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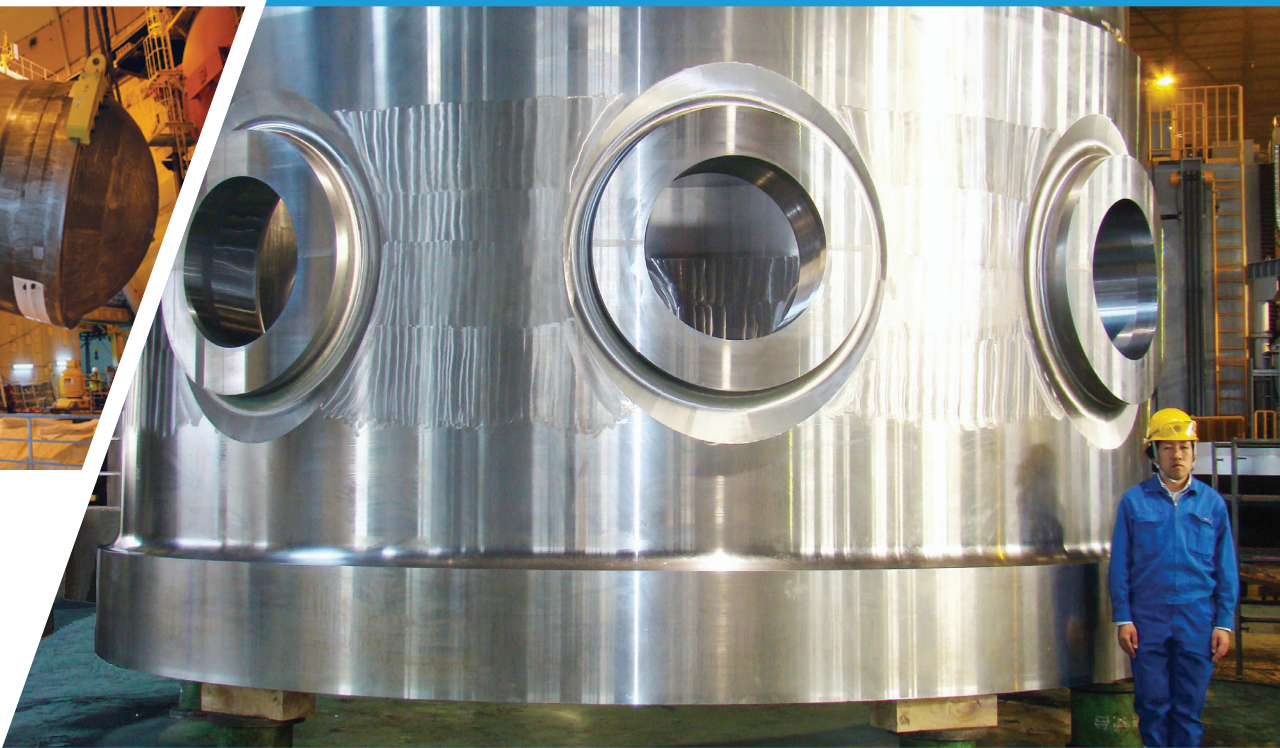

Comparison of Fatigue Life Analysis Methods

Comparison of Pressure Vessel Fatigue Codified Design Rules Based on S-N Approach

Cooperation in Reactor Design Evaluation and Licensing – Mechanical Codes and Standards Task Force

Title: Comparison of Fatigue Life Analysis Methods
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Design Rules Based on S-N Approach
Produced by: World Nuclear Association
Published: June 2020
Report No. 2020/004

Cover photos: EDF; Japan Steel Works M&E, Inc.

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Foreword

The Cooperation in Reactor Design Evaluation and Licensing (CORDEL) Working Group was established in 2007 to promote the development of a worldwide regulatory environment where internationally standardized reactor designs can be widely deployed without major design changes due to national regulations. The Mechanical Codes and Standards Task Force (MCSTF) of the CORDEL Working Group was set up in 2011 to collaborate with the Standards Development Organizations Board (SDO Board) and the Multinational Design Evaluation Program (MDEP) Codes and Standards Working Group (CSWG) on the international convergence of mechanical codes and standards related to the design of nuclear power plant components important to safety. It has worked to date principally in three areas: qualification of non-destructive examination (NDE) personnel; non-linear analysis design rules; fatigue analysis and design rules.

In the area of fatigue analysis and design rules, the topics identified by the MCSTF for investigation with a view to harmonized approaches are: differences in nuclear mechanical design codes; pressure vessel and piping fatigue design approach; fatigue crack growth analysis; and environmental effects on fatigue.

This report, the first of four, reviews and compares the current code and standard requirements of major nuclear design codes in the area of fatigue analysis and design rules based on the S-N approach against ASME III NB. The report focuses on Class 1 vessels of Light Water Reactor (LWR) plants.

The main findings of this report can be summarised as follows:

- The nuclear design codes and standards analysed are equivalent to ASME III NB in most areas.
- The requirements of RCC-M are either the same as - or equivalent to - ASME III NB except in the definition of the fatigue curve, the plasticity correction (K_e) factor, and the method for assessing local structural discontinuities.
- The requirements of KEPIC MN MNB are the same as those of ASME III NB in all areas.
- The requirements of the JSME S NC1 are either the same as - or equivalent to - ASME III NB, except in the definition of the fatigue curve, the plasticity correction (K_e) factor, and the fatigue strength reduction factor (FSRF).

Abbreviations and Acronyms

AFCEN	Association française pour les règles de conception, de construction et de surveillance en exploitation des matériels des chaudières electro-nucléaires (French Association for Design, Construction and In-service Inspection Rules for Nuclear Island Components)
AFNOR	Association française de normalisation (French Association of Standardization)
AIA	Authorized inspection agency
ANI	Authorized nuclear inspector
ASME	American Society of Mechanical Engineers
ASN	Autorité de sûreté nucléaire française (French Nuclear Safety Authority)
ASTM	American Society for Testing and Materials
ISO	International Organization for Standardization
BPVC	Boiler and Pressure Vessel Code
CEA	Commissariat à l'energie atomique (Atomic Energy Commission)
CEN	European Committee for Standardization
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
MDEP	Multinational Design Evaluation Programme
CSWG	MDEP Codes and Standards Working Group (formerly WGCMO)
EBW	Electron beam welding
EN	European norms
ESPN	Equipement sous pression nucléaire (French regulation for pressurized equipment for nuclear applications)
WNA	World Nuclear Association
CORDEL WG	Cooperation in Reactor Design Evaluation and Licensing Working Group (a WNA Working Group)
MCSTF	Mechanical Codes & Standards Task Force (a CORDEL Task Force)
RCC-M	Règles de Conception et de Construction des Matériels Mècaniques des Ilots Nucléaires PWR (in English, "Design and Construction Rules for the Mechanical Components of PWR Nuclear Islands)
JSME	Japan Society of Mechanical Engineers
KEPIC	Korea Electric Power Industry Code
BSI	British Standards Institution
PD	Published document

Technical Nomenclature

CUF	Cumulative usage factor
E	Elastic modulus used in analysis
E_c	Elastic modulus of design fatigue curve
EPP	Elastic-perfectly plastic
FSRF	Fatigue strength reduction factor
K_e	Strain concentration factor
K_n	Notch plasticity adjustment factor
K_v	Poisson's ratio correction factor
K_T	Elastic stress concentration factor
q_p	Elastic follow-up factor
m	Material parameter in ASME K_e equation
n	Strain hardening parameter in ASME K_e equation
N	Number of permissible cycles
SCF	Stress concentration factor
S_a	Stress amplitude
S_{alt}	Alternating stress intensity
S_m	Design stress intensity
S_n	Range of primary plus secondary stress intensity
$S_{n\text{-}tb}$	Range of primary plus secondary stress intensity excluding thermal bending
S_p	Range of primary plus secondary plus peak stress intensity
$S_{p,lt}$	Range of local thermal stress intensity
$S_{p,mech}$	Range of total mechanical stress intensity
$S_{p,ther}$	Range of total thermal stress intensity
S_y	Yield strength
ν, ν_e, ν_p	Poisson's ratio (assuming elastic or plastic behaviour)
UTS	Ultimate tensile strength

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1 Introduction

The CORDEL Mechanical Codes and Standards Task Force (MCSTF) has identified fatigue analysis as an area where important differences exist between the major design codes and standards [1], which is impacting nuclear power plant designs.

In line with its mission of promoting the convergence of requirements, MCSTF has initiated a project in the fatigue analysis area to systematically compare the current methodologies used in major nuclear design codes and standards, identify the best practices and R&D approaches and propose common methods.

As part of this project, four reports/ outputs are proposed:

- Report 1: *Comparison of Pressure Vessel Fatigue Codified Design Rules Based on S-N (cyclic stress versus cycles to failure) Approach*
- Report 2: *Proposed Common/ Harmonized Pressure Vessel and Piping Fatigue Design Rules*
- Report 3: *Proposed Common/ Harmonized Fatigue Crack Growth Analysis*
- Report 4: *Proposed Common/ Harmonized Environmental Effects on Fatigue and Fatigue Crack Growth Analysis*

This first report reviews and compares the current code and standard requirements of major nuclear design codes in the area of fatigue analysis and design rules based on the S-N approach. It focuses on Class 1 vessels of Light Water Reactor (LWR) plants.

2 Scope of Review and Comparison

The comparison undertaken in this report focuses on the codes and standards for Class 1 vessel components of the following major nuclear codes: ASME BPVC Section III NB [2]; AFCEN RCC-M [3]; JSME [4]; and KEPIC [5].

3 Comparison Methodology

3.1 General

As observed in a previous international comparison report [1], JSME, KEPIC, and AFCEN codes were originally developed based on ASME BPVC Section III. Consequently, the ASME BPVC was used as the baseline and the requirements of the codes and standards included in the scope of work were compared with the corresponding ones from the ASME BPVC Section III.

Based on these, a high-level comparison structure was developed, as shown in Table 3-1. For each standard listed in this table (right-hand side column), a line-by-line comparison with the requirements of the corresponding sections of the ASME BPVC was carried out, where possible. When specific requirements in the codes and standards included in the scope of work referenced other codes or standards (e.g. ASTM or ISO standards for material specification or mechanical testing methods), the referenced standard is noted but the comparison did not extend to the detailed requirements of the reference standards, unless these could be readily compared.

Table 3-1: Schematic representation of code comparison for fatigue life analysis of nuclear mechanical design codes applicable to low-temperature facilities (BWRs/PWRs)

Baseline code (ASME BPVC)	Codes to be compared		
Section III, Division 1, Subsection NB	RCC-M B	JSME S-NC-1	KEPIC MNB

The corresponding requirements were then evaluated according to the comparison scale described in Section 3.2.

3.2 Comparison Scale

The comparison scale used in this report and in the appendices is described below. This is based on the scale used for the MDEP comparison project, which was modified to address more specifically the cases in which significant differences between codes or standards requirements were identified.

A1 = Same

Requirements classified as category A1 are considered to be technically identical. Requirements are classified as category A1 and considered to be the same even if there are inconsequential differences in wording, such as might result due to translation from one language to another, as long as the wording does not change the meaning or interpretation of the requirement. Likewise, differences in paragraph numbering are not considered when classifying requirements as long as the same requirement exists in both codes being compared.

A2 = Equivalent

Requirements are considered to be equivalent when applying either code or standard, if compliance with the applied code or standard will also meet the requirements of the other code or standard. Equivalence is not affected by differences in level of precision of unit conversions

B1 = Different – Not Specified

Requirements are considered to be different – not specified, if one code or standard includes requirements that the compared code or standard does not specify. This classification may result because of differences in the scope of equipment covered by a respective code, the scope of industrial practices applied in the context of the respective code, differences in regulatory requirements applicable in conjunction with application of a particular code, or simply as a result of differences in requirements addressed in one code versus those in another.

B2 = Technically Different

Requirements are considered to be technically different if either code requires something more or less than, or otherwise technically different from, the requirements imposed by the other. These differences might be due to different technical approaches applied by a code or imposition of regulatory requirements within the country from which a code originates.

4 Comparison

4.1 Highlights of the Various Codes

4.1.1 ASME Section III NB

ASME Section III NB covers the requirements, methods and procedures for fatigue assessment of Class 1 pressure retaining components (pressure vessel and piping, valve bodies) subject to cyclic loads under temperatures up to the limits above which creep effects must be considered. Table 4-1 summarises the major items relevant to fatigue assessment required by Section III NB.

The relevant descriptions of fatigue assessments are dispersed through the whole Section III NB and Section III Appendices, Mandatory Appendix I, but Appendix XIII-3500 is the main place where a variety of fatigue assessment aspects are discussed.

Appendix XIII-3510 stipulates six conditions which must all be met by the specified service loading of a component for which a fatigue analysis is not required. The six loading conditions cover:

- Atmospheric to service pressure cycle;
- Normal service pressure fluctuation;
- Temperature difference — startup and shutdown;
- Temperature difference — normal service;
- Temperature difference — dissimilar materials;
- Mechanical loads.

The procedure for analysis for cyclic loading is detailed in Appendix XIII-3520, which covers six aspects:

- Stress differences;
- Local structural discontinuities;
- Crack-like defects;
- Design fatigue curves;
- Effect of elastic modulus;
- Cumulative damage.

The procedure of Appendix XIII-3520 is stress-based (associated artificially to strain amplitude), with alternating stress intensity calculated according to the Tresca theory of failure and on the assumption of elastic behaviour (Appendix XIII-3500 (c)). To account for the potential enhancement of strain range not captured in the elastic analysis, a plasticity correction factor, K_e, is used to correct the alternating stress in the low-cycle regime to ensure conservatism. This is the objective of Simplified Elastic-Plastic Analysis described in ASME III Appendix XIII-3450, which provides separate expressions for calculation of K_e for carbon steels, low-alloy steels, and austenitic stainless steels/nickel-chromium-iron alloys. K_e varies as a function of the primary plus secondary stress intensity range, S_n, and applies when S_n exceeds the $3S_m$ limit, which is indicative of gross section plastic cycling. Figure 8-1 (Appendix C) shows the Appendix XIII-3450 K_e vs S_n/S_m plasticity correction curves for each material class. The maximum possible Ke penalty is 5 for carbon and low-alloy steels, and 3.33 for austenitic stainless steels and nickel-chromium-iron alloys. Whilst straightforward to apply, the ASME III Appendix XIII-3450 Ke is widely acknowledged as excessively conservative, and this is supported by results obtained from elastic-plastic finite element (FE) analysis (Figure 8-10, Appendix C) of typical thermal transients.

ASME III Appendix XIII-2500 also details how a different value of Poisson's ratio should be used in cases where the maximum stress range exceeds the yield strength of the material. This correction is used to account for surface plasticity effects due to the change in Poisson's ratio assuming plastic incompressibility and a biaxial state of stress. The Poisson's ratio correction applies only to the local thermal stress range, and the magnitude of the correction varies according to the number of design cycles of the component. For low-cycle fatigue, the modified Poisson's ratio approaches 0.5, and for a high number of cycles it approaches its elastic value of 0.3. Appendix XIII-3450 and Appendix XIII-2500 are mutually exclusive – if K_e is invoked, then the Poisson's ratio correction is not required.

The effect of a local structural discontinuity (*e.g.* notches and welds) on fatigue strength is accounted for by a fatigue strength reduction factor (FSRF), defined by Appendix XIII-1300 (g). The FSRF varies with the level of severity of local structural discontinuity, though is generally less than 5 (per Appendix XIII-3520 (b)). NB-3352.2 indicates, for instance, that for welded joints of Category B, a FSRF of no less than 2 should be used in an Appendix XIII-3500 fatigue assessment. ASME III therefore does provide some guidance on the minimum FSRF required for specific geometries. Otherwise, the appropriate FSRF may be obtained from the component design specification or derived based on analyst engineering judgement.

The design fatigue curves presented in Mandatory Appendix I were obtained from strain-controlled fatigue tests as strain amplitude vs life curves which were subsequently adjusted using design factors and formally converted to pseudo-stress amplitude vs. life curves by multiplying the applied elastic-plastic strains by a reference modulus of elasticity, E_c, which is representative of the elastic behaviour of that material. The value of E_c is essentially arbitrary, and is only relevant as far as it facilitates the transformation of strains to generate the pseudo-stress-based fatigue curves. Any E_c value could be chosen so long as the pseudo-stress amplitude values are adjusted to be consistent with the actual values of strain amplitude applied during testing. The design fatigue curves for carbon and low-alloy steels, and austenitic stainless steels/nickel-based alloys are specified in Figures I-9.1-M and I-9.2M of ASME Section III, Appendix I, respectively. These are shown in Figure 7-1 (Appendix B). Two separate curves are specified in Figure I-9.1M for carbon and low-alloy steels, which correspond to different ranges of ultimate tensile strength of the material. Interpolation is permitted between curves where the strength level falls between these two ranges (Appendix XIII-3520 (c)). When determining the permissible number of cycles at an alternating stress level that falls between tabular values, Appendix I permits the use of logarithmic interpolation.

