Task Group 04 – Non-linear Design Rules

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Technical Program Status on Code Comparison – Draft 2

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2 First Review of International Codes: Vessels, Piping, Boilers

2.1 Introduction

The objectives of this short Analysis is to locate in Pressure Vessel and Piping Codes, the different article concerned by nonlinear rules:

- Limit loads analysis rules
- Elastic-plastic analysis rules
- Creep analysis rules
- Cyclic elastic-plastic or elastic-visco-plastic analyses rules

This analysis will be followed by detail review and comparison of these rules

2.2 EN 13445-3: Pressure Vessels Design Rules -2009

Annex B – Design by Analysis – Direct Route

B.1 Introduction

B.1.1 General

This annex is currently limited to sufficiently ductile materials, like the whole standard, but it is, for components operating in the creep range, also limited to sufficiently creep ductile materials.

NOTE The steels and steel castings listed in Table E.2-1 of EN 13445-2:2009 for which, for the relevant temperature range, creep strengths are given in the referred to material standards, are considered to be sufficiently creep ductile".

B.1.2 Purpose

Design-by-analysis (DBA) provides rules for the design of any component under any action. It may be used:

— as an alternative to design-by-formulas (see 5.4.1)

— as a complement to design-by-formulas for:

  — cases not covered by that route;

  — cases involving superposition of environmental actions;

  — cases where the manufacturing tolerances given in EN 13445-4:2009, Clause 5, are not fulfilled, in agreement with the parties concerned.

In the last item, any deviations beyond tolerance limits shall be clearly documented.

B.1.3 Special requirements

Due to the advanced methods applied, until sufficient in-house experience can be demonstrated, the involvement of an independent body, appropriately qualified in the field of DBA, is required in the assessment of the design (calculations) and the potential definition of particular NDT requirements.

B.1.4 Creep design

For components which, under reasonably foreseeable conditions, may operate in the creep range, the lifetime of this creep load case (or the lifetimes for more than one of such load cases) shall be specified (by the user or his representative). For each load case which includes operation in the creep range, the specified time for operation in the creep range shall not be less than 10 000 h. If none is specified, the manufacturer shall assume a reasonable time, but at least 100 000 h.

NOTE Whereas for structures with solely non-creep load cases the load cases can be specified quite independently, the specification of load cases for structures with creep load cases requires careful consideration of the total design life taking into consideration all reasonably foreseeable load cases. Alternative total design lives may be used.

The (specified or assumed) design life shall be stated in the Technical Documentation.

If calculation temperatures are below the creep range (See 5.1) no creep design checks are required, and B.5.1.3 and B.9 do not apply.

If the minimum of the two values:

a) the product of 1,2 and the creep rupture strength at calculation temperature and for the relevant lifetime,

b) the product of 1,5 and the 1% creep strain strength at calculation temperature and for the relevant lifetime

is larger than the 0,2% proof strength at calculation temperature, no creep design checks are required, and B.5.1.3 and B.9 do not apply. If the minimum of the two values is not larger than the 0,2% proof strength at calculation temperature, creep design checks are required, and B.5.1.3 and B.9 apply.

The designations creep rupture strength and 1 % creep strain strength refer to mean values, as specified in the material standard, for which a scatter band of experimental results of ± 20 % is assumed. For larger scatter bands 1,25 times the minimum band values shall be used instead of mean values.

For interpolation and possible extrapolation of strength values, and for the determination of time to creep rupture or 1 % creep strain, the procedures given in Clause 19 shall be used.

To be updated with 2021 Edition

2.3 EN 13480-3: Pressure Piping Design Rules

No particular nonlinear Design Rules
(to be confirmed…)

2.4 EN 12952-3: Boilers Design Rules

2.5 ASME BPVC – Section I : Rules for construction of power boilers - Design Rules - 2015

- PG-16 GENERAL

  PG-16.1 The design of power boilers, high temperature water boilers, and other pressure parts included within the scope of these rules shall conform to the general design requirements in the following paragraphs and in addition to the specific requirements for design given in the applicable Parts of this Section that pertain to the methods of construction used.

This Section does not contain rules to cover all possible details of design. When detailed rules are not given, it is intended that **the Manufacturer**, subject to the acceptance of the Inspector, **shall provide details of design** that will be as safe as those provided by the rules of this Section. This may be done **by appropriate analytical methods, the appropriate use of rules from other design codes or, as permitted by PG-18, by proof test**.

