEA (KEPIC), JSME (S-NC1), CSA,(N285.0) NIKIET (PNAE-G7)

- Code Comparison Report - STP-NU-051
  - [http://files.asme.org/STLLC/31181.pdf](http://files.asme.org/STLLC/31181.pdf)

- **Industry**: WNA CORDEL
  - The international voice of the industry promoting convergence of nuclear design codes
**Aim:** To promote the convergence of nuclear mechanical codes and standards in order to facilitate the international standardization of reactor designs:

- For one component designed to a specific code to be easily exportable
- Harmonization of requirements of codes & standards
- Acceptance that international codes can be used to meet regulatory requirements

**Membership:** Major international reactor vendors, large international utilities, engineering consulting companies and code users.
Harmonisation Work Plan of CORDEL MCSTF

Select topics with input from:
- Industry (CORDEL)
- Regulators (MDEP-CSWG)
- SDOs (Convergence Board)

Convene group of experts from the industry to work within CORDEL MCSTF

Report current status of codes

Propose harmonised rules

Define common Code Case
CORDEL MCSTF Projects

Finalised Projects
• Certification of NDE Personnel – Published 2015 ✔

• Comparison Report on Welding Qualification and Welding Quality Assurance – STP-NU-078 – Published 2016 ✔

On-Going Projects
Non-linear analysis design rules
• Part 1: Code comparison – Published February 2017 ✔
• Part 2: Industry Practices – First draft available
• Part 3: Benchmark – Workshop to review results to be held in early 2018

Harmonisation of Fatigue Life Analysis Methods
• Part 1: Comparison of Pressure Vessel and Piping Fatigue Design Rules based on S-N (cyclic stress vs. cycles to failure) Approach – under drafting
• Part 2: Proposed Harmonized Pressure Vessel and Piping Fatigue Design Rules
• Part 3: Proposed Harmonized Fatigue Crack Growth Analyses
• Part 4: Proposed Harmonized Environmental Effects on Fatigue and Fatigue Crack Growth Analysis
Non-linear analysis design rules

• **Question:** How to improve Pressure Equipment Code rules considering nonlinear behavior of materials?

• **Damages Investigated**
  - Plastic collapse / excessive deformation
  - Plastic instability / ultimate load
  - Local Failure
  - Fatigue
  - Plastic shakedown and ratcheting

• **Other aspects:** the stress classification rules (reinforced nozzles, elastic follow-up…)

• **Loads:**
  - Mechanical and thermal
  - Quasi-static, cyclic or dynamic (later)

• **Analysis methods:**
  - Elastic
  - Elastic-plastic monotonic/cyclic
  - Limit load

• **No buckling; no creep; no cracks**
Part 1: Existing Code comparisons

Main conclusions:

- No Code for the use of non-linear analysis methods to assess for all failure mechanisms
- 2 Codes have more detailed requirements for non-linear analysis:
  - AFCEN RCC-MRx
  - ASME BPVC Section VIII Div. 2
- Large improvements to existing Codes are needed

The report lists:

- Major Open Points
- Major Gaps and Needs
Overview of the non-linear analysis methodologies for **monotonic** loads

<table>
<thead>
<tr>
<th>Plastic collapse</th>
<th>Plastic instability</th>
<th>Stress triaxiality</th>
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</thead>
<tbody>
<tr>
<td><strong>Limit analysis</strong></td>
<td><strong>Direct elastic-plastic FEA</strong></td>
<td><strong>Limit analysis</strong></td>
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<tr>
<td><strong>Material properties</strong></td>
<td><strong>Criteria</strong></td>
<td><strong>Material properties</strong></td>
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<tr>
<td>RCCM</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>ASME III</td>
<td>Y</td>
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<tr>
<td>JSME</td>
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<td>RCC-MRx</td>
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<td>KEPI</td>
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<td>PNAEG</td>
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<td>R5</td>
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<tr>
<td>ASME VIII</td>
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<tr>
<td>EN 13445</td>
<td>Y</td>
<td>Y</td>
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</tbody>
</table>