The procedures of ASME III Subsection NB summarised above are intended for application to fatigue design below the creep regime. They are limited to use at temperatures of 370°C and below for ferritic materials, and 425°C and below for austenitic materials. For design above these temperatures (*i.e.* where creep effects may be significant), the elevated temperature service rules outlined in ASME Section III, Division 5 [6] are applicable. These rules are beyond the scope of this report.

4.1.2 RCC-M

RCC-M, paragraph B 3200 covers the requirements applicable to the analysis of the behaviour of Class 1 pressure-retaining components. The requirements pertinent to Level A Service Loadings requiring fatigue analysis are detailed in paragraph B 3234. The design fatigue curves for the different classes of materials are specified in Annex ZI 4.0.

For locations excluding local discontinuities, assurance against fatigue initiation is achieved by satisfying the requirements of B 3234.5, which provides a systematic procedure for the analysis of fatigue at a point using elastic stress analysis with corrections to account for plasticity. The procedure has its roots heavily based on ASME III, though there has been some divergence since its inception.

Most notably, B 3234.6 includes separate expressions for determination of mechanical (K_e^{mech}) and thermal (K_e^{ther}) plasticity correction factors applicable to austenitic stainless steels and nickel-chromium-iron alloys. K_e^{mech} is equivalent to the ASME III Appendix XIII-3450 K_e. K_e^{mech} and K_e^{ther} are applied respectively to the mechanical and thermal contributions to the overall stress range. This is different to ASME III Appendix XIII-3450, which does not distinguish between mechanical and thermal stresses when applying K_e. Figure 8-5 (Appendix C) shows the comparison between the RCC-M K_e^{mech} and RCC-M K_e^{ther} plasticity correction curves vs S_n/S_m. The RCC-M K_e^{ther} is considerably less conservative than the ASME III Appendix XIII-3450 K_e for the case of high thermal stress. RCC-M B 3234.6 also does not explicitly differentiate between sectional and surface plasticity, and does not prescribe any separate Poisson's ratio correction similar to ASME III Appendix XIII-2500. However, since K_e^{ther} is applicable beyond a much lower threshold of $S_n \geq 0.51S_m$, it achieves the purpose of also accounting for surface plasticity effects where $S_n \leq 3S_m$. Both of these observations are confirmed from the results of elastic-plastic FE analysis (Figure 8-10 in Appendix C), which shows the RCC-M K_e^{ther} to be conservative by a factor of 1.2x to 1.4x, with the highest conservatism observed for $S_n < 3S_m$. It is concluded that RCC-M and ASME III NB show a significant difference in methodology for treatment of cyclic plasticity effects in austenitic stainless steels and nickel-chromium-iron alloys.

RCC-M B adopts a novel assessment procedure based on the theory of critical distances for assessing local structural discontinuities. However, it does permit the application of experimentally determined FSRFs in B 3234.5 as an alternative, so long as appropriate justification is provided. For the assessment of local discontinuities, acceptable alternative rules are provided in RCC-M Annex ZD to be applied in lieu of B3234.5. In the procedure of Annex ZD 2000, local discontinuities are treated as crack-like defects, and the severity of fatigue damage is dictated by the elastic stress range calculated at a small (critical) distance from the fictitious crack-tip. To determine the number of allowable cycles, Annex ZD 2300 provides a set of experimentally derived initiation curves for low-alloy steels (16MND5), stainless steels, and nickel-chromium-iron alloys (Figure 7-5 in Appendix B). Alternatively, the applicable design fatigue curves of Annex ZI 4.0 may be used, where the local strain amplitude for entering the fatigue curve is estimated by Neuber's rule. The RCC-M approach for analysing fatigue at local discontinuities is fundamentally different to ASME III NB.

Concerning the design fatigue curves of Annex ZI 4.0, there are some notable differences in comparison to ASME III, Mandatory Appendix I. Figure 7-2 (Appendix B) shows the Annex ZI 4.0 design fatigue curves for carbon and low-alloy steels (RCC-M Figure ZI 4.1) and austenitic stainless steels (Figure ZI 4.2), presented in terms of strain amplitude vs permissible cycles. The clearest difference is that Annex ZI 4.0 curves are only defined in the range of 10^1-10^6 cycles, whereas the ASME III curves are extended in the high-cycle regime up to 10^{11} cycles. As shown by Figure 7-3 (Appendix B), the Figure ZI 4.1 fatigue curves for carbon and low-alloy steels are very similar to the Figure I-9.1M curves defined in ASME III, albeit with a small difference in the range of ultimate tensile strength of the material to which the curves apply. On the other hand, Figure 7-4 (Appendix B) shows that the Figure ZI 4.2 fatigue curve for austenitic stainless steels and nickel-based alloys is quite different to its ASME III counterpart prescribed in Figure I-9.2M. In the very low-cycle regime (approximately <300 cycles), the Figure ZI 4.2 fatigue curve is more conservative. However, both curves cross at around 300 cycles, beyond which the Figure I-9.2M fatigue curve becomes increasingly conservative relative to the Figure ZI 4.2 fatigue curve. RCC-M Annex ZI 4.0 also specifies the use of logarithmic interpolation to determine the permissible number of cycles at intermediate stress levels, which is the same as ASME III, Mandatory Appendix I.

4.1.3 JSME

The Japan Society of Mechanical Engineers (JSME) Rules on Design and Construction for Nuclear Power Plants (Division I, Light Water Reactor Structural Design Standard, JSME S-NC-1), contains provisions for fatigue analysis of Class 1 pressure-retaining components in PVB-3000. Overall, the fatigue analysis requirements of JSME are generally similar to ASME III NB, though a number of notable differences exist, especially concerning the K_e factor.

The JSME K_e factor specified in PVB-3315 was originally developed by the Thermal and Nuclear Power Engineering Society (TENPES) in Japan. It has a different technical basis and is more mathematically complex than ASME III NB. The JSME K_e factor is based on the elastic follow-up concept, and was derived based on the results obtained from a series of FE analyses conducted on representative plant structures using elastic-perfectly-plastic (EPP) material properties. The JSME K_e is calculated from a series of formulae, which describe different curve-fits ($K_{e,A0}$ and K_e') that vary depending on the loading condition. Figure 8-6, Figure 8-7, and Figure 8-8 (Appendix C) show the comparison between the JSME PVB-3315.1 and ASME III Appendix XIII-3450 K_e vs. S_n/S_m plasticity correction curves for carbon steel, low-alloy steel, and austenitic stainless steel, respectively. It is observed that the JSME K_e is generally less conservative, with the exception of the discontinuity induced at $S_n=3S_m$. For cases of peak stress concentration (*e.g.* notches, high local thermal stresses, *etc.*) at, or slightly above, the $3S_m$ limit, the JSME K_e is more conservative. The JSME K_e was originally developed with this situation in mind, where the ASME III Appendix XIII-3450 K_e has previously been found to be not fully conservative. Based on the results of elastic-plastic FE analysis (Figure 8-10, Appendix C), the JSME K_e was found to be conservative by a factor of 1.2x to 1.7x for $S_n \geq 3S_m$; interestingly, the degree of conservatism increases with increasing S_n/S_m.

The JSME Code also includes a Code Case entitled "NC-CC-005: Alternative Structural Evaluation Criteria for Class 1 Vessels Based on Elastic-Plastic Finite Element Analysis", which includes expressions for an alternative plasticity correction factor, denoted K_e''. K_e'' varies as a function of the total stress range, S_p, and elastic follow-up factor, q_p, and can be applied directly on the surface of a component without stress linearization. Figure 8-9 (Appendix C) shows the NC-CC-005 K_e'' vs. S_p/S_m plasticity correction curve. By the default approach, the value of q_p is set so as to bound the results obtained for all FE models used in deriving K_e'. It is therefore more conservative than K_e' and can still apply for $S_n < 3S_m$. As shown from the results obtained from elastic-plastic FE analysis (Figure 8-10), K_e'' is about 1.3x to 1.5x more conservative than K_e', but is still less conservative than ASME III Appendix XIII-3450. NC-CC-005 recommends that q_p be determined from the actual K_e determined by elastic-plastic analysis, so as to enable derivation of more accurate K_e'' expressions for different structures. The K_e methodology of JSME PVB-3315 and NC-CC-005 are therefore concluded to be fundamentally different to ASME III NB.

4.1.4 KEPIC

South Korean fatigue requirements are specified in KEPIC MN MNB for below creep regime and MNH for high temperature structures, respectively.

4.2 Summary of Comparison Results

The comparison results between ASME III NB and RCC-M, JSME S NC1, and KEPIC MN MNB are summarised in Table 4-1.

Table 4-1. Summary of Comparison Results with ASME Section III, Division 1, Subsection NB

Code/Standard	Temperature Limit, °C	Applicable Materials	Stress	Effect of Elastic Modulus	Cumulative Usage	Plasticity, K_e	Design Curve	FSRF
ASME III, NB	370	Carbon, low alloy and high tensile steels	Amplitude	Y	Miner's rule	Y	Y	Y
	425	Austenitic steels, nickel-chromium-iron alloy, nickel-iron-chromium alloy and nickel-copper alloy	Amplitude	Y	Miner's rule	Y	Y	Y
RCC-M	A2	A2	A1	A1	A1	B1	A1 for ferritic A2 for austenitic	A2
JSME S NC1	A2	A2	A1	A2	A1	B2	A2	B2*
KEPIC MN MNB	A1	A1	A1	A1	A1	A1	A1	A1

*Currently not enough details regarding the difference in FSRF requirements

5 Concluding remarks

This report has made a detailed comparison between ASME Section III, Subsection NB with other Nuclear Pressure Vessel and Piping Design Codes and Standards applicable to LWR plants.

It can be seen from Table 4-1 that:

- In general, other LWR Design Codes and Standards are equivalent to ASME III NB in most areas.
- The requirements of RCC-M are either the same as or equivalent to ASME III NB in the majority of areas, except the definition of the fatigue curve, plasticity correction (K_e) factor, and method for assessing local structural discontinuities.
- The requirements of South Korean KEPIC MN MNB are the same as those of ASME III NB in all areas.
- The requirements of JSME S NC1 are either the same as or equivalent to ASME III NB, except the definition of the fatigue curve, the plasticity correction (K_e) factor, and fatigue strength reduction factor (FSRF).

6 Appendix A - Comparison tables

The comparison between ASME Section III, Division 1, Subsection NB with other Codes/Standards applicable to LWR plants are presented in the following tables:

Nuclear Codes and Standards Applicable to Light-Water Reactors (BWRs/PWRs)

Table 6-1: Comparison of ASME Section III, Division 1, Subsection NB with RCC-M

Table 6-2: Comparison of ASME Section III, Division 1, Subsection NB with JSME S NC1

Table 6-3. Comparison of ASME Section III, Division 1, Subsection NB with KEPIC MN MNB

6.1 Comparison of ASME Section III Division 1, Subsection NB with RCC-M

Table 6-1. Comparison of ASME Section III, Division 1, Subsection NB with RCC-M

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
		Scope of applicability			
NB-1120	The temperature limits for application of the procedures are prescribed, that is, fatigue design curves and specified methods for fatigue analysis are not applicable above 370°C for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.4, and above 425°C for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.2 and I-9.3.	Annex ZI: Tables ZI 1.0-1.3 Figures ZI 4.1-4.3	The temperature limit is 370°C for carbon and low alloy steels. In B 3234.6, the table shows a temperature of 430°C for austenitic stainless steel and nickel-chromium-iron alloy. "B 3000 recommendations assume that creep phenomenon's can be neglected. It is the case when the material temperature doesn't exceed the limit temperature indicated in tables ZI 1.0 to ZI 3.0. If the material should be used above these ranges of temperatures, a supplementary assessments of potential creeps hazards should be performed in addition to recommendation of present subsection".	A2	
Appendix I NB-1120	The fatigue design curves are applicable to the following materials: • Carbon, low alloy and high tensile steels with UTS ≤ 552MPa or between 793MPa and 896MPa, E = 207x10³MPa and temperature ≤ 370°C; • Austenitic steels, nickel–chromium–iron alloy, nickel–iron–chromium alloy and nickel–copper alloy with temperature ≤ 425°C (UTS limits not specified) and E = 195x10³MPa.	Annex ZI: ZI 4.0	The fatigue design curves are applicable to the following materials: • Carbon, low alloy steels with UTS ≤ 550MPa or between 790MPa and 900MPa; for 550MPa ≤ UTS ≤ 790MPa, interpolate; E = 207x10³MPa* • Austenitic steels and Nickel alloys with E = 179x10³MPa.	A2	A comparison of E_c is irrelevant, and it is the underlying strain amplitude vs cycles that is more appropriate for comparison. These strain-based curves are included in Appendix A1 for reference.
		Assessment methods, procedures and conditions			
Appendix XIII-2400	The determination of stress differences shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point.	B 3231.5	Peak stress is therefore taken into account only when fatigue or fast fracture is considered. In fact, it is the total stress at a given point resulting from all applied loads which are taken into account in the determination of resistance to fatigue and fast fracture.	A2	
Appendix XIII-3500	The assessment conditions and procedures for analysis for cyclic operation are presented in this subparagraph.	B 3234.5	Analysis of fatigue behaviour in zones with no geometrical discontinuities.	A2	

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
	The conditions and procedures are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I.		The resistance to fatigue of a component subjected to fluctuations of mechanical or thermal loads over time shall be verified in accordance with the rules in b) and c)…or by experimental analysis in accordance with annex Z II. Acceptance criteria shall be verified at every point for all the conditions specified requiring compliance with level A criteria.		
Appendix XIII-3500(c)	The fatigue curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behaviour and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero.	B 3234.5 (b)	These curves give the allowable S_a value for the alternating stress intensity S_{alt} as a function of the number of cycles. The range of total stresses is calculated assuming elastic behaviour of the material and thus has the dimension of stress. It does not represent a real stress when the yield strength is exceeded. The fatigue curves in Annex ZI are derived from uniaxial strain cycling tests, the imposed strains being multiplied by the modulus of elasticity E_c for which the value is set for each curve to obtain stresses. These curves are applicable whatever the average stresses around which the stress considered varies.	A2	
Appendix XIII-3510	The conditions are prescribed for components not requiring analysis for cyclic service.				
Appendix XIII-3520(c)	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.	B 3234.5 b)	When several fatigue curves are presented for a given material, the annex specifies the applicability of each curve to materials of various strength levels. The strength level is the specified minimum room temperature value.	A1	

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
Appendix XIII-3520(d)	Effect of elastic modulus is accounted for by multiplying S_a by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis.	B 3234.5 c) 1) b)	$[S'_{alt}(1)]_{pq} = E_c/E\ [S_{alt}(1)]_{pq}$ with: E_c =Modulus of elasticity associated with the fatigue curve of the material. E=Modulus of elasticity used to determine the stresses.	A1	
Appendix XIII-3520(e)	If there are two or more types of stress cycle which produce significant stresses, the cumulative usage factor accounting for these individual loadings is evaluated with Miner's rule (*i.e.* linear summation of the individual fatigue damage), and it shall not exceed 1.0.	B 3234.5 (c) 1) f)	The cumulative usage factor is equal to the sum of the usage factors determined using the procedure above. The cumulative usage factor shall be less than 1.	A1	
Appendix XIII-3600(e)	Tests, with the exception of the first 10 hydrostatic tests in accordance with NB-6220, the first 10 pneumatic tests in accordance with NB-6320, or any combination of 10 such tests, shall be considered in the fatigue evaluation of the component. In the fatigue evaluation, the limits on the primary plus secondary stress intensity range may be taken as the larger of $3S_m$ or $2S_y$ when at least one extreme of the stress intensity range is determined by the Test Loadings.	B 3237 (d)	The first 10 test conditions that are conducted may not be considered in the fatigue analysis. Test conditions are the regulatory hydrostatic tests (B 3126).	A2	
Appendix XIII-2500	Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on the primary plus secondary stress intensity of $3S_m$ (see Appendix XIII-3420) has been placed at a level that ensures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation.	B 3231.4	The verification of primary and secondary stress criteria in conjunction with the application of the rule on thermal ratchet provides protection against progressive deformation and ensures the confinement of plastic deformation concentration zones. The amplitude of local deformations imposed on these zones is then controlled by surrounding material which is subjected to elastic cycling conditions. This validates the methods used in the elastic analysis of the resistance of components to fatigue.	A2	
Appendix XIII-3500 (c)	The stress intensity amplitude is calculated on the assumption of elastic behaviour and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded.	B 3234.5 (b)	The range of total stresses is calculated assuming elastic behaviour of the material and thus has the dimension of a stress. It does not represent a real stress when the yield strength is exceeded.		

<table>
<tr><th colspan="2">ASME Section III NB</th><th colspan="2">RCC-M</th><th>Comparison</th><th>Comments</th></tr>
<tr><th>Reference</th><th>Description</th><th>Reference</th><th>Description</th><th></th><th></th></tr>
<tr>
<td>Appendix
XIII-3450</td>
<td>In accordance with the simplified elastic-plastic analysis rule given in this subparagraph, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided that the requirements below are met:
• The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be ≤ $3S_m$.
• the value of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where
$$K_e = \begin{cases} 1.0 & if\ S_n \leq 3S_m \\ 1.0 + \frac{1-n}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right) & if\ 3S_m < S_n < 3mS_m \\ \frac{1}{n} & if\ S_n \geq 3mS_m \end{cases}$$
The values of the material parameters m and n for the various classes of permitted materials are as given in Table XIII-3450-1.