- PG-18 DESIGN VALIDATION BY PROOF TEST

  Where no rules are given for calculating the strength of a boiler or any part thereof, the Manufacturer may establish MAWP by testing a full-size sample in accordance with A-22, Proof Tests to Establish Maximum Allowable Working Pressure.

To be updated with 2021 Edition

2.6 ASME BPVC – Section VIII – Division 2 – 2021 – Alternative Rules

2.6.1 PART 5 - Design by Analysis Requirements

2.6.1.1 Scope

. The design requirements for application of the design-by-analysis methodology of this Division are described in Part 5. Detailed design procedures utilizing the results from a stress analysis are provided to evaluate components for plastic collapse, local failure, buckling, and cyclic loading. Supplemental requirements are provided for the analysis of bolts, perforated plates and layered vessels. Procedures are also provided for design using the results from an experimental stress analysis, and for fracture mechanics evaluations.

. (a) Protection Against Plastic Collapse – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules.

. (b) Protection Against Local Failure – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules. It is not necessary to evaluate the protection against local failure, 5.3, if the component design is in accordance with Part 4 (e.g., component wall thickness and weld detail per 4.2).

. (c) Protection Against Collapse From Buckling – these requirements apply to all components where the thickness and configuration of the component is established using design-by-analysis rules and the applied loads result in a compressive stress field.

. (d) Protection Against Failure From Cyclic Loading

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2.6.2 5.2 - Protection against Plastic Collapse

2.6.2.1 5.2.1-Overview

2.6.2.1.1 5.2.1.1-Three alternative analysis methods

Provided for evaluating protection against plastic collapse. A brief description of these analysis methodologies is provided below.

(a) Elastic Stress Analysis Method – Stresses are computed using an elastic analysis, classified into categories, and limited to allowable values that have been conservatively established such that a plastic collapse will not occur.

Limit-Load Method – A calculation is performed to determine a lower bound to the limit load of a component. The allowable load on the component is established by applying design factors to the limit load such that the onset of gross plastic deformations (plastic collapse) will not occur.

(b) Elastic–Plastic Stress Analysis Method – A collapse load is derived from an elastic–plastic analysis considering both the applied loading and deformation characteristics of the component. The allowable load on the component is established by applying design factors to the plastic collapse load.

2.6.2.1.2 5.2.1.2-For components with a complex geometry and/or complex loading the categorization of stresses requires significant knowledge and judgment. This is especially true for three-dimensional stress fields. Application of the **limit-load or elastic–plastic analysis methods** in 5.2.3 and 5.2.4, respectively, is recommended for cases where the categorization process may produce ambiguous results.

2.6.2.2 5.2.3-Limit-Load Analysis Method

2.6.2.2.1 5.2.3.1-Overview

(a) Limit-load analysis addresses the failure modes of ductile rupture and the onset of gross plastic deformation (plastic collapse) of a structure. As defined in the following paragraphs, it provides one option to protect a vessel or component from plastic collapse. It is to be applied to single or multiple static loading, applied in any specified order. Limit-load analysis provides an alternative to elastic analysis and stress linearization and the satisfaction of primary stress limits in 5.2.2.2.

(c) Displacements and strains indicated by a limit analysis solution have no physical meaning. If the User's Design Specification requires a limit on such variables, the procedures in 5.2.4 shall be used to satisfy these requirements.

(d) Protection against plastic collapse using limit-load analysis is based on the theory of limit analysis that defines a lower bound to the limit load of a structure as the solution of a numerical model with the following properties:

(1) The material model is elastic-perfectly plastic with a specified yield strength.
(2) The strain-displacement relations are those of small displacement theory.
(3) Equilibrium is satisfied in the un-deformed configuration.

2.6.2.3 5.2.4-Elastic–Plastic Stress Analysis Method

2.6.2.3.1 5.2.4.1 - Overview

(a) Protection against plastic collapse is evaluated by determining the plastic collapse load of the component using an elastic–plastic stress analysis. The allowable load on the component is established by applying a design factor to the calculated plastic collapse load.

(b) Elastic–plastic stress analysis provides a more accurate assessment of the protection against plastic collapse of a component relative to the criteria in 5.2.2 and 5.2.3 because the actual structural behavior is more closely approximated.

(c) The redistribution of stress that occurs as a result of inelastic deformation (plasticity) and deformation characteristics of the component are considered directly in the analysis.