Y = covered; N = Not covered; P = Partially covered
Part 1: Existing Code comparisons

Overview of the non-linear analysis methodologies for **cyclic** loads

<table>
<thead>
<tr>
<th>Plastic shakedown</th>
<th>Fatigue $K_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct elastic-plastic analysis using FEA</td>
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</tr>
<tr>
<td>Material properties</td>
<td>Material constitutive equation</td>
</tr>
<tr>
<td>RCCM</td>
<td>N</td>
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<td>ASME III</td>
<td>N</td>
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$Y = \text{covered}; \ N = \text{Not covered}; \ P = \text{Partially covered}$
Part 2: Recommended practices

Draft Report available with content:

1. General introduction
   - presentation of "usable" different methods
   - Recommendation to users
   - definitions / glossary

2. Proposed rules by damage
   - Step by step approach
   - Validation

3. Required Material properties

4. Criteria

5. Quality management
Part 3: Benchmarks

• 2 benchmarks to apply and improve "guidelines report"
  ➢ Large Low Alloy Steel (LAS) vessel nozzle under pressure and piping loads
  ➢ Small Stainless Steel (SS) piping nozzle under pressure and thermal loads

• All the data are in the report
• Result presentation guidelines are also in the report

• Benchmark 1
  • Elastic codified rules
  • Elastic-plastic
  • Limit loads

• Benchmark 2
  • Elastic codified rules
  • Simplified elastic-plastic and $K_e$ in Fatigue
  • Direct cyclic and plastic shake down
This report reviews and compares the current code requirements of fatigue analysis and design rules based on the S-N approach in the major nuclear and non-nuclear design codes.

**Major nuclear codes:**
ASME BPVC Section III NB & NH, AFCEN RCC-M & RCC-MRx, JSME, KEPIČ, PNEA and R5.

**Selected non-nuclear codes:**
ASME BPVC Section VIII Division 2, EN 12952-3, EN 13445-3, PD 5500 and JB4732.
Additional Slides

Benchmark problem
Benchmark 1: LAS Vessel nozzle (1/3)

- **2D and 3D model**
- **Loads:**
  - Pressure
  - or pressure + piping loads

- **Damages**
  - Plastic collapse
  - Plastic instability
  - Local failure

- **Methods**
  - Elastic codified rules
  - Elastic-plastic
  - Limit load
Benchmark 1: LAS Vessel nozzle (2/3)

Figure 5: Class 1 Low Alloy Steel Vessel Nozzle – 0° scheme
Benchmark 1: LAS Vessel nozzle (3/3)

- Results presentation

C1, C2, C3: center of connecting radius

No weld in the basic model, same material than the nozzle for the pipe.

CLASS 1 VESSEL

OUT OF SCALE SKETCH

Radial section (scale effect...)

Main Coolant Line

S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12

60°

700
Benchmark 2: SS Piping Nozzle

- 2D and 3D models
- 2 cyclic thermal shocks
  - 220°C thermal shock 100 cycles
  - 110°C thermal shock 800 cycles
- Damages
  - Fatigue
  - Plastic shakedown
- Methods
  - Elastic codified rules
  - Simplified Elastic-plastic: $K_e$
  - Elastic-plastic evaluation of cyclic strains
Benchmark 2 : SS Piping Nozzle (1/5)
Benchmark 2 : SS Piping Nozzle
(2/5) - Transients description

Thermal and Pressure Transients

Fluid Temperature

Times in s

Transient 1
Transient 2

P = 15.5 MPa

P = 1.0 MPa
Benchmark 2: SS Piping Nozzle (3/5) - Material properties

Monotonic Stress-Strain curve

Traction 316L 350°C E 172000 Mpa Rp0.2 120 Mpa
Benchmark 2: SS Piping Nozzle
(4/5) - Material properties

RCCM-Rx Cyclic Stress-strain curve 316L - 350°C
Benchmark 2 : SS Piping Nozzle
(5/5) - Results presentation

OUT OF SCALE SKETCH

C4, C5 : center of connecting radius
Thank You