Table XIII-3450-1
<table>
<tr><th>Materials</th><th>m</th><th>n</th><th>T_{max} (°C)</th></tr>
<tr><td>Carbon steel</td><td>3.0</td><td>0.2</td><td>370</td></tr>
<tr><td>Low alloy steel</td><td>2.0</td><td>0.2</td><td>370</td></tr>
<tr><td>Martensitic stainless steel</td><td>2.0</td><td>0.2</td><td>370</td></tr>
<tr><td>Austenitic stainless steel</td><td>1.7</td><td>0.3</td><td>425</td></tr>
<tr><td>Nickel-chromium-iron</td><td>1.7</td><td>0.3</td><td>425</td></tr>
<tr><td>Nickel-copper</td><td>1.7</td><td>0.3</td><td>425</td></tr>
</table>
Note: T_{max} is the maximum metal temperature.</td>
<td>B3234.3
B3234.6</td>
<td>The criteria in B3234.2 concerning the limit on the range of primary plus secondary stresses may be exceeded if the requirements below are met:
• The S_n* range determined in accordance with B3232.7 from the sum of the primary plus secondary stresses, excluding thermal bending stresses, is limited to $3S_m$. (i.e. $S_n^* \leq 3S_m$)
• The requirements in B3234.8 relative to thermal ratchet shall be met.
• The operating temperature shall not exceed the maximum values for which the elastoplastic strain correction factors are defined in B3234.6.
• The ratio of the specified minimum value of the yield strength over the specified minimum value of the tensile strength of the material shall be less than 0.8; values for yield strength and tensile strength are taken at room temperature.

The application of this rule corresponds in every case to the introduction of an elastoplastic strain correction factor, K_e (per B3234.6), greater than 1.0 into the fatigue analysis.

a. The elastoplastic strain correction factor dealt with in B 3234.3 and B 3234.5 is defined as being the ratio of the real strain amplitude over the theoretical strain amplitude determined by elastic analysis.
b. An acceptable value for this factor K_e value can be determined using the following procedure:

The fictitious transients (1) and (2) covered in B 3234.5.c.1.a can be replaced by transients calculated from the extreme values of $S_{p,mech}$ and $S_{p,ther}$ during the situation, or by transients calculated from the values $S_{p,mech}$ and S_p,ther at the instants which increase the value of S_{alt} below.</td>
<td>B1</td>
<td>RCC-M K_e methodology differs on a fundamental level, with a different technical basis (see Welding Research Council (WRC) Bulletin 361)

RCC-M $K_{e,mech}$ is equivalent to ASME III Appendix XIII-3450 K_e, but applies only to total surface stresses arising due to mechanical actions.

RCC-M $K_{e,ther}$ applies only to total surface stresses arising due to thermal actions. $K_{e,ther}$ varies between 1.0 and 1.86, and is applicable for S_n exceeding $0.51S_m$. $K_{e,ther}$ does not distinguish between surface and sectional plasticity.</td>
</tr>
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<tr><th colspan="2">ASME Section III NB</th><th colspan="2">RCC-M</th><th>Comparison</th><th>Comments</th></tr>
<tr><th>Reference</th><th>Description</th><th>Reference</th><th>Description</th><th></th><th></th></tr>
<tr><td></td><td>• The rest of the fatigue evaluation stays the same as required in XIII-3500, except that the procedure of XIII-2500 need not be used.
• The component meets the thermal ratcheting requirement of XIII-3430.
• The temperature does not exceed those listed in Table XIII-3450-1 for the various classes of materials.
• The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.</td><td></td><td>The value S_{alt} covered in B 3234.5.c.1.b takes the following value:

$[S_{alt}(1)]_{pq} = 0.5 \max_{ij} (K_{e\ mech})_{pq} (S_{p\ mech}(1))_{ij} + (K_{e\ ther})_{pq} (S_{p\ ther}(1))_{ij}$

where:

$(S_{p\ mech}(1))_{ij}$: range of the mechanical part of the stresses $(S_p(1))_{ij}$, between the two instants i and j or the maximum value of this mechanical part during the transient. It is calculated from the loads of mechanical origin comprising pressure, weight, earthquake (inertial and movement of anchors), as well as the effect of thermal expansion.

$(K_{e\ mech})_{pq}$: elastoplastic stress correction factor for the mechanical part calculated from the maximum range S_n of the three differences of linearized stresses during the whole of the two situations p and q, defined in compliance with B 3234.2.

$K_{e,mech}$ is equivalent to the ASME III, Appendix XIII-3450 K_e factor, where m and n are provided in the following table and are essentially equivalent to ASME III, Table XIII-3450-1:

Materials / *m* / *n* / T_{max} (°C)
Low alloy steel / 2.0 / 0.2 / 370
Martensitic stainless steel / 2.0 / 0.2 / 370
Carbon steel / 3.0 / 0.2 / 370
Austenitic stainless steel / 1.7 / 0.3 / 430
Nickel-chromium-iron alloy / 1.7 / 0.3 / 430

Note: T_{max} is the maximum metal temperature.</td><td></td><td></td></tr>
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<tr><th colspan="2">ASME Section III NB</th><th colspan="2">RCC-M</th><th>Comparison</th><th>Comments</th></tr>
<tr><th>Reference</th><th>Description</th><th>Reference</th><th>Description</th><th></th><th></th></tr>
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$(S_{p\ ther}\ (1))_{ij}$: range of the thermal part of the stresses $(S_p\ (1))_{ij}$, between the two instants i and j or the maximum value of this thermal part during the transient. It is calculated from the loads of thermal origin comprising those of temperature gradients in the walls and the temperature variations on either side of thickness and material discontinuities. It is acceptable to take as the value of $S_{p\ ther}$, the difference between the total S_p and $S_{p\ mech}$ adopted above.

$(K_{e\ ther})_{p,q}$: elastoplastic stress correction factor for the thermal part, calculated in the case of austenitic stainless steels and nickel-chromium-iron alloys, by the following formula:

$$K_{e,ther} = max\left(1.0,\ 1.86\left[1 - \frac{1}{1.66 + \frac{S_n}{S_m}}\right]\right)$$

from the maximum range S_n of the three differences of linearized stresses during the whole of the two situations p and q, defined in compliance with B 3234.2.

For ferritic steels, the formula used shall be validated on a case by case basis.

It is acceptable not to impose a mechanical/thermal division but to apply the expression of the factor $K_{e\ mech}$ for correction of the total stress S_p.

An upper limit on the global effect of plastic stress corrections can be introduced if the results of

</td><td></td><td></td></tr>
</table>

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
			elastoplastic studies are available, obtained for similar geometric configurations subjected to envelope transients and loads, increasing the loads and transients taken into account in the behaviour analyses.		
Code Case N-779	Alternative Rules for Simplified Elastic-Plastic Analysis Class 1 Section III, Division 1 The $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided the following requirements are met: • The requirements of subparagraphs (a), (b), (c), (d), (e), and (f) of Appendix XIII-3450 are satisfied. • The value of the stress amplitude, S_a, for entering the design fatigue curve is one-half of the stress intensity range calculated by the combination of terms in (3), (4), and (5) given below. • The total stress intensity range, excluding both thermal bending stresses caused by linear through-wall thermal gradients and local thermal stresses, is multiplied by the K_e factor defined in Appendix XIII-3450 (b). • The local thermal stress range (as defined in Appendix XIII-1300 (aj) (2)) is multiplied by a Poisson's ratio correction factor, K_v, where $K_v = \begin{cases} 1.0 & if\ S_p \leq 3S_m \\ 1.0 + 0.4\dfrac{S_p - 3S_m}{S_{n,tb+lt}} & if\ S_p > 3S_m\ and\ S_{p-lt-tb} < 3S_m \\ 1.4 & if\ S_p > 3S_m\ and\ S_{p-lt-tb} \geq 3S_m \end{cases}$ S_p = total stress intensity range	B3234.6		B1	

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
	S_{tb+lt} = thermal bending plus local thermal stress intensity range $S_{p-tb-lt}$ = total stress intensity range excluding thermal bending and local thermal stresses • The thermal bending stress range caused by linear through-wall thermal gradients is multiplied by the product of K_v and a notch plasticity adjustment factor, K_n, where $$K_n = \begin{cases} 1.0 & if\ S_{p-lt} \leq 3S_m \\ 1.0 + \left[\left(\frac{S_{p-lt}}{S_n}\right)^{\frac{1-n}{1+n}} - 1\right]\frac{S_{p-lt} - 3S_m}{S_{p-lt}} & if\ S_{p-lt} > 3S_m \end{cases}$$ and $K_n K_v \leq K_e$ S_{p-lt} = total stress intensity range less local thermal stresses S_n = primary plus secondary stress intensity range n = strain hardening exponent from Table XIII-3450-1 • As an alternative to (2) through (5) above, an alternative plasticity correction factor, K_e', may be determined directly from an elastic-plastic analysis of the component for the load case under consideration, where K_e' is defined as the ratio of the numerically maximum principal strain from the plastic analysis to that from the elastic analysis. K_e' may then be applied to other load cases for which the elastically calculated stress is less than or equal to the elastic stress range of the load case used to derive K_e'. The value of S_a used for entering the design fatigue curve is multiplied by K_e'.				

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
Proposed Code Case [Record 17-225]	A new Code Case for ASME BPVC Section III, Division I, Alternative Rules for Simplified Elastic-Plastic Analysis has recently been approved by the ASME Board on Nuclear Codes and Standards (BNCS). The proposed Code Case has been discussed extensively within the relevant standards committees, and important technical comments have been addressed. It is expected that this new Code Case will be published in the near future. Like RCC-M, the proposed Code Case is also based on WRC-361, using a weighted average approach for stresses arising due to thermal and mechanical loads. A summary of the proposed Code Case is given in full below, and shares the same preconditions as Appendix XIII-3450: The $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided that: • The primary plus secondary membrane plus bending stress intensity, less the contribution of thermal bending stresses, shall be $\leq 3S_m$. • The value of alternating stress for entering the design fatigue curve, S_a, is multiplied by a correction factor, K_e^R: $K_e^R = \begin{cases} 1.0 & if\ S_n \leq 3S_m \\ min[K_e R + K_{th}^R(1-R)K_n^R, K_e] & if\ 3S_m < S_n \leq 3mS_m \\ min\left[K_e R^* + K_{th}^R(1-R^*)K_n^R, \frac{1}{n}\right] & if\ S_n > 3mS_m \end{cases}$ where K_e is the Appendix XIII-3450(b) plasticity correction factor; K_{th}^R is a thermal-plastic correction factor corresponding to the maximum possible Poisson's ratio correction factor of 1.4, assuming fully-plastic behaviour; R defines the relative contribution of the range of	B3234.6		B1	The Ranganath and RCC-M approaches are both based on WRC-361, this makes a direct comparison possible. Overall, the two methodologies are similar in their separation of mechanical and thermal stresses. However, the proposed ASME Code Case treats the range of thermal membrane stress intensity as primary, and it is combined with the remaining mechanical stress range and multiplied by the much more conservative Appendix XIII-3450 K_e factor, while RCC-M simply separates the total mechanical and thermal stresses and does not consider stress categorisation here. The other methodological difference is that Ranganath's method now incorporates a Neuber notch

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
	membrane plus bending stress intensity, less thermal bending stresses, to the range of primary plus secondary stress intensity; and R* represents the range of membrane plus bending stress intensity, excluding thermal bending stresses, normalised by $3mS_m$: $$K_{th}^R = \frac{1 - v_e}{1 - v_p} \cong \frac{0.7}{0.5} = 1.4$$ $$R = \frac{S_{n-tb}}{S_n}$$ $$R^* = \frac{S_{n-tb}}{3mS_m}$$ K_n^R is a Neuber notch correction factor, intended to account for additional plastic strain concentration at local discontinuities under globalized plasticity: $$K_n^R = K_T^{\frac{1-n}{1+n}}$$ Where K_T is the stress concentration factor based on elastic analysis. In the above equations, the material parameters m and n are the same as those given in Table XIII-3450-1. • The rest of the fatigue evaluation remains the same as required in XIII-3500, except that the procedure of XIII-2500 need not be used. • The component satisfies the thermal stress ratchet requirements of XIII-3430. • The temperature does not exceed those listed in Table XIII-3450-1 for the various classes of materials.				correction factor, K_n^R. RCC-M does not explicitly consider notch effects in the B 3234.6 K_e methodology.

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
			Design fatigue curve		
Appendix XIII-3500(c) Appendix I	The design fatigue curves, which are stress-based, show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles.	B 3234.5 (b) Annex ZI	The design fatigue curves give the allowable S_a value for the alternating stress intensity S_{alt} as a function of the number of cycles. The range of total stresses is calculated assuming elastic behaviour of the material and thus has the dimension of a stress. It does not represent a real stress when the yield strength is exceeded.	A2	Fatigue curves defined in RCC-M annex ZI are different to the ones defined in ASME.
Appendix XIII-3500(c)	The design fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress.	B 3234.5 b)	RCC-M 2018 The fatigue curves in Annex ZI are derived from strain cycling tests, the imposed strains being multiplied by the modulus of elasticity E_c for which the value is set for each curve to obtain stresses. These curves are applicable whatever the average stresses around which the stress considered varies.	A2	Fatigue curves defined in RCC-M annex ZI are different to the ones defined in ASME.
Appendix XIII-3520(c)	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.	B 3234.5 b)	When several fatigue curves are presented for a given material, the annex specifies the applicability of each curve to materials of various strength levels. The strength level is the specified minimum room temperature value.	A1	
Appendix I	Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot. See Tables I-9.0 or Table I-9.0M. Accordingly, for $S_i > S > S_j$, $$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{[log(S_j/S)/log(S_i/S_j)]}$$ where S, S_i, and S_j are values of S_a; N, N_i, and N_j are the corresponding number of cycles from the design fatigue data.	Annex ZI: ZI 4.0	When computed value S_a falls between two values S_i and S_j given in the table ($S_i > S_a > S_j$), the number of admissible cycles N is determined by interpolation, as follows: $$N = N_i \times (N_j/N_i)^{[\log(S_i/S_a)/log(S_i/S_j)]}$$ where N_i and N_j are the numbers of admissible cycles associated with stress variation amplitude S_i and S_j.	A1	
NB-3121	It should be noted that the tests on which the design fatigue curves (Section III Appendices, Mandatory Appendix I) are based did not include tests in the presence of corrosive environments which might accelerate fatigue failure.	B 3173	It should be noted that the group of tests on which the fatigue curves in figures Z I 4.0 are based, do not include tests performed in a corrosive environment which might accelerate fatigue damage.	A1	

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
Figure I-9.1M	Design Fatigue Curves for Carbon, Low Alloy, and High Tensile Steels for Metal Temperatures Not Exceeding 370°C	Figure ZI 4.1	Fatigue Curves for Carbon and Low Alloy Steels (for metal temperature not exceeding 370°C)	A1	
Figure I-9.2M	Design Fatigue Curves for Austenitic Steels, Nickel–Chromium–Iron Alloy, Nickel–Iron–Chromium Alloy, and Nickel–Copper Alloy for Temperatures Not Exceeding 425°C	Figure ZI 4.2	Fatigue Curves for Austenitic Steels and Nickel Alloys	A2	
Figure I-9.3M	Design Fatigue Curves for Wrought 70 Copper–30 Nickel Alloy for Temperatures Not Exceeding 425°C				
Figure I-9.4M	Design Fatigue Curves for High Strength Steel Bolting for Temperatures Not Exceeding 370°C	Figure ZI 4.3	Fatigue Curves for Steel Bolting	A1	
Fatigue strength reduction factor (FSRF)					
Appendix XIII-1300(g)	FSRF is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. Values for some specific cases, based on experiment, are given. A theoretical stress concentration factor or stress index may be used. A fatigue strength reduction factor or stress index may also be determined using the procedures in Mandatory Appendix II-1600.	Annex ZD	Local discontinuity zones whose geometrical contour includes sharp variations are the sites of acute stress concentrations. The method and stress notion introduced in B3234.5 are unsuitable for zones with local discontinuities. Another stress range must be used in these zones to determine the number of cycles allowable with regard to fatigue damage. The acceptable methods for determining this range are given in annex ZD. Annex ZD, referred to in paragraph B 3234.7, concerns the acceptable rules for analysing fatigue behaviour in zones with geometrical discontinuities similar to crack-type discontinuities. The rules in this annex are based upon the standard method in which a magnitude is determined: this magnitude is compared with a criterion, and used to calculate an allowable number of cycles before the appearance of fatigue damage, (*i.e.* before fatigue crack initiation). This magnitude is designated the initiation factor. These rules form a part of the elastic analysis of the material covered in B 3230. As specified in B 3244.b), it is also acceptable to use the experimental analysis rules of Annex Z II.	A2	Some details of Annex ZD are described here. There is no equivalent procedure provided in ASME III NB.