2.6.2.3.2 5.2.4.2-Numerical Analysis

The plastic collapse load is the load that causes overall structural instability. In practice, an estimate of the plastic collapse load can be obtained using a numerical analysis technique (e.g., finite element method) by incorporating an elastic–plastic material model to obtain a solution. The effects of non-linear geometry shall be considered in this analysis. The estimated plastic collapse load is the maximum load before overall structural instability occurs. Structural instability is indicated by the inability to achieve an equilibrium solution for a small increase in load (i.e., the solution will not converge).

2.6.2.3.3 5.2.4.3-Acceptance Criteria.

2.6.2.3.4 5.2.4.4-Assessment Procedure.

2.6.2.3.5 5.2.4.5-Test Condition for Components Designed Using Elastic–Plastic Stress Analysis Method.

2.6.3 5.3-Protection against Local Failure

2.6.3.1 5.3.1-OVERVIEW

2.6.3.1.1 5.3.1.1-Local Failure Criteria

In addition to demonstrating protection against plastic collapse as defined in 5.2, the applicable local failure criteria below shall be satisfied for a component. These requirements apply to all components where the thickness and configuration of the component are established by using design-by-analysis rules. It is not necessary to evaluate protection against local failure (5.3), if the component design is in accordance with Part 4 (e.g., component wall thickness and weld detail per 4.2).

2.6.3.1.2 5.3.1.2-Two analysis methodologies are provided for evaluating protection against local failure under applied design loads. When protection against plastic collapse is satisfied by the method in 5.2.3, either method listed below is acceptable.

(a) The analysis procedures in 5.3.2 provide an approximation of the protection against local failure based on the results of an elastic analysis.

(b) A more accurate estimate of the protection against local failure of a component can be obtained using the elastic–plastic stress analysis procedures in 5.3.3.

2.6.3.2 5.3.3-ELASTIC-PLASTIC ANALYSIS- LOCAL STRAIN LIMIT

2.6.4 5.4-Protection against Collapse from Buckling

2.6.4.1 5.4.1 DESIGN FACTORS

2.6.4.1.1 5.4.1.1-Buckling

In addition to evaluating protection against plastic collapse as defined in 5.2, a design factor for protection against collapse from buckling shall be satisfied to avoid buckling of components with a compressive stress field under applied design loads.

2.6.4.1.2 5.4.1.2-Structural Stability

The design factor to be used in a structural stability assessment is based on the type of buckling analysis performed. The following design factors shall be the minimum values for use with shell components when the buckling loads are determined using a numerical solution (i.e., bifurcation buckling analysis or elastic–plastic collapse analysis).

(a) **Type 1** – If a bifurcation buckling analysis is performed using an elastic stress analysis without geometric nonlinearities in the solution to determine the pre-stress in the component, a minimum design factor of $\Phi_B = 2/\beta_{cr}$ shall be used (see 5.4.1.3). In this analysis, the pre-stress in the component is established based on Design Load Combinations 1) through (9) in Table 5.3.

(b) **Type 2** – If a bifurcation buckling analysis is performed using an elastic–plastic stress analysis with the effects of non-linear geometry in the solution to determine the pre-stress in the component, a minimum design factor of $\Phi_B = 1.667/\beta_{cr}$ shall be used (see 5.4.1.3). In this analysis, the pre-stress in the component is established based on Design Load Combinations (1) through (9) in Table 5.3.

(c) **Type 3** – If a collapse analysis is performed in accordance with 5.2.4, and imperfections are explicitly considered in the analysis model geometry, the design factor is accounted for in the factored load combinations in Table 5.5. It should be noted that a collapse analysis can be performed using elastic or plastic material behavior. If the structure remains elastic when subject to the applied loads, the elastic–plastic material model will provide the required elastic behavior, and the collapse load will be computed based on this behavior.

2.6.4.1.3 5.5.1.5-Under certain combinations of steady-state and cyclic loadings

There is a possibility of ratcheting. **A rigorous evaluation of ratcheting** normally requires an elastic–plastic analysis of the component; however, under a limited number of loading conditions, an approximate analysis can be utilized based on the results of an elastic stress analysis, see 5.5.6.

2.6.4.1.4 5.5.1.6-Protection against ratcheting

It shall be considered for all operating loads listed in the User's Design Specification and shall be performed even if the fatigue screening criteria are satisfied (see 5.5.2). Protection against ratcheting is satisfied if one of the following three conditions is met:

(a) The loading results in only primary stresses without any cyclic secondary stresses.

(b) Elastic Stress Analysis Criteria – Protection against ratcheting is demonstrated by satisfying the rules of 5.5.6.

(c) Elastic–Plastic Stress Analysis Criteria – Protection against ratcheting is demonstrated by satisfying the rules of 5.5.7.