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
		Annex ZD 2100 & Annex ZD 2200	Given the stress range in the structure to be analysed at some critical distance, d, from the discontinuity, it is possible to determine the number of permissible cycles for the loading condition under consideration. The method of evaluation is outlined as follows: a. Determine the stress state at critical distance, d, from the tip of the discontinuity (or fictitious crack tip) using elastic stress analysis. d is unique to each material and is specified in Table ZD 2300. The stress state is to be expressed in a local polar coordinate system whose origin coincides with the fictitious crack tip. The angle between the radial direction and crack plane is denoted θ. b. Resolve the stress state onto the next candidate plane by rotating the original coordinate system to the new orientation defined by θ. 1. For each value of θ considered and for each condition analysed, the variation of stress calculated at distance d from the fictitious crack tip and acting normal to the radial direction, $\sigma_t(d)$, is determined. 2. For each event, identify the extreme values (instants) of σ_t and assign each a number of occurrences, n, for the corresponding event, p, under consideration. For any combination of two values, σ_t (k) and σ_t (l), taken from the set of extreme values of σ_t, calculate the stress range $\Delta\sigma_t$ (k,l) as follows: $\Delta\sigma_t(k,l) = \lvert\sigma_t(k) - \sigma_t(l)\rvert$ 3. The number of occurrences, n_{kl}, associated to each fatigue pair (k,l) is defined as the minimum frequency of occurrence of the two events which comprise the fatigue pair: $n_{kl} = min\{n_k, n_l\}$		

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		

4. The maximum stress range $\Delta\sigma t$ (m,n) out of the set of extreme ranges $\Delta\sigma t$ (k,l) is determined, whose associated number of occurrences n_{kl} is greater than zero. The value of $\Delta\sigma_t$ (m,n) is then corrected to account for plasticity, where the plasticity correction factor is limited to 1.15 by default.
5. The value $\Delta\sigma_t$ (m,n) is entered into the initiation curves $\Delta\sigma = f(N)$ referred to in ZD 2300 after correcting for mean stress (R-ratio) according to the following rule:

$$R = \frac{\sigma_{\theta\theta}(d), min}{\sigma_{\theta\theta}(d), max}$$

then,

$$\Delta\sigma_{\theta\theta}(d)_{eff} = \Delta\sigma_{\theta\theta}/(1 - R/2)$$

6. These fatigue curves give the number of permissible cycles, N_{mn}, which would be acceptable if the type of cycles considered were unique. The initiation factor due to $\Delta\sigma_t$ (m,n) is then determined by:

$$U_{mn} = \frac{n_{mn}}{N_{mn}}$$

7. After accounting for the combination $\Delta\sigma_t$ (m,n), a new set of extremes for σ_t is established by correcting the number of occurrences as follows:

$$n_m = n_m - n_{mn}$$

$$n_n = n_n - n_{mn}$$

8. The procedure is repeated from (3) until the number of occurrences associated with any extreme value of σ_t is zero.

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
			9. The cumulative initiation factor associated with the value of θ under consideration is determined from the sum of the initiation factors calculated by applying procedures (1) to (7) above. c. The procedure presented in (b) above is repeated for each value of θ used. d. The initiation factors thus determined shall be less than or equal to unity.		
		Annex ZD 3000	Annex ZD 3000 also permits the number of allowable cycles to be determined using the Annex ZI S-N curves. The number of allowable cycles is calculated in the following steps: 1. Using the elastic stress range, $\Delta\sigma_t$, calculated at distance, d, from the discontinuity, estimate the actual elastic-plastic strain range, $\Delta\varepsilon$, at this point using Neuber's rule: $\Delta\sigma\Delta\varepsilon(d) = (1/E) \cdot [\Delta\sigma_t(m,n)]^2$ 2. In determination of $\Delta\varepsilon$ in (1), the cyclic strain-hardening curve of the relevant material is used. If this curve is not incorporated into the code, the curve used must be substantiated by the analyst. 3. Evaluate the number of allowable cycles using the S-N curves in Annex ZI. The pseudo-stress amplitude for entering the design curve is obtained by conversion of $\Delta\varepsilon$ by: $S_a = (E\Delta\varepsilon)/3$		
Appendix II-1600 Appendix II-1610	Experimental determination of fatigue strength reduction factors shall be in accordance with the procedures of (a) through (e) below.	Annex ZII 530	Experimental determination of fatigue strength reduction factors shall be in accordance with the procedures of (a) to (f).	A2	

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
	a. The test part shall be fabricated from a material within the same P-Number grouping of Section IX, Table QW/QB-422 and shall be subjected to the same heat treatment as the component. b. The stress level in the specimen shall be such that the stress intensity does not exceed the limit prescribed by XIII-3400, and so that failure does not occur in less than 1000 cycles. c. The configuration, surface finish, and stress state of the specimen shall closely simulate those expected in the components. In particular, the stress gradient shall not be more abrupt than that expected in the component. d. The cyclic rate shall be such that appreciable heating of the specimen does not occur. e. The fatigue strength reduction factor shall preferably be determined by performing tests on notched and unnotched specimens and calculated at the ratio of the unnotched stress to the notched stress for failure.				
Appendix XIII-3520(b)	Except for the case of crack-like defects and specified piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than five need be used.	B 3234.7	RCC-M 2018 The effect of local discontinuities where stress concentrations occur, may be accounted for using stress concentration factors determined from theoretical, numerical, experimental, or photo-elastic studies. Fatigue is analysed according to the rules of B 3234.5, taking these factors into consideration. It is not necessary to consider a stress concentration factor greater than 5. Certain local discontinuities correspond to geometric singularities with similarities to a crack-type discontinuity. In this case, the recommended methods are given in Annex ZD. As an alternative, the method in B 3234.7 (a) can also be used, as long as justification is provided.	A2	

ASME Section III NB		RCC-M		Comparison	Comments
Reference	Description	Reference	Description		
NB-3352.2 NB-3352.4 NB-3136 (b) (3)	• For joints of Category B with backing strip, FSRF ≥ 2; • For partial penetration joints of Category D, FSRF ≥ 4; • For design of certain small diameter appurtenance welded joints, FSRF = 4.		• Configuration not allowed by RCC-M in class 1 • No value given – ZD recommended		
NB-3338	Fatigue evaluation of stresses in openings is provided in this paragraph. While three methods (Analytical Method, Experimental Stress, and Stress Index Method) of determining peak stresses around the opening are given in NB-3338.1, only the details for Stress Index Method are provided in NB-3338.2. The following points can be summarized for the Stress Index Method: • The term stress index is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r (Figure NB-3338.2(a)-1) under consideration to the computed membrane hoop stress in the unpenetrated vessel material; however, the material which increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. • Table NB-3338.2(c)-1 provides the stress indices for nozzles designed in accordance with the applicable rules of NB-3330, provided that the conditions stipulated in (1) through (7) in NB-3338.2 (d) are satisfied.				

6.2 Comparison of ASME Section III Division 1, Subsection NB with JSME S NC1

Table 6-2. Comparison of ASME Section III, Division 1, Subsection NB with JSME S NC1

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
Scope of applicability					
NB-1120	The temperature limits for application of the procedures are prescribed, that is, fatigue design curves and specified methods for fatigue analysis are not applicable above 370°C for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.4, and above 425°C for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.2 and I-9.3.	PVB-1120	Class 1 vessels shall not be used at temperatures exceeding the limits for which the design stress intensities (S_m) in Table 1 and Table 2, Article 1, Part 3 of Rules on Materials for Nuclear Facilities are specified.	A2	
Appendix I NB-1120	The fatigue design curves applicable for the following materials: • Carbon, low alloy and high tensile steels with UTS ≤ 552MPa or between 793MPa and 896MPa, and temperature ≤ 370°C; • Austenitic steels, nickel–chromium–iron alloy, nickel–iron–chromium alloy and nickel–copper alloy with temperature ≤ 425°C (UTS limits not specified).	Appendix 4-2	• Carbon, low alloy and high tensile steels UTS < 550MPa or between 790 MPa and 900 MPa, and temperature < 370ºC • Austenitic steels, nickel–chromium–iron alloy, nickel–iron–chromium alloy and nickel–copper alloy with temperature ≤ 430ºC (UTS limits not specified).	A2	Temperature limit for austenitic stainless steels and nickel-based alloys should be 425°C, not 450°C.
Assessment methods, procedures and conditions					
Appendix XIII-2400	The determination of stress differences shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point.	GNR-2130 PVB-3114	Stress intensity refers to the algebraic difference between the maximum principal stress and the minimum principle stress at a given point. Fatigue analysis shall meet the requirement.	A2	
Appendix XIII-3500 Appendix I	The assessment conditions and procedures for analysis for cyclic operation are presented in this subparagraph. The conditions and procedures are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I.	PVB-3114 PVB-3140 Appendix 4-2	Fatigue analysis shall be performed in accordance with PVB-3114.1 to PVB-3114.2 except that PVB-3140 “Conditions Not Requiring Fatigue Analysis” cannot be satisfied. The design fatigue curves are specified in Appendix 4-1.	B2	The K_e factor of JSME is more rational than that of ASME. The JSME incorporates the design fatigue curves of ASME 2005Ad.
Appendix XIII-3500 (c)	The fatigue curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles.	PVB-3114 Appendix 4-2	The fatigue curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles.	A2	The JSME does not clearly specify the provision of the ASME, but the

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
	This stress intensity amplitude is calculated on the assumption of elastic behaviour and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero.				provision of the ASME is the basis of the requirement of the JSME.
Appendix XIII-3510	The conditions are prescribed for components not requiring analysis for cyclic service.	PVB-3140	The conditions are prescribed for components not requiring analysis for cyclic service.	A2	Except the design fatigue curves.
Appendix XIII-3520 (c) Appendix I	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value. Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot. See Tables I-9.0 or Table I-9.0M. Accordingly, for $S_i > S > S_j$, $$\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{[log(S_j/S)/log(S_i/S_j)]}$$ where S, S_i, and S_j are values of S_a; N, N_i, and N_j are the corresponding number of cycles from the design fatigue data.	Appendix 4-2: 4	Interpolation is specified as the following equation. $$N_a = N_2 \times \left(\frac{N_1}{N_2}\right)^{\frac{log(S_2/S_a)}{\log(S_2/S_1)}}$$	A2	

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
Appendix XIII-3520 (d)	Effect of elastic modulus is accounted for by multiplying S_a by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis.	Appendix 4-2: 3.1(2), 3.2(1), etc.	[Example of 3.1(2)] The alternating peak stress intensity in Fig. Appendix 4-2-1 shall be calculated by multiplying the alternating stress intensity by fatigue analysis by (2.07 x 105/E).	A2	
Appendix XIII-3520 (e)	If there are two or more types of stress cycle which produce significant stresses, the cumulative usage factor accounting for these individual loadings is evaluated with Miner's rule (*i.e.* linear summation of the individual fatigue damage), and it shall not exceed 1.0.	PVB-3114	Cumulative usage factor U_f in Service Conditions A and B shall satisfy the following limit. $U_f = \sum_{i=1}^{k} \frac{N_c(i)}{N_a(i)} \leq 1.0$		
Appendix XIII-3600 (e)	Tests, with the exception of the first 10 hydrostatic tests in accordance with NB-6220, the first 10 pneumatic tests in accordance with the NB-6320, or any combination of 10 of such tests, shall be considered in the fatigue evaluation of the component. In the fatigue evaluation, the limits on the primary plus secondary stress intensity range may be taken as the larger of $3S_m$ or $2S_y$ when at least one extreme of the stress intensity range is determined by the Test Loadings.	Table PVB-3110-1 (Note 9)	Fatigue evaluation for test conditions shall be applied when the number of test conditions exceeds 10 times.	A1	
XIII-2500 (b)	In application of elastic analysis for stresses beyond the yield strength, all stresses, except those which result from local thermal stresses (NB-3213.13(b)), shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression: $\upsilon = 0.5 - 0.2\left(\frac{S_y}{S_a}\right), but\ not\ less\ than\ 0.3$	----	----	B1 Not specified	
Appendix XIII-3450	In accordance with the simplified elastic-plastic analysis rule given in this subparagraph, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided that the requirements below are met:	PVB-3315.1	The K_e methodology according to the JSME Code involves two functions, $K_{e,A0}$ and K_e', which describe curve fits as a function of $S_n/3S_m$ and a parameter K, defined as a ratio of the total (including peak) stress	B2	JSME K_e factor was originally developed by the Thermal and Nuclear Power

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
	• The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be ≤ $3S_m$. • the value of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where $K_e = \begin{cases} 1.0 & if\ S_n \leq 3S_m \\ 1.0 + \frac{1-n}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right) & if\ 3S_m < S_n < 3mS_m \\ \frac{1}{n} & if\ S_n \geq 3mS_m \end{cases}$ • The rest of the fatigue evaluation stays the same as required in Appendix XIII-3520, except that the procedure of Appendix XIII-2500 need not be used. • The component meets the thermal ratcheting requirement of Appendix XIII-3430. • The temperature does not exceed those listed in Table XIII-3450-1 for the various classes of materials. • The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.		intensity range to the primary-plus-secondary stress intensity range. There are two possible cases depending on whether the $K_{e,A0}$ and K_e' curves intersect. In the case that $K_{e,A0}$ and K_e' do not intersect, a tangent line from the value of $K_{e,A0}$ at $S_n = 3S_m$ to the K_e' curve shall be drawn. $K < B_0$ describes the case of intersection of K_e' and $K_{e,A0}$, whilst $K \geq B_0$ describes the case of no intersection of K_e' and $K_{e,A0}$. The K_e factors are calculated as follows, where the elastic follow-up factor, q, and material-specific parameters, A_0 and B_0, are defined in Table PVB-3315.1: $K_e = 1.0 + A_0\left(\frac{S_n}{3S_m} - K\right)\ for\ K$ $< B_0\ and\ \frac{S_n}{3S_m} < C_0$ $= 1.0 + (q-1)\left(1 - \frac{3S_m}{S_n}\right) for\ K$ $< B_0\ and\ \frac{S_n}{3S_m} \geq C_0$ $= a\frac{S_n}{3S_m} + A_0\left(1 - \frac{1}{K}\right) + 1 - a\ for\ K$ $\geq B_0\ and\ \frac{S_n}{3S_m} < C_1$ $= 1 + (q-1)\left(1 - \frac{3S_m}{S_n}\right) for\ K$ $\geq B_0\ and\ \frac{S_n}{3S_m} \geq C_1$		Engineering Society (TENPES) in Japan. $K_{e,A0}$ and K_e' functions represent bounding fits to results obtained from FE analysis of typical plant structures based on elastic-perfectly-plastic (EPP) material model. To visualize better $K_{e,A0}$ and K_e' with S_n/S_m for different values of K (*e.g.* S_p/S_n = 1.0, 1.5, 2.0, etc.), some plots for each material class are included in Appendix C.

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		

where

$$K = \frac{S_p}{S_n}$$

$$C_0 = \frac{\left[\left(q + \frac{A_0}{K} - 1\right) - \sqrt{\left(q + \frac{A_0}{K} - 1\right)^2 - 4A_0(q-1)}\right]}{2A_0}$$

$$a = A_0\left(1 - \frac{1}{K}\right) + (q-1) - 2\sqrt{A_0\left(1 - \frac{1}{K}\right)(q-1)}$$

$$C_1 = \left[(q-1) - \sqrt{A_0\left(1 - \frac{1}{K}\right)(q-1)}\right] / a$$

Table PVB-3315.1

Materials	q	A_0	B_0 (*1)
Low alloy steel	3.1	1.0	1.25
Martensitic stainless steel	3.1	1.0	1.25
Carbon steel	3.1	0.66	2.59
Austenitic stainless steel	3.1	0.7	2.15
Nickel-chromium-iron	3.1	0.7	2.15

(*1) $B_0 = \frac{A_0(q-1) + 2A_0\sqrt{A_0(q-1)}}{4A_0(q-1) - (q-1)^2}$

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
Code Case N-779	Alternative Rules for Simplified Elastic-Plastic Analysis Class 1 Section III, Division 1 The $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided the following requirements are met: • The requirements of subparagraphs (a), (b), (c), (d), (e), and (f) of Appendix XIII-3450 are satisfied. • The value of the stress amplitude, S_a, for entering the design fatigue curve is one-half of the stress intensity range calculated by the combination of terms in (3), (4), and (5) given below. • The total stress intensity range, excluding both thermal bending stresses caused by linear through-wall thermal gradients and local thermal stresses, is multiplied by the K_e factor defined in Appendix XIII-3450 (b). • The local thermal stress range (as defined in Appendix XIII-1300 (aj) (2)) is multiplied by a Poisson's ratio correction factor, K_v, where $K_v = \begin{cases} 1.0 & if\ S_p \leq 3S_m \\ 1.0 + 0.4\dfrac{S_p - 3S_m}{S_{n,tb+lt}} & if\ S_p > 3S_m\ and\ S_{p-lt-tb} < 3S_m \\ 1.4 & if\ S_p > 3S_m\ and\ S_{p-lt-tb} \geq 3S_m \end{cases}$ S_p = total stress intensity range S_{tb+lt} = thermal bending plus local thermal stress intensity range	Code Case NC-CC-005	The JSME Committee on Stress Compensated Factor for Simplified Elastic-Plastic Analysis (C-K_e Factor) developed an alternative K_e factor, K_e'', which has been incorporated into Code Case NC-CC-005. K_e'' is based on S_p only and therefore does not require stress linearization to apply. The K_e'' is calculated as follows: $K_e'' = 1 + (q_p - 1)\left(1 - \dfrac{1}{S_p/3S_m}\right)$ where q_p is the elastic follow-up factor for local plasticity, $q_p = (q_1 - q_0) \cdot \left(1 - \dfrac{1}{\frac{S_p}{3S_m}}\right) + q_0$ where $q_0 = 1.5, q_1 = 4.0$ NC-CC-005 also allows for direct calculation of K_e by elastic-plastic FE analysis with elastic-perfectly-plastic (EPP) material of which the yield strength is set equal to $1.5S_m$.	B2	The NC-CC-005 K_e'' was derived based on the same FE models used to derive the PVB-3315.1 K_e, assuming EPP material properties. The values of q_0 and q_1 were conservatively set to bound the actual K_e obtained by elastic-plastic FE analysis. Therefore, NC-CC-005 actually recommends calculation of K_e by elastic-plastic analysis to determine a more accurate value of q_p for each structure.

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
	$S_{p\text{-}tb\text{-}lt}$ = total stress intensity range excluding thermal bending and local thermal stresses • The thermal bending stress range caused by linear through-wall thermal gradients is multiplied by the product of K_v and a notch plasticity adjustment factor, K_n, where $K_n = \begin{cases} 1.0 & if\ S_{p-lt} \leq 3S_m \\ 1.0 + \left[\left(\frac{S_{p-lt}}{S_n}\right)^{\frac{1-n}{1+n}} - 1\right]\frac{S_{p-lt} - 3S_m}{S_{p-lt}} & if\ S_{p-lt} > 3S_m \end{cases}$ and $K_n K_v \leq K_e$ $S_{p\text{-}lt}$ = total stress intensity range less local thermal stresses S_n = primary plus secondary stress intensity range n = strain hardening exponent from Table XIII-3450-1 • As an alternative to (2) through (5) above, an alternative plasticity correction factor, K_e', may be determined directly from an elastic-plastic analysis of the component for the load case under consideration, where K_e' is defined as the ratio of the numerically maximum principal strain from the plastic analysis to that from the elastic analysis. K_e' may then be applied to other load cases for which the elastically calculated stress is less than or equal to the elastic stress range of the load case used to derive K_e'. The value of S_a used for entering the design fatigue curve is multiplied by K_e'.				

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
Proposed Code Case [Record 17-225]	A new Code Case for ASME BPVC Section III, Division I, Alternative Rules for Simplified Elastic-Plastic Analysis has recently been approved by the ASME Board on Nuclear Codes and Standards (BNCS). The proposed Code Case has been discussed extensively within the relevant standards committees, and important technical comments have been addressed. It is expected that this new Code Case will be published in the near future. Like RCC-M, the proposed Code Case is also based on WRC-361, using a weighted average approach for stresses arising due to thermal and mechanical loads. A summary of the proposed Code Case is given in full below, and shares the same preconditions as Appendix XIII-3450: The $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided that: • The primary plus secondary membrane plus bending stress intensity, less the contribution of thermal bending stresses, shall be ≤ $3S_m$. • The value of alternating stress for entering the design fatigue curve, S_a, is multiplied by a correction factor, K_e^R: $K_e^R = \begin{cases} 1.0 & if\ S_n \leq 3S_m \\ min\left[K_e R + K_{th}^R(1-R)K_n^R, K_e\right] & if\ 3S_m < S_n \leq 3mS_m \\ min\left[K_e R^* + K_{th}^R(1-R^*)K_n^R, \frac{1}{n}\right] & if\ S_n > 3mS_m \end{cases}$ where K_e is the Appendix XIII-3450(b) plasticity correction factor; K_{th}^R is a thermal-plastic correction factor corresponding to the maximum possible Poisson's ratio correction factor of 1.4, assuming fully-plastic behaviour; R defines the relative contribution of the range of membrane plus bending stress intensity, less thermal bending stresses, to the range of primary plus secondary	B3234.6		B1	The Ranganath and RCC-M approaches are both based on WRC-361, this makes a direct comparison possible. Overall, the two methodologies are similar in their separation of mechanical and thermal stresses. However, the proposed ASME Code Case treats the range of thermal membrane stress intensity as primary, and it is combined with the remaining mechanical stress range and multiplied by the much more conservative Appendix XIII-3450 K_e factor, while RCC-M simply separates the total mechanical and thermal stresses and does not consider stress categorisation here. The other methodological difference is that Ranganath's method now incorporates a Neuber notch

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
	stress intensity; and R* represents the range of membrane plus bending stress intensity, excluding thermal bending stresses, normalised by $3mS_m$: $$K_{th}^R = \frac{1-v_e}{1-v_p} \cong \frac{0.7}{0.5} = 1.4$$ $$R = \frac{S_{n-tb}}{S_n}$$ $$R^* = \frac{S_{n-tb}}{3mS_m}$$ K_n^R is a Neuber notch correction factor, intended to account for additional plastic strain concentration at local discontinuities under globalized plasticity: $$K_n^R = K_T^{\frac{1-n}{1+n}}$$ Where K_T is the stress concentration factor based on elastic analysis. In the above equations, the material parameters m and n are the same as those given in Table XIII-3450-1. • The rest of the fatigue evaluation remains the same as required in XIII-3500, except that the procedure of XIII-2500 need not be used. • The component satisfies the thermal stress ratchet requirements of XIII-3430. • The temperature does not exceed those listed in Table XIII-3450-1 for the various classes of materials.				correction factor, K_n^R. RCC-M does not explicitly consider notch effects in the B 3234.6 K_e methodology.
Design fatigue curve					
Appendix	The design fatigue curves, which are stress-based, show	GNR-2130	Alternating peak stress intensity is defined as half of the	A2	

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
XIII-3500 (c) Appendix I	the allowable amplitude Sa of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles.	Appendix 4-2	difference between maximum and minimum values in previous peak stress cycles		
Appendix XIII-3500 (c)	The design fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress.	Appendix 4-2	(Not clearly specified)	A2	The JSME does not clearly specify the provision of the ASME, but the provision of the ASME is the basis of the requirement of the JSME.
Appendix XIII-3520 (c) Appendix I	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value. Interpolation between tabular values is permissible based upon data representation by straight lines on a log-log plot (see Tables I-9.0 or Table I-9.0M). Accordingly, for $S_i > S > S_j$, $\frac{N}{N_i} = \left(\frac{N_j}{N_i}\right)^{[log(S_j/S)/log(S_i/S_j)]}$ Where S, S_i, and S_j are values of S_a; N, N_i, and N_j are the corresponding number of cycles from the design fatigue data.	Appendix 4-2: 4.	Interpolation is specified as the following equation. $N_a = N_2 \times \left(\frac{N_1}{N_2}\right)^{\frac{log(S_2/S_a)}{\log(S_2/S_1)}}$	A2	
		Fatigue strength reduction factor (FSRF)			
Appendix XIII-1300 (g)	FSRF is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength.	PVB-3130	Provision of fatigue strength reduction factor	A2	The JSME does not clearly specify the provision of the ASME, but the provision of the ASME is the basis of the requirement of the JSME.

ASME Section III NB		JSME S NC1		Comparison	Comments
Reference	Description	Reference	Description		
Appendix II-1300 (g)	FSRF values for some specific cases, based on experiment are given. In the absence of experimental data, the theoretical stress concentration factor may be	PVB-3130 (1)	The fatigue strength reduction factors and the stress concentration factors used for fatigue analysis shall be obtained theoretically or experimentally.	A2	
	used. An experimental fatigue strength reduction factor may also be determined using the procedures outlined in Mandatory Appendix II-1600.				
Appendix XIII-3520(b)	Except for the case of crack-like defects and specified piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than five need be used.	PVB-3130	The maximum FSRF specified in Table PVB-3130-1 is five.	A2	
NB-3352.2 NB-3352.4 NB-3136 (b) (3)	• For joints of Category B, FSRF ≥ 2; • For joints of Category D, FSRF ≥ 4; • For design of certain small diameter appurtenance welded joints, FSRF = 4.	PVB-3130	The FSRF of fillet welds for attaching attachments, *e.g.* lugs and brackets (excluding reinforcement, support structures and core support structures) shall be four.	B2	
NB-3338	Fatigue evaluation of stresses in openings is provided in this paragraph. While three methods (Analytical Method, Experimental Stress, and Stress Index Method) of determining peak stresses around the opening are given in NB-3338.1, only the details for Stress Index Method are provided in NB-3338.2. The following points can be summarised for the Stress Index Method: • The term stress index is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r (Figure NB-3338.2(a)-1) under consideration to the computed membrane hoop stress in the unpenetrated vessel material; however, the material which increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. • Table NB-3338.2(c)-1 provides the stress indices for nozzles designed in accordance with the applicable rules of NB-3330, provided that the conditions stipulated in (1) through (7) in NB-3338.2 (d) are satisfied.	PVB-3540 PVB-3112	[PVB-3540] When the vessel conforms to PVB-3541, the stress indices specified in PVB-3542 may be used for stress due to internal pressure of the peak stress intensity in the fatigue analysis at the vicinity of circular openings in accordance with PVB-3510(2). PVB-3112 is for fatigue analysis and this is applicable to openings.	B2	Partially equivalent

6.3 Comparison of ASME Section III Division 1, Subsection NB with KEPIC MN MNB

Table 6-3. Comparison of ASME Section III, Division 1, Subsection NB with KEPIC MN MNB

ASME Section III NB		KEPIC MN MNB		Comparison	Comments
Reference	Description	Reference	Description		
Scope of applicability					
NB-1120	The temperature limits for application of the procedures are prescribed, that is, fatigue design curves and specified methods for fatigue analysis are not applicable above 370°C for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.1 and I-9.4, and above 425°C for materials covered by Section III Appendices, Mandatory Appendix I, Figures I-9.2 and I-9.3.	MNB 1120	Fatigue design curves and specified methods for fatigue analysis are not applicable above 370°C for materials covered by KEPIC-MNZ Figs I-9.1 and I-9.4, and above 425°C for materials covered by Figs I-9.2 and I-9.3. • Figs I-9.1: Design Fatigue Curves for Carbon, Low Alloy, and High Tensile Steels for Metal Temperatures Not Exceeding 370°C • Figs I-9.4: Design Fatigue Curves for High Strength Steel Bolting for Temperature Not Exceeding 370°C • Figs I-9.2: Design Fatigue Curves for Austenitic Steels, Nickel-Chromium-Iron Alloy, Nickel-Iron-Chromium Alloy, and Nickel-Copper Alloy for Temperature Not Exceeding 425°C • Figs I-9.3: Design Fatigue Curves for Wrought 70 Copper 30 Nickel Alloy for Temperatures Not Exceeding 425°C	A1	Temperature limits for other materials' design curves are same as ASME code NB also.
Appendix I NB-1120	The fatigue design curves applicable for the following materials: • Carbon, low alloy and high tensile steels with UTS ≤ 552MPa or between 793MPa and 896MPa, and temperature ≤ 370°C; • Austenitic steels, nickel–chromium–iron alloy, nickel–iron–chromium alloy and nickel–copper alloy with temperature ≤ 450°C (UTS limits not specified).	MNZ Appendix I MNB 1120	Figs I-9.1: • UTS ≤ 552MPa or between 793MPa and 896MPa • E = 207 x 103 MPa Figs I-9.2 • UTS limits not specified • E = 195 x 103 MPa	A1	Same as in application of UTS and E application
Assessment methods, procedures and conditions					
Appendix XIII-2400	The determination of stress differences shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point.	MNB 3216	The determination shall be made on the basis of the stresses at a point of the component, and the allowable stress cycles shall be adequate for the specified service at every point. Only the stress differences due to cyclic service loadings as specified in the Design Specification need be considered.	A1	

ASME Section III NB		KEPIC MN MNB		Comparison	Comments
Reference	Description	Reference	Description		
Appendix XIII-3500 Appendix I	The assessment conditions and procedures for analysis for cyclic operation are presented in this subparagraph. The conditions and procedures are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of Section III Appendices, Mandatory Appendix I.	MNB 3222.4 MNZ Appendix I	The conditions and procedures are based on a comparison of peak stresses with strain cycling fatigue data. The strain cycling fatigue data are represented by design fatigue strength curves of MNZ Mandatory Appendix I.	A1	
Appendix XIII-3500 (c)	The fatigue curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. This stress intensity amplitude is calculated on the assumption of elastic behaviour and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero.	MNB 3222.4(3)	The fatigue curves (MNZ Mandatory Appendix I) show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles. Alternating stress intensity range is calculated based on peak stress intensity which is the combination of all primary, secondary and peak stresses. This stress intensity amplitude is calculated on the assumption of elastic behaviour and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero.	A1	
Appendix XIII-3510	The conditions are prescribed for components not requiring analysis for cyclic service.	MNB 3222.4(4)	The conditions are prescribed for components not requiring analysis for cyclic service. If the conditions are met, it may be assumed that the limits on peak stress intensities as governed by fatigue have been satisfied for a component by compliance with the applicable requirements for material, design, fabrication, examination, and testing of MNB.	A1	

ASME Section III NB		KEPIC MN MNB		Comparison	Comments
Reference	Description	Reference	Description		
Appendix XIII-3520 (c)	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.	MNB 3222.4 (5) (c)	When more than one curve is presented for a given material, the applicability of each is identified. Where curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.	A1	
Appendix XIII-3520 (d)	Effect of elastic modulus is accounted for by multiplying S_a by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis.	MNB 3222.4 (5) (d)	Effect of elastic modulus is accounted for by multiplying S_a by the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. (Background: Because fatigue design curve (S-N curve) is based on room temperature experiment, S_a value of fatigue design curve should be modified considering analysis temperature.)	A1	
Appendix XIII-3520 (e)	If there are two or more types of stress cycle which produce significant stresses, the cumulative usage factor accounting for these individual loadings is evaluated with Miner's rule (*i.e.* linear summation of the individual fatigue damage), and it shall not exceed 1.0.	MNB 3222.4 (5) (e)	For cumulative damage, Miner's rule is applied and cumulative usage factor shall not exceed 1.0.	A1	
Appendix XIII-3600 (e)	Tests, with the exception of the first 10 hydrostatic tests in accordance with NB-6220, the first 10 pneumatic tests in accordance with the NB-6320, or any combination of 10 of such tests, shall be considered in the fatigue evaluation of the component. In the fatigue evaluation, the limits on the primary plus secondary stress intensity range may be taken as the larger of $3S_m$ or $2S_y$ when at least one extreme of the stress intensity range is determined by the Test Loadings.	MNB 3226	Tests, with the exception of the first 10 hydrostatic tests, the first 10 pneumatic tests, or any combination of 10 of such tests, shall be considered in the fatigue evaluation of the component. In the fatigue evaluation, the limits on the primary plus secondary stress intensity range may be taken as the larger of $3S_m$ or $2S_y$ when at least one extreme of the stress intensity range is determined by the Test Loadings.	A1	
Appendix XIII-2500 (b)	In application of elastic analysis for stresses beyond the yield strength, all stresses, except those which result from local thermal stresses (Appendix XIII-1300 (aj) (2)), shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression: $v = 0.5 - 0.2\left(\frac{S_y}{S_a}\right), but\ not\ less\ than\ 0.3$	MNB 3227.6 (2)	In application of elastic analysis for stresses beyond the yield strength, all stresses, except those which result from local thermal stresses (MNB 3213.13(2)), shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used, except that the numerical value substituted for Poisson's ratio shall be determined from the expression: $v = 0.5 - 0.2\left(\frac{S_y}{S_a}\right), but\ not\ less\ than\ 0.3$	A1	

ASME Section III NB		KEPIC MN MNB		Comparison	Comments
Reference	Description	Reference	Description		
Appendix XIII-3450	In accordance with the simplified elastic-plastic analysis rule given in this subparagraph, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded provided that the requirements below are met: • The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be ≤ $3S_m$. • The value of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where $K_e = \begin{cases} 1.0 & if\ S_n \le 3S_m \\ 1.0 + \frac{1-n}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right) & if\ 3S_m < S_n < 3mS_m \\ \frac{1}{n} & if\ S_n \ge 3mS_m \end{cases}$ • The rest of the fatigue evaluation stays the same as required in Appendix XIII-3520, except that the procedure of Appendix XIII-2500 need not be used. • The component meets the thermal ratcheting requirement of Appendix XIII-3430. • The temperature does not exceed those listed in Table XIII-3450-1 for the various classes of materials. • The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.	MNB 3228.5	The $3S_m$ limit on the range of primary plus secondary stress intensity (MNB 3222.2) may be exceeded provided that the requirements of (1) through (6) below are met. 1. The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be ≤$3S_m$. 2. The value of S_a used for entering the design fatigue curve is multiplied by the factor K_e, where: $K_e = \begin{cases} 1.0 & if\ S_n \le 3S_m \\ 1.0 + \frac{1-n}{n(m-1)}\left(\frac{S_n}{3S_m} - 1\right) & if\ 3S_m < S_n < 3mS_m \\ \frac{1}{n} & if\ S_n \ge 3mS_m \end{cases}$ S_n = range of primary plus secondary stress intensity The values of the material parameters m and n for the various classes of permitted materials are as given in Table MNB 3228.5. 3. The rest of the fatigue evaluation stays the same as required in MNB 3222.4, except that the procedure of MNB 3227.6 need not be used. 4. The component meets the thermal ratcheting requirement of MNB 3222.5. 5. The temperature does not exceed those listed in Table MNB 3228.5 for the various classes of materials. 6. The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.	A1	