2.6.4.2 5.5.4 FATIGUE ASSESSMENT — ELASTIC–PLASTIC STRESS ANALYSIS AND EQUIVALENT STRAINS

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2.6.4.3 5.5.7 RATCHETING ASSESSMENT — ELASTIC–PLASTIC STRESS ANALYSIS

2.6.4.3.1 5.5.7.1-Overview

To evaluate protection against ratcheting using elastic–plastic analysis, an assessment is performed by application, removal and re application of the applied loadings. If protection against ratcheting is satisfied, it may be assumed that progression of the stress–strain hysteresis loop along the strain axis cannot be sustained with cycles and that the hysteresis loop will stabilize. A separate check for plastic shakedown to alternating plasticity is not required. The following assessment procedure can be used to evaluate protection against ratcheting using elastic–plastic analysis.

2.6.4.3.2 5.5.7.2-Assessment Procedure

2.7 ASME B.31 Piping Standards

2.7.1 List of B.31 Standards

- B31.1 Power Piping
  Piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems and central and district heating and cooling plants.
- B31.3 Process Piping
  Piping typically found in petroleum refineries, chemical, pharmaceutical, textile, per, semiconductor and cryogenic plants and related processing plants and terminals.
- B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
  Piping transporting products which are predominately quid between plants and terminals and within terminals, pumping, regulating, and metering stations.
- B31.5 Refrigeration Piping
  Piping for refrigerants and secondary coolants.
- B31.8 Gas Transportation and Distribution Piping Systems
  Piping transporting products which are predominately gas between sources and terminals including compressor, regulating and metering stations, gas gathering pipelines.
- B31.9 Building Services Piping
  Piping typically found in industrial, institutional, commercial and public buildings and in multi-unit residences which does not require the range of sizes, pressures and temperatures covered in B311.1
- B31.11 Slurry Transportation Piping Systems
  Piping transporting aqueous slurries between plants and terminals within terminals, pumping and regulating stations.
- B31.12 Hydrogen Piping and Pipelines
  Code applicable to piping in gaseous and liquid hydrogen service and to pipelines in gaseous hydrogen service.

2.8 API 579 Standards

2.9 CODAP

2.10 ASME BPVC – Section III – Division 1 – 2021 – Rules for Construction of Nuclear Facility Components

MANDATORY APPENDIX XIII - DESIGN BASED ON STRESS ANALYSIS

XIII-1200 DESIGN ACCEPTABILITY

XIII-1210 REQUIREMENTS FOR DESIGN ACCEPTABILITY

The requirements for the acceptability of a design are as follows:

(a) The design shall be such that the stresses shall not exceed the limits described in this Appendix.

(b) For configurations where compressive stresses occur, in addition to the requirement in (a), the critical buckling stress shall be taken into account.

(c) The requirements for material, design, fabrication, examination, and testing of the applicable Subsection shall be met.

XIII-1220 BASIS FOR DETERMINING STRESSES

The theory of failure used in the rules of this Appendix is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

XIII-1300 TERMS RELATING TO STRESS ANALYSIS

Terms used in this Appendix relating to stress analysis are defined in (a) through (l) below.

(j) Inelasticity.

Inelasticity is a general characteristic of material behavior in which the material does not return to its original shape and size after removal of all applied loads. Plasticity and creep are special cases of inelasticity.

(k) Limit Analysis.

Limit analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (non-strain-hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field. For beams and frames, the term mechanism is commonly used in lieu of kinematically admissible velocity field.

(l) Limit Analysis—Collapse Load.

The methods of limit analysis are used to compute the maximum load that a structure assumed to be made of ideally plastic material can carry. At this load, which is termed the collapse load, the deformations of the structure increase without bound.

XIII-3200 APPLICATIONS OF PLASTIC ANALYSIS

The following sub-sub-articles provide guidance in the application of plastic analysis to determine the collapse load C_L and achieve some relaxation of the basic primary stress limits that is allowed if plastic analysis is used. The limits on general primary membrane stress intensity, local primary membrane stress intensity, and primary membrane plus primary bending stress intensity (see XIII-3110, XIII-3120, and XIII-3130) need not be satisfied at a specific location if it can be shown that the specified loadings do not exceed k C_L where C_L is the collapse load determined using the procedure defined in XIII-3210, XIII-3220, or XIII-3230 and the value of k is specified in Table XIII-3200-1. When one of these rules is used, the effects of plastic strain concentrations in localized areas of the structure, such as the points where hinges form, shall be considered. The effects of the concentrations of strain on the fatigue behavior, ratcheting behavior, or buckling behavior of the structure shall be considered in the design.
The design shall satisfy the minimum wall thickness requirements of the applicable Subsection.