ASME Section III NB		KEPIC MN MNB		Comparison	Comments
Reference	Description	Reference	Description		
		Design fatigue curve			
Appendix XIII-3500 (c) Appendix I	The design fatigue curves, which are stress-based, show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles.	MNB 3222.4 (3) MNZ Appendix I	The strain cycling fatigue data are represented by design fatigue strength curves of KEPIC- MNZ Figs I-9.0. These curves show the allowable amplitude S_a of the alternating stress intensity component (one-half of the alternating stress intensity range) plotted against the number of cycles.	A1	
Appendix XIII-3500 (c)	The design fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress.	MNB 3222.4 (3)	This stress intensity amplitude is calculated on the assumption of elastic behaviour and, hence, has the dimensions of stress, but it does not represent a real stress when the elastic range is exceeded. The fatigue curves are obtained from uniaxial strain cycling data in which the imposed strains have been multiplied by the elastic modulus and a design margin has been provided so as to make the calculated stress intensity amplitude and the allowable stress intensity amplitude directly comparable. Where necessary, the curves have been adjusted to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value that is different from zero.	A1	
Appendix XIII-3520 (c)	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.	MNB 3222.5 (c)	Where design fatigue curves for various strength levels of a material are given, linear interpolation may be used for intermediate strength levels of these materials. The strength level is the specified minimum room temperature value.	A1	
		Fatigue strength reduction factor (FSRF)			
Appendix XIII-1300 (g)	FSRF is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength.	MNB 3213.17	FSRF is a stress intensification factor which accounts for the effect of a local structural discontinuity (stress concentration) on the fatigue strength. In the absence of experimental data, the theoretical stress concentration factor may be used.	A1	
Appendix XIII-1300 (g)	FSRF values for some specific cases, based on experiment, are given. In the absence of experimental data, the theoretical stress concentration factor may be used. An experimental fatigue strength reduction factor may also be determined using the procedures outlined in Mandatory Appendix II-1600.	MNB 3338 MNB 3339	Theses paragraph refer to fatigue evaluation of openings and nozzles. The experimental data or theoretical stress concentration factor may be used for FSRF.	A1	

ASME Section III NB		KEPIC MN MNB		Comparison	Comments
Reference	Description	Reference	Description		
Appendix XIII-3520(b)	Except for the case of crack-like defects and specified piping geometries for which specific values are given in NB-3680, no fatigue strength reduction factor greater than five need be used.	MNB 3222.4 (5) (b)	Except for the case of crack-like defects and specified piping geometries for which specific values are given in MNB 3680, no fatigue strength reduction factor greater than five need be used.	A1	
NB-3352.2 NB-3352.4 NB-3136 (b) (3)	• For joints of Category B, FSRF ≥ 2; • For joints of Category D, FSRF ≥ 4; • For design of certain small diameter appurtenance welded joints, FSRF = 4.	MNB 3352.2 MNB 3352.4 MNB 3136 (2) (c)	• For joints of Category B, FSRF ≥ 2; (Category B : Girth seam weld) • For joints of Category D, FSRF ≥ 4; (Category D : Nozzle to shell weld) • For design of certain small diameter appurtenance welded joints, FSRF = 4.	A1	
NB-3338	Fatigue evaluation of stresses in openings is provided in this paragraph. While three methods (Analytical Method, Experimental Stress, and Stress Index Method) of determining peak stresses around the opening are given in NB-3338.1, only the details for Stress Index Method are provided in NB-3338.2. The following points can be summarised for the Stress Index Method: • The term stress index is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r (Figure NB-3338.2(a)-1) under consideration to the computed membrane hoop stress in the unpenetrated vessel material; however, the material which increases the thickness of a vessel wall locally at the nozzle shall not be included in the calculations of these stress components. • Table NB-3338.2(c)-1 provides the stress indices for nozzles designed in accordance with the applicable rules of NB-3330, provided that the conditions stipulated in (1) through (7) in NB-3338.2 (d) are satisfied.	MNB 3338	Analytical Method, Experimental Stress and Stress Index Method of determining peak stresses around the opening is provided with more details for Stress Index Method.	A1	

7 | Appendix B - Design Fatigue Curves

This appendix presents and compares the design fatigue curves for the different Codes/Standards under comparison. To enable direct comparison, the pseudo-stress-based design curves have been transformed and presented graphically in terms of total strain amplitude vs permissible cycles. This aims at making a comparison between the different curves easier by eliminating the issue of pseudo-stress based curves having different reference modulus, E_c.

7.1 ASME Section III, Mandatory Appendix I

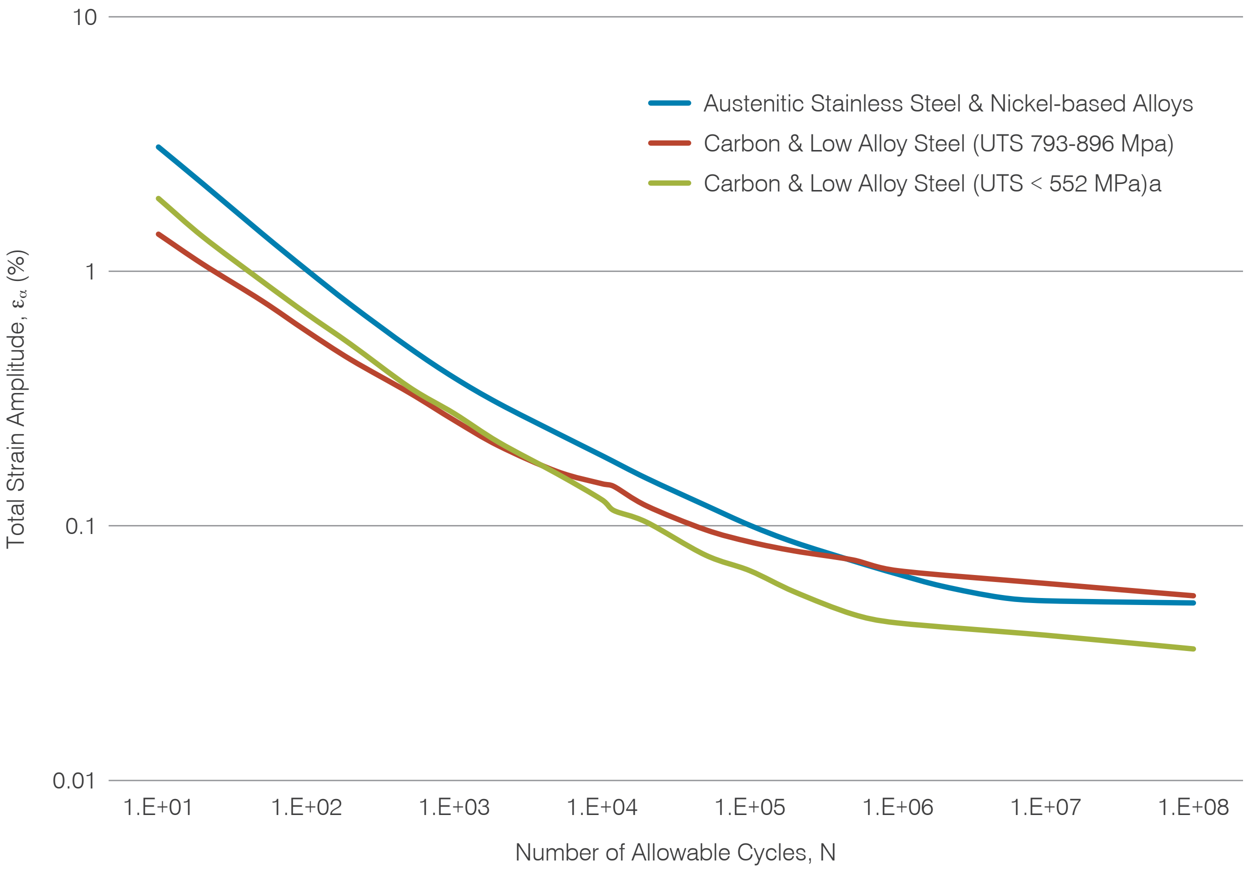

Figure 7-1. ASME Section III, Appendix I Design Strain-Life Curves (Figure I-9.1M and Figure I-9.2M)

Table 7-1. Tabulated values of strain amplitude, ε_a (%), and pseudo-stress amplitude, S_a (MPa), for Figure 7-1.

Austenitic Stainless Steel & Nickel-based Alloys (E_c = 195 GPa)			Carbon & Low-alloy Steels (E_c = 207 GPa)				
				UTS < 552 MPa		UTS 793-896 MPa	
N	ε_a (%)	S_a (MPa)	N	ε_a (%)	S_a (MPa)	ε_a (%)	S_a (MPa)
1.0E+01	3.077	6000	1.0E+01	1.932	3999	1.399	2896
2.0E+01	2.205	4300	2.0E+01	1.366	2827	1.066	2206
5.0E+01	1.409	2748	5.0E+01	0.916	1896	0.766	1586
1.0E+02	1.014	1978	1.0E+02	0.683	1413	0.583	1207
2.0E+02	0.738	1440	2.0E+02	0.516	1069	0.450	931
5.0E+02	0.499	974	5.0E+02	0.350	724	0.333	689
1.0E+03	0.382	745	1.0E+03	0.276	572	0.260	538
2.0E+03	0.303	590	2.0E+03	0.213	441	0.206	427
5.0E+03	0.231	450	5.0E+03	0.160	331	0.163	338
1.0E+04	0.189	368	1.0E+04	0.127	262	0.146	303
2.0E+04	0.154	300	1.2E+04	0.115	238	0.143	296
5.0E+04	0.121	235	2.0E+04	0.103	214	0.120	248
1.0E+05	0.101	196	5.0E+04	0.0768	159	0.0966	200
2.0E+05	0.0862	168	1.0E+05	0.0667	138	0.0864	179
5.0E+05	0.0728	142	2.0E+05	0.0551	114	0.0797	165
1.0E+06	0.0646	126	5.0E+05	0.0449	93	0.0734	152
2.0E+06	0.0580	113	1.0E+06	0.0415	86	0.0667	138
5.0E+06	0.0523	102	1.0E+07	0.0372	77	0.0594	123
1.0E+07	0.0508	99	1.0E+08	0.0329	68	0.0531	110
1.0E+08	0.0498	97.1	1.0E+09	0.0295	61	0.0473	98
1.0E+09	0.0491	95.8	1.0E+10	0.0261	54	0.0420	87
1.0E+10	0.0484	94.4	1.0E+11	0.0232	48	0.0372	77
1.0E+11	0.0481	93.7					

7.2 RCC-M

7.2.1 Annex ZI 4.0

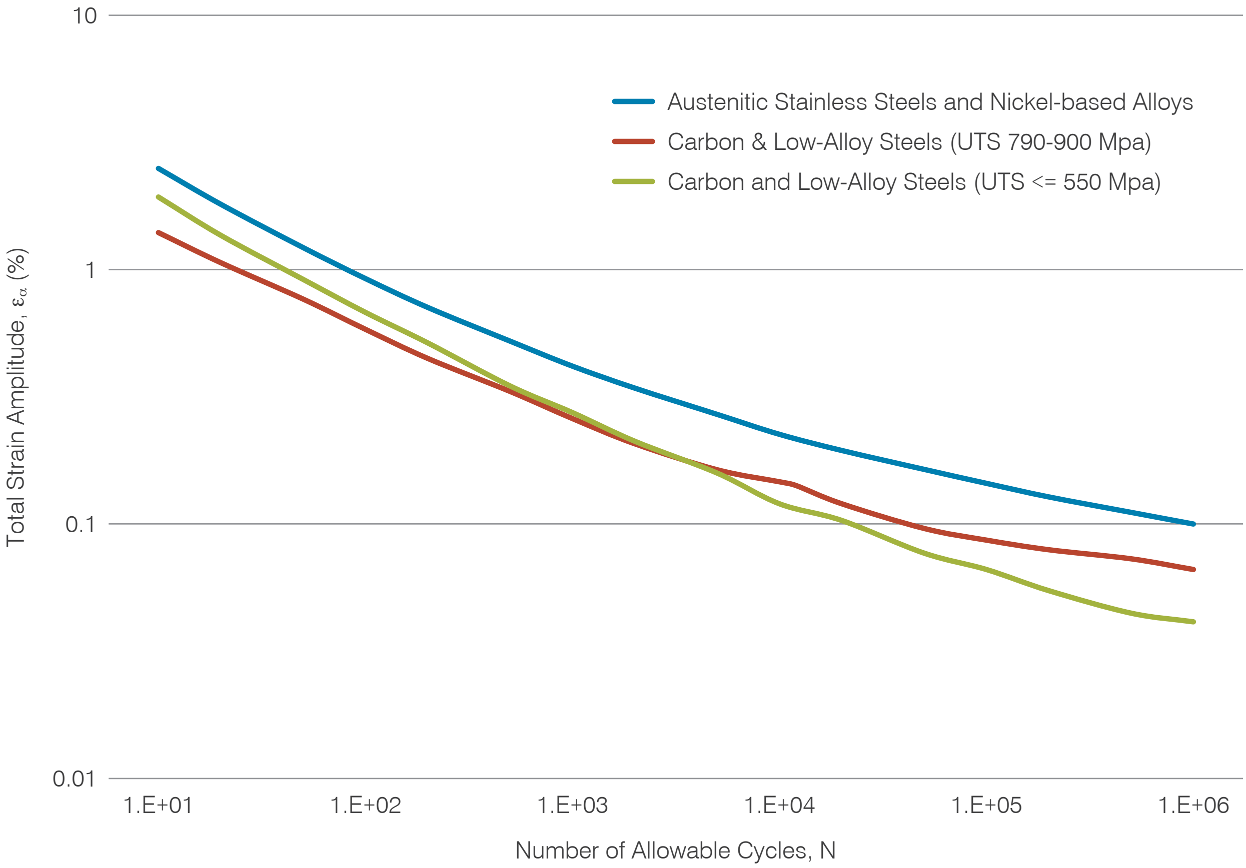

Figure 7-2. RCC-M Appendix ZI 4.0 Design Strain-Life Curves (Figure ZI 4.1 and Figure ZI 4.2)

Table 7-2. Tabulated values of strain amplitude, ε_a (%), and pseudo-stress amplitude, S_a (MPa), for Figure 7-2.

Austenitic Stainless Steel & Nickel-based Alloys (E_c = 179 GPa)			Carbon & Low-alloy Steels (E_c = 207 GPa)				
				UTS < 550 MPa		UTS 790-900 MPa	
N	ε_a (%)	S_a (MPa)	N	ε_a (%)	S_a (MPa)	ε_a (%)	S_a (MPa)
1.0E+01	2.503	4480	1.0E+01	1.932	4000	1.400	2900
2.0E+01	1.810	3240	2.0E+01	1.367	2830	1.068	2210
5.0E+01	1.223	2190	5.0E+01	0.918	1900	0.768	1590
1.0E+02	0.925	1655	1.0E+02	0.681	1410	0.585	1210
2.0E+02	0.712	1275	2.0E+02	0.517	1070	0.449	930
5.0E+02	0.525	940	5.0E+02	0.350	725	0.333	690
1.0E+03	0.419	750	1.0E+03	0.275	570	0.261	540
2.0E+03	0.344	615	2.0E+03	0.213	440	0.208	430
5.0E+03	0.271	485	5.0E+03	0.159	330	0.164	340
1.0E+04	0.226	405	1.0E+04	0.121	250	0.147	305
2.0E+04	0.196	350	1.2E+04			0.143	295
5.0E+04	0.165	295	2.0E+04	0.104	215	0.121	250
1.0E+05	0.145	260	5.0E+04	0.0773	160	0.0966	200
2.0E+05	0.129	230	1.0E+05	0.0667	138	0.0870	180
5.0E+05	0.112	200	2.0E+05	0.0551	114	0.0797	165
1.0E+06	0.101	180	5.0E+05	0.0449	93	0.0734	152
			1.0E+0 6	0.0416	86	0.0667	138

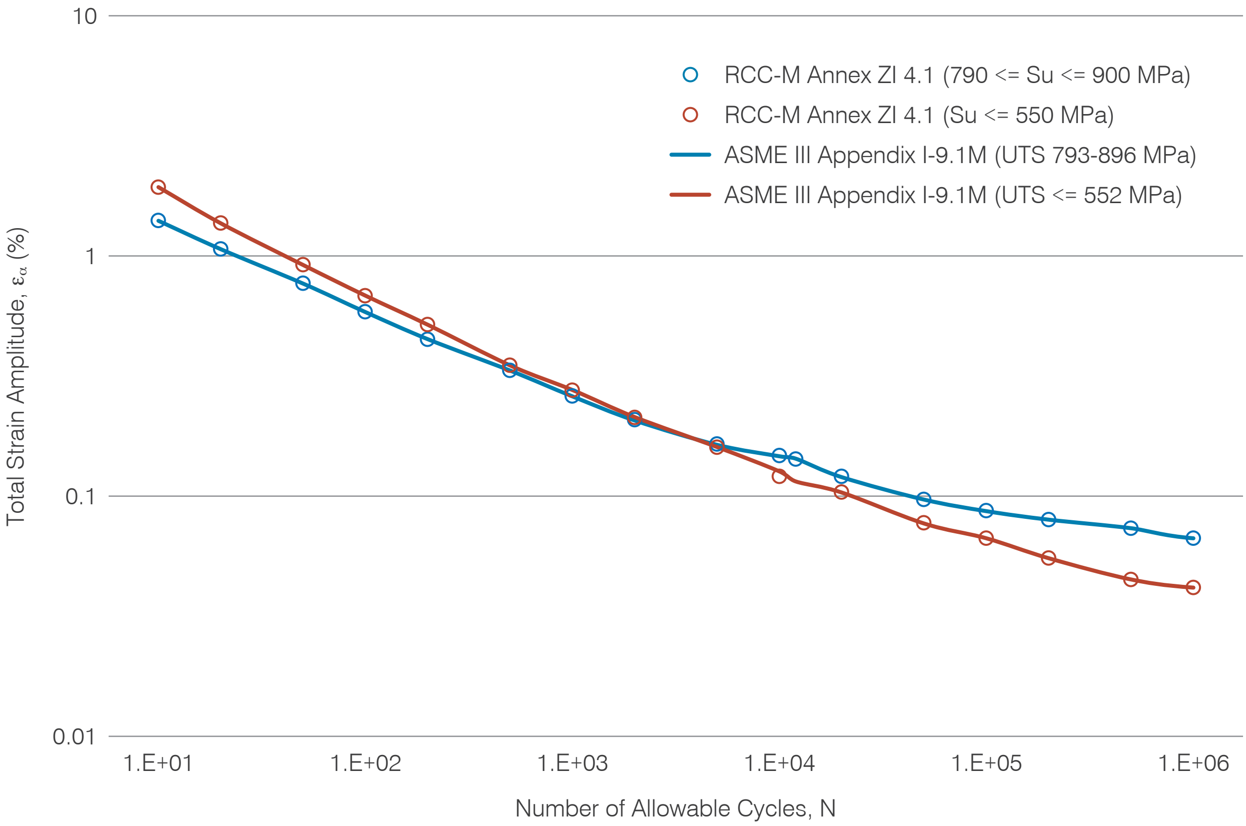

Figure 7-3. Comparison of RCC-M Annex ZI 4.1 with ASME III Appendix I-9.1M Design Curves for Carbon & Low-alloy Steels

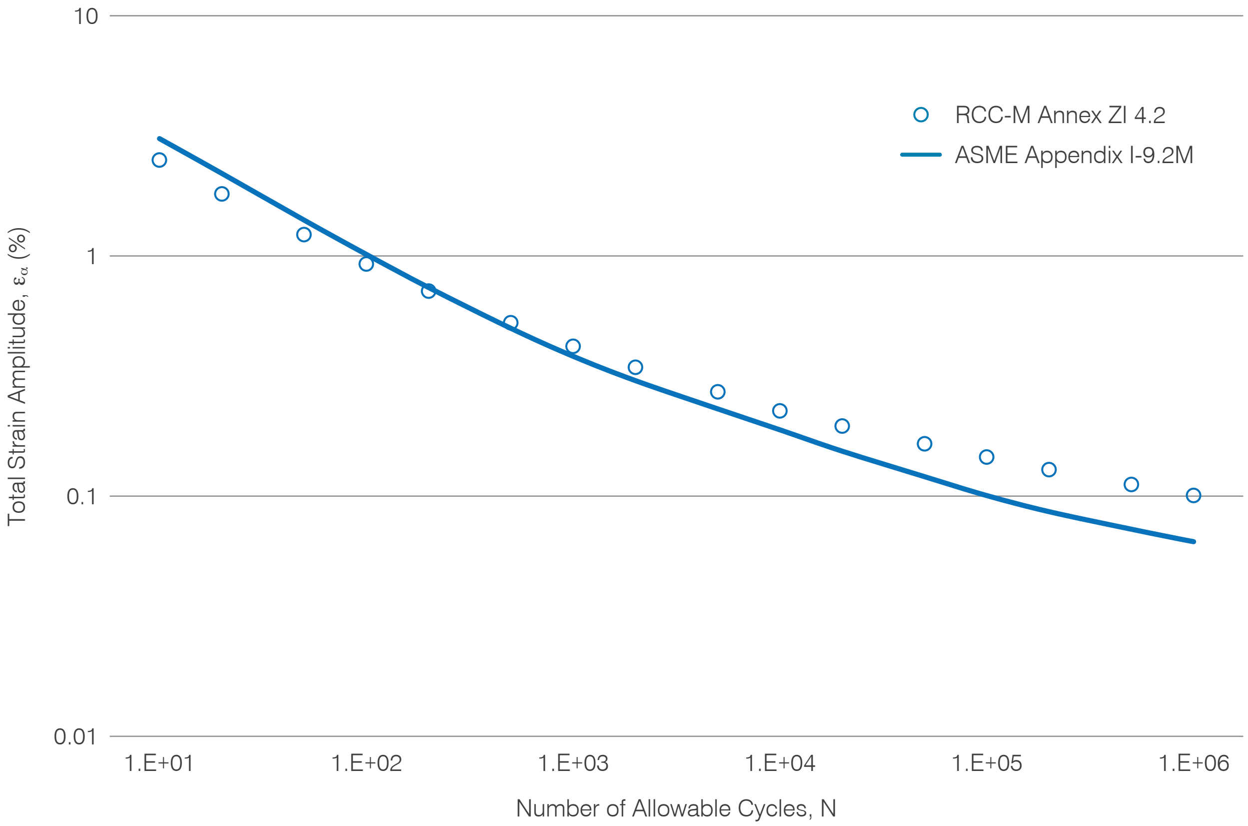

Figure 7-4. Comparison of RCC-M Annex ZI 4.2 and ASME III Appendix I-9.2M Design Curves for Austenitic Stainless Steels and Nickel-based Alloys

7.2.2 Annex ZD 2300

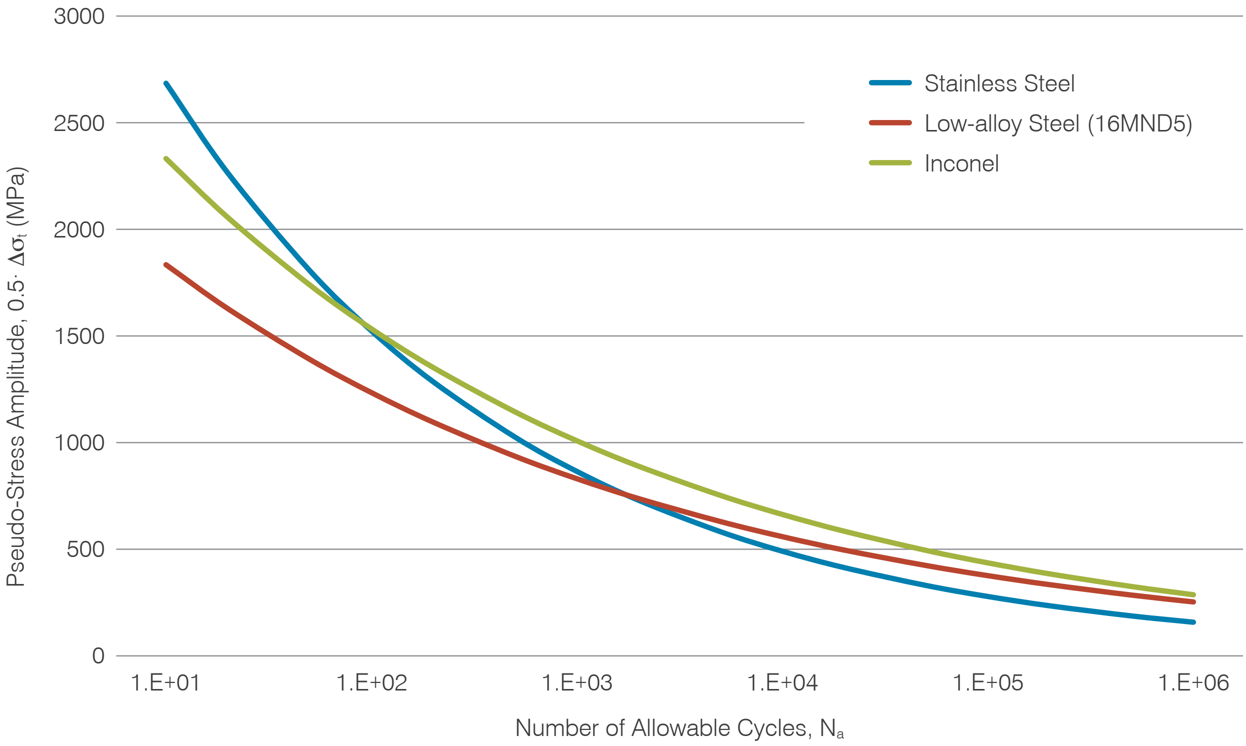

Figure 7-5. RCC-M Annex ZD 2300 Discontinuity Initiation Curves by Material Class

Table 7-3. (Table ZD 2300) Initiation Curve Relations for Figure 7-5.

Material	Environment	Distance, d (mm)	Curve
Low-alloy steel, type 16MND5	AIR and PWR	0.05	$\Delta\sigma_t = 5450(N_a)^{-0.172}$
Stainless Steel	AIR and PWR	0.059	$\Delta\sigma_t = 9460(N_a)^{-0.246}$
Inconel	AIR and PWR	0.046	$\Delta\sigma_t = 7090(N_a)^{-0.182}$

8 Appendix C - Plasticity Correction (K_e) Factors

This appendix presents the plasticity correction (K_e) factors for the different Codes/Standards under comparison. The K_e correction curves are presented graphically in terms vs S_n/S_m or S_p/S_m, whichever is applicable. Furthermore, the different Code K_e factors are also compared with K_e factors calculated directly from elastic-plastic FE analysis of representative plant components.

8.1 ASME III, Subsection NB

8.1.1 Mandatory Appendix XIII-3450

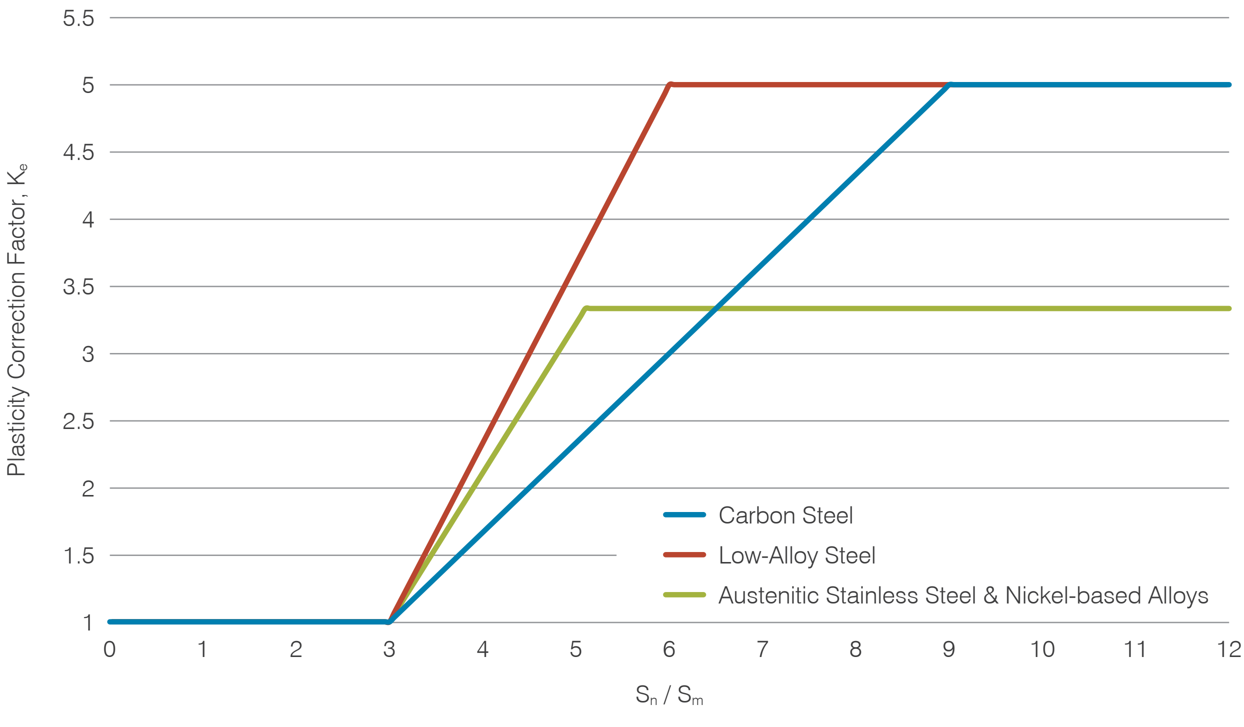

Figure 8-1. ASME Section III, Appendix XIII-3450 K_e vs. S_n / S_m Plasticity Correction Curves

8.1.2 Proposed Code Case (Record 17-225)

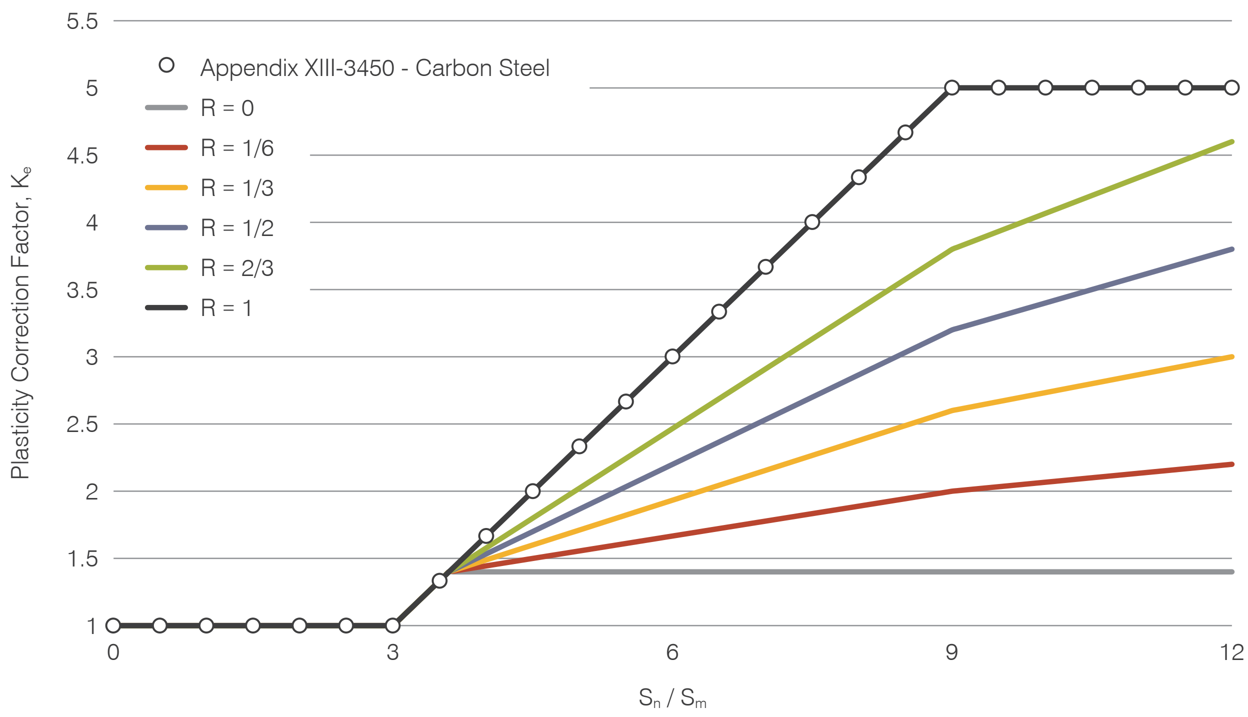

Figure 8-2. ASME Proposed Code Case (Record 17-225) K_e^R vs S_n / S_m Correction Curves for Carbon Steel