. XIII-3210 LIMIT ANALYSIS

The lower bound collapse load is determined using limit analysis. The yield strength to be used in these calculations is 1.5 S_m. The use of 1.5 S_m for the yield strength of those materials of Section II, Part D, Subpart 1, Tables 2 A and 2 B to which Note G 7 in Table 2 A or Note G 1 in Table 2 B is applicable may result in small permanent strains during the first few cycles of loading. If these strains are not acceptable, the yield strength to be used shall be reduced according to the strain-limiting factors of Section II, Part D, Subpart 1,Table Y-2.

. XIII-3220 EXPERIMENTAL ANALYSIS

The collapse load is determined by application of II-1430.

. XIII-3230 PLASTIC ANALYSIS

Plastic analysis is a method of structural analysis by which the structural behavior under given loads is computed by considering the actual material stress–strain relationship and stress redistribution, and it may include either strain hardening or change in geometry, or both.

The collapse load is determined by application of II-1430 to a load–deflection or load–strain relationship obtained by plastic analysis.

. XIII-3430 THERMAL STRESS RATCHET

. XIII-3440 SHAKEDOWN ANALYSIS

. XIII-3450 SIMPLIFIED ELASTIC–PLASTIC ANALYSIS

2.11 RCC-M - DESIGN AND CONSTRUCTION RULES FOR MECHANICAL COMPONENTS OF PWR NUCLEAR ISLANDS – 2020

- ANNEX Z C IMPLEMENTATION OF NON-LINEAR CALCULATIONS TO CHECK THE DESIGN CRITERIA
- ANNEX Z G FAST FRACTURE RESISTANCE
- ANNEX Z P UNACCEPTABLE DEFECTS: ANALYSIS WITH REGARD TO EQUIPMENT INTEGRITY

ANNEX Z G FAST FRACTURE RESISTANCE	
Z G 1000	INTRODUCTION
Z G 1100	SCOPE
Z G 1200	METHODOLOGY
Z G 2000	SCREENING CRITERIA
Z G 2100	GENERAL
Z G 2200	FERRITIC COMPONENTS
Z G 2300	AUSTENITIC OR AUSTENITIC-FERRITIC COMPONENTS
Z G 2400	DISSIMILAR WELDS
Z G 3000	CONVENTIONAL FAST FRACTURE ANALYSIS
Z G 3100	GENERAL
Z G 3200	FERRITIC VESSELS
Z G 3300	FERRITIC PIPING
Z G 3400	AUSTENITIC AND AUSTENITIC-FERRITIC VESSELS
Z G 3500	AUSTENITIC AND AUSTENITIC-FERRITIC PIPING
Z G 3600	OTHER COMPONENTS
Z G 4000	DETAILED FAST FRACTURE ANALYSIS METHOD
Z G 4100	GENERAL
Z G 4200	VESSELS
Z G 4300	PIPING
Z G 5000	METHODS FOR DETERMINING ANALYSIS PARAMETERS
Z G 5100	DETERMINATION OF STESS INTENSITY FACTORS K
Z G 5200	DETERMINATION OF THE CRACK-EXTENSION FORCE J
Z G 6000	MATERIAL PROPERTIES
Z G 6100	TOUGHNESS PROPERTIES OF FERRITIC MATERIAL
Z G 6200	TOUGHNESS PROPERTIES OF AUSTENITIC MATERIALS

ANNEX Z C IMPLEMENTATION OF NON-LINEAR CALCULATIONS TO CHECK THE DESIGN CRITERIA

- **Z C 1000 INTRODUCTION**

Z C 1100 PURPOSE

When the elastic analysis does not allow for a certain design criteria to be checked, the designer may have to implement non-linear methods. The purpose of this annex is to give recommendations on the implementation of these methods. This annex makes it possible to check the components of level 1 or 2 and their supports as well as the reactor internals subjected to any loads based on calculations in which the plastic stress redistribution is taken into account.

It takes into account damages such as:

- excessive deformation,
- plastic instability,
- progressive deformation,
- fatigue,
- fast fracture.

Especially for fatigue analysis, this annex can be used:

- to refine the plastic strain amplification via an adapted Ke parameter,
- to determine the elastoplastic strain ranges.

It does not address elastic or elastoplastic instability damage (buckling).

This annex does not address dynamic analyses.
There are three types of non-linear analyses:

- the limit analyses which are used to cover essentially the excessive deformation damage,
- the elastoplastic analyses which are used to cover the plastic instability and fast fracture damages,
- the cyclic analyses which are used to cover progressive deformation and fatigue damages.

Implementation recommendations for the various analyses envisaged as well as the material behavior models that can be used in these analyses are provided. For better readability, the criteria to be checked are also recalled, in coherence with those of subsections B, C, H and G.

Z C 1200 ORGANISATIOORGANISATION

Apart from this introduction chapter, this annex comprises 5 chapters:

- Z C 2000 provides the definitions and symbols used.
- Z C 3000 explains the approach to check the criteria for the different damages based on the results of a non-linear calculation.
- Z C 4000 explains the different types of calculations and specifies the implementation and check recommendations.
- Z C 5000 provides references in which codified material data necessary to the analyses can be found.
- Z C 6000 describes several behavior models and the general identification procedures of their parameters.

ANNEX Z P UNACCEPTABLE DEFECTS: ANALYSIS WITH REGARD TO EQUIPMENT INTEGRITY	
Z P 1000	**INTRODUCTION**
Z P 1100	**PURPOSE**
Z P 1200	**METHODOLOGY**
Z P 1210	Defect tolerance analysis
Z P 1220	Fatigue propagation sturdiness analysis
Z P 2000	**ANALYSIS EXEMPTION CRITERIA**
Z P 3000	**FATIGUE PROPAGATION STURDINESS ANALYSIS**
Z P 3100	**DEFINITION OF THE CALCULATION DEFECT**
Z P 3110	Technological defect
Z P 3120	Definition of equivalent surface defect
Z P 3130	Calculation defect adopted for the analysis
Z P 3200	**FATIGUE PROPAGATION STURDINESS CRITERION**
Z P 3300	**ASSESSMENT OF DEFECT PROGRESSION**
Z P 3310	General
Z P 3320	Initiation phase
Z P 3330	Propagation phase
Z P 4000	**FATIGUE CRACK GROWTH LAWS**

2.12 RCC-MRx - DESIGN AND CONSTRUCTION RULES FOR MECHANICAL COMPONENTS OF NUCLEAR INSTALLATIONS: HIGH TEMPERATURE, RESEARCH AND FUSION REACTORS – 2018

- **Section III – Tome 1** – Subsection Z - **Appendix A 10**: Elastoplastic analysis of a structure subjected to cyclic loading

- **Section III – Tome 1** – Subsection Z - **Appendix A11**: Elasto-visco-plastic analysis of a structure subjected to cyclic loading

- **Section III – Tome 1** – Subsection Z - **Appendix A 16**: Guide for prevention of fast fracture, Leak Before Break analysis and defect assessment

Note: Monotonic nonlinear design rules are included in the core of the Code

3 Open Points

3.1 Monotonic loads

3.1.1 Limit analysis

- Theoretical justified for Plastic Collapse with $\sigma_{flow} = \sigma_y$
- no theoretical justification for Plastic Instability: experimental σ_{flow} is needed…
- what's a "flat" stress- strain curve ?
- how flat stress-strain curves are considered in your Finite Element Code ?
- plastic hardening model: isotropic / kinematic ?
- small / large displacement, in particular for plastic instability analysis ?
- what kind of convergence criteria to stop the analysis ?

3.1.2 Elastic-plastic analysis

- plastic hardening model: isotropic / kinematic ?
- small / large displacement, in particular for plastic instability analysis ?
- Strain criteria to stop the analysis ?

3.2 Cyclic loads

- Model selection: Chaboche, Ohno, Amstrong Frederic, many others…
- Material constitutive equation model: calibration / validation
- Effect of ratchetting: covered / not covered through specific validation tests
- Final Validation on "selective tests"

3.3 Buckling

- Geometry tolerances
- Bi-furcation and post-buckling analysis

3.4 Specific cases

- Elastic follow-up rules
- Nozzle reinforcement rules
- Bolted flange nonlinear analysis, including seal
- Cracked component reference stress
- Local failure: $\sigma_I + \sigma_{II} + \sigma_{III} < 4 S_{all}$
- Strain based criteria for High Seismic Analysis
- Creep consequences
- HDPE piping

3.5 Final Report

- **Recommended practices and associated validation**
- Proposed selective validation analysis
- Material properties and standard tests
- EPERC benchmarks
- Practical case examples
- Finite Element Code validation
- User qualification recommendations