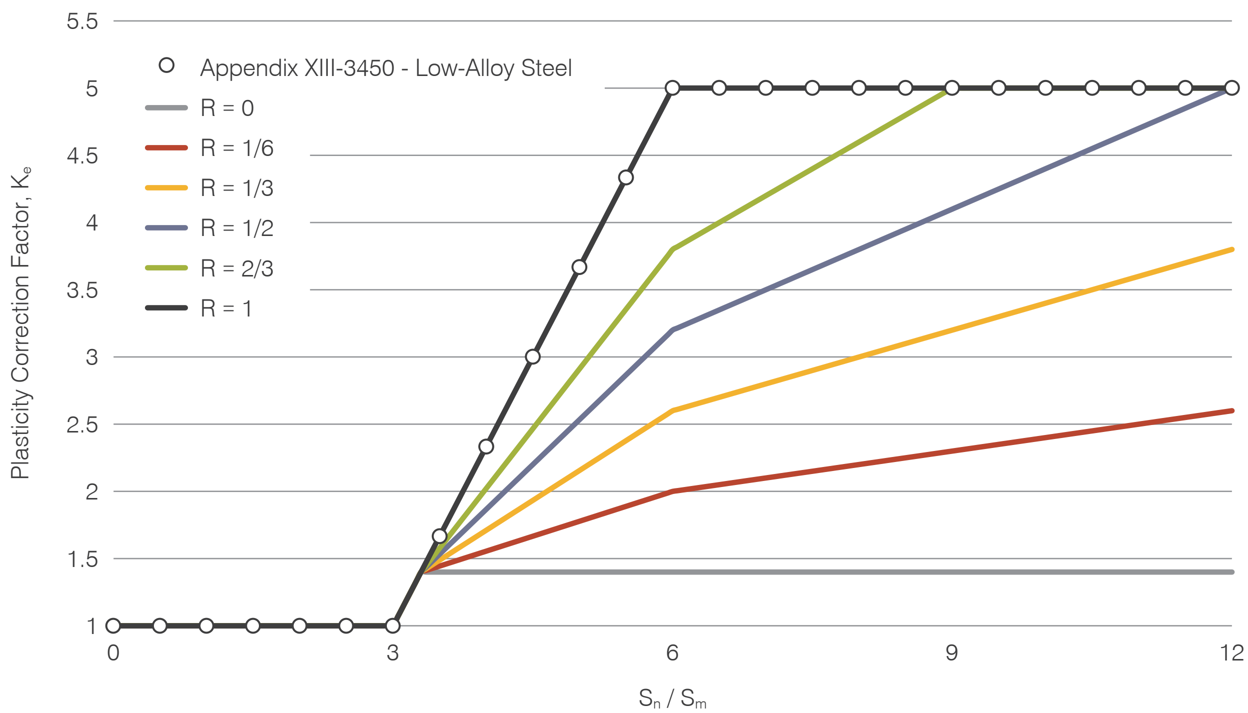

Figure 8-3. ASME Proposed Code Case (Record 17-225) K_e^R vs S_n / S_m Correction Curves for Low Alloy Steel

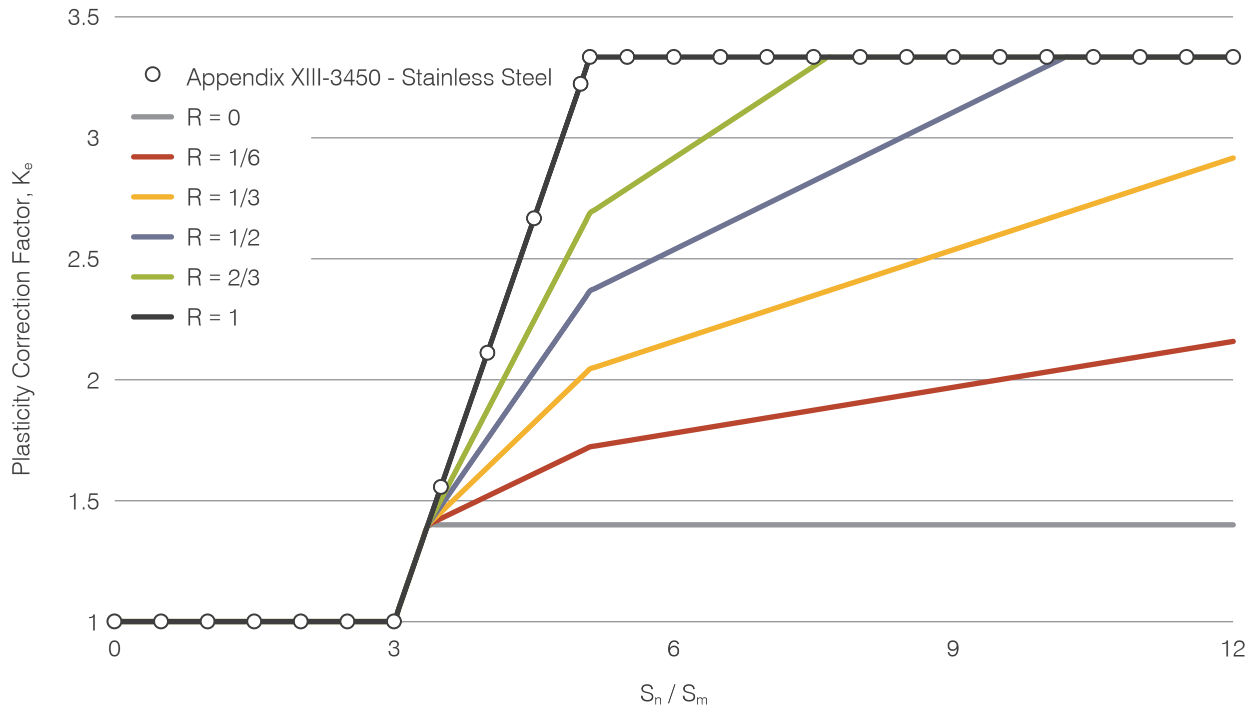

Figure 8-4. Proposed Code Case (Record 17-225) K_e^R vs S_n / S_m Correction Curves for Austenitic Stainless Steel and Nickel-based Alloys.

8.2 RCC-M B 3234.6

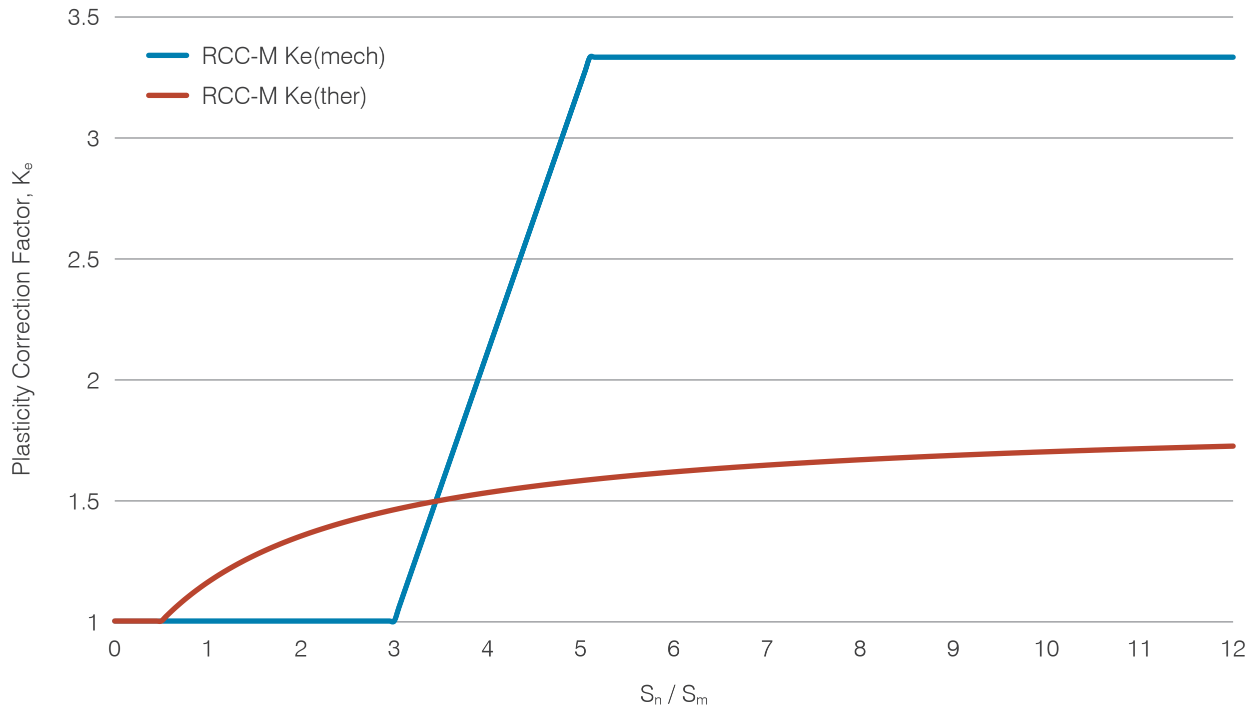

Figure 8-5. RCC-M B3234.6 Mechanical (K_e^{mech}) - and Thermal (K_e^{ther})-Plastic Correction Curves for Austenitic Stainless Steel and Nickel-based Alloys

8.3 JSME

8.3.1 PVB 3315.1

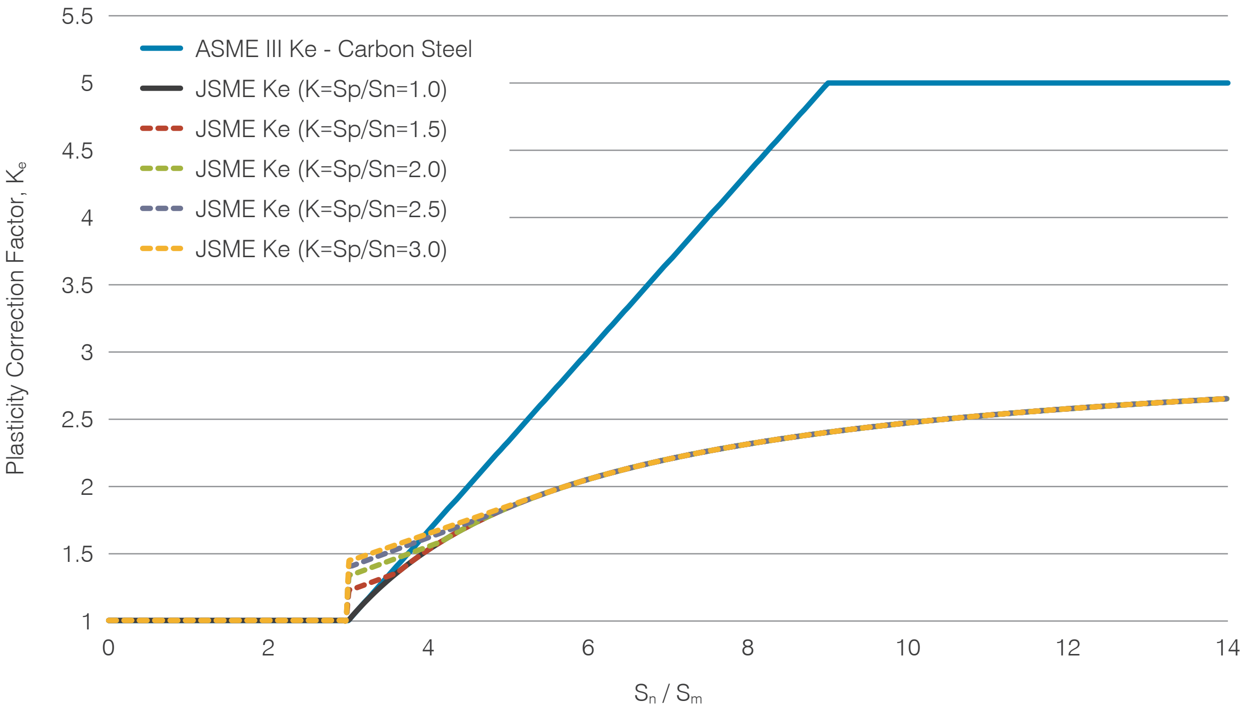

Figure 8-6. JSME PVB 3315.1 K_e vs S_n / S_m Correction Curves for Carbon Steel

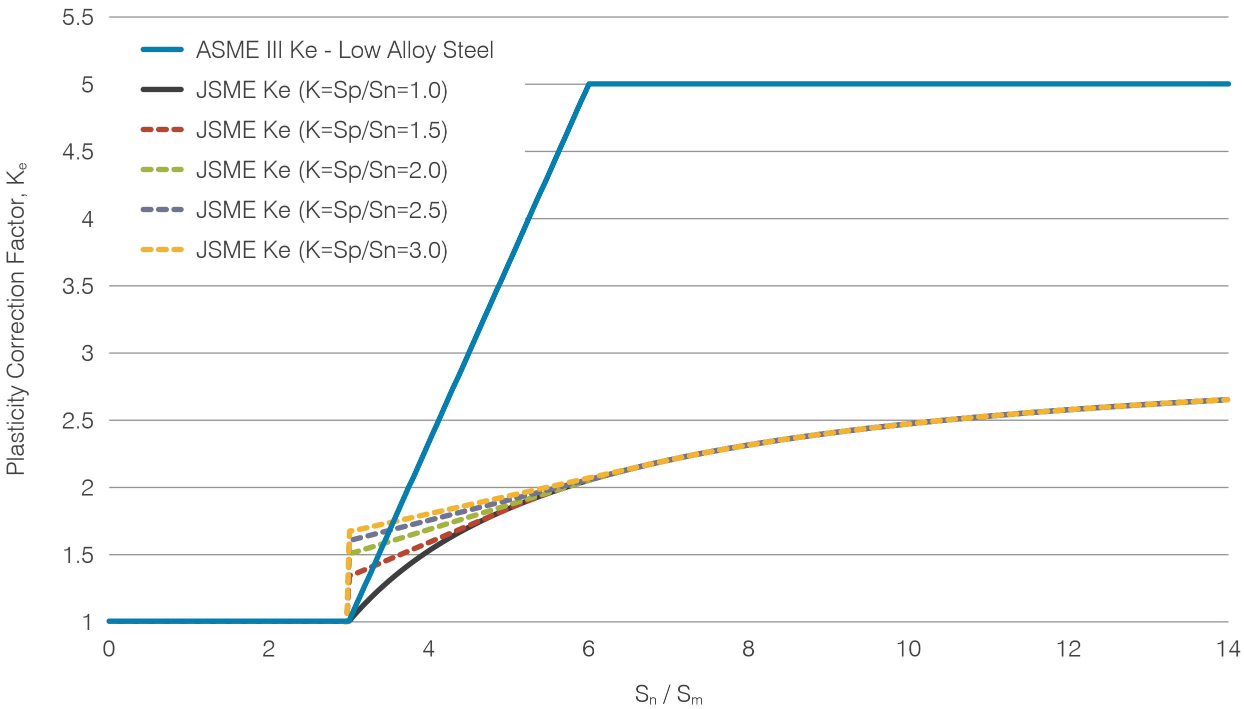

Figure 8-7. JSME PVB 3315.1 K_e vs S_n / S_m Correction Curves for Low Alloy Steel

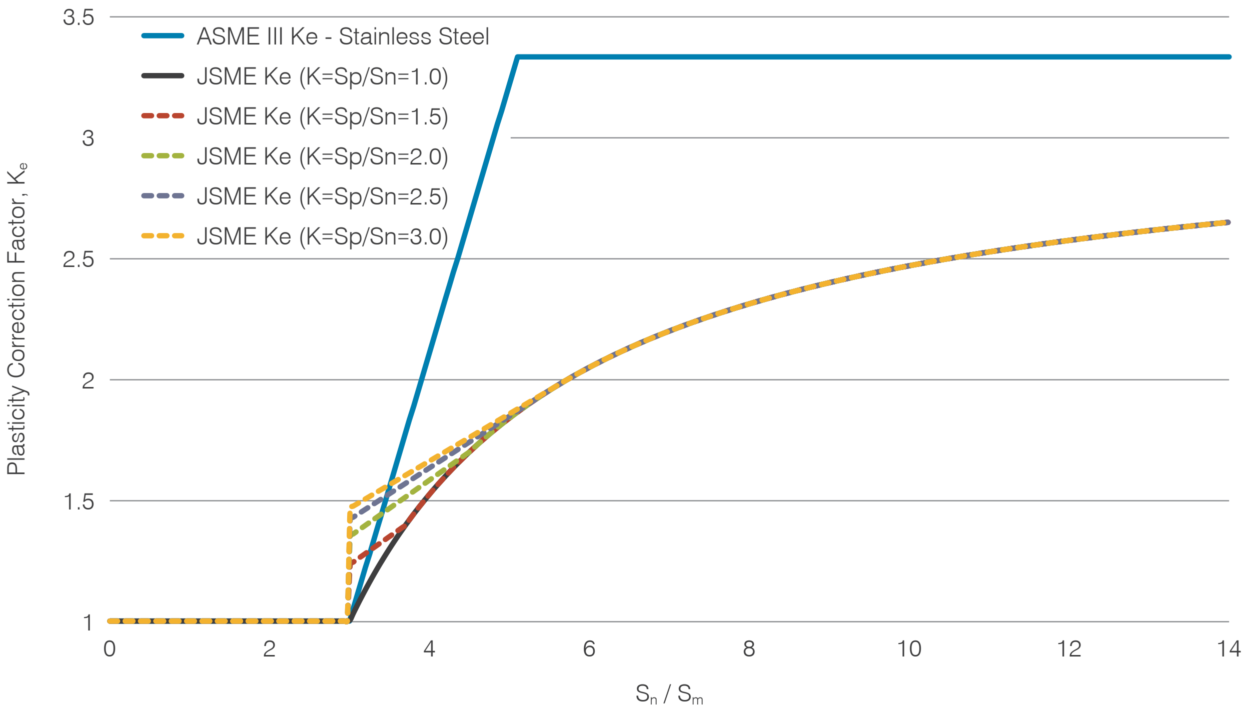

Figure 8-8. JSME PVB 3315.1 K_e vs S_n / S_m Correction Curves for Austenitic Stainless Steel

8.3.2 Code Case NC-CC-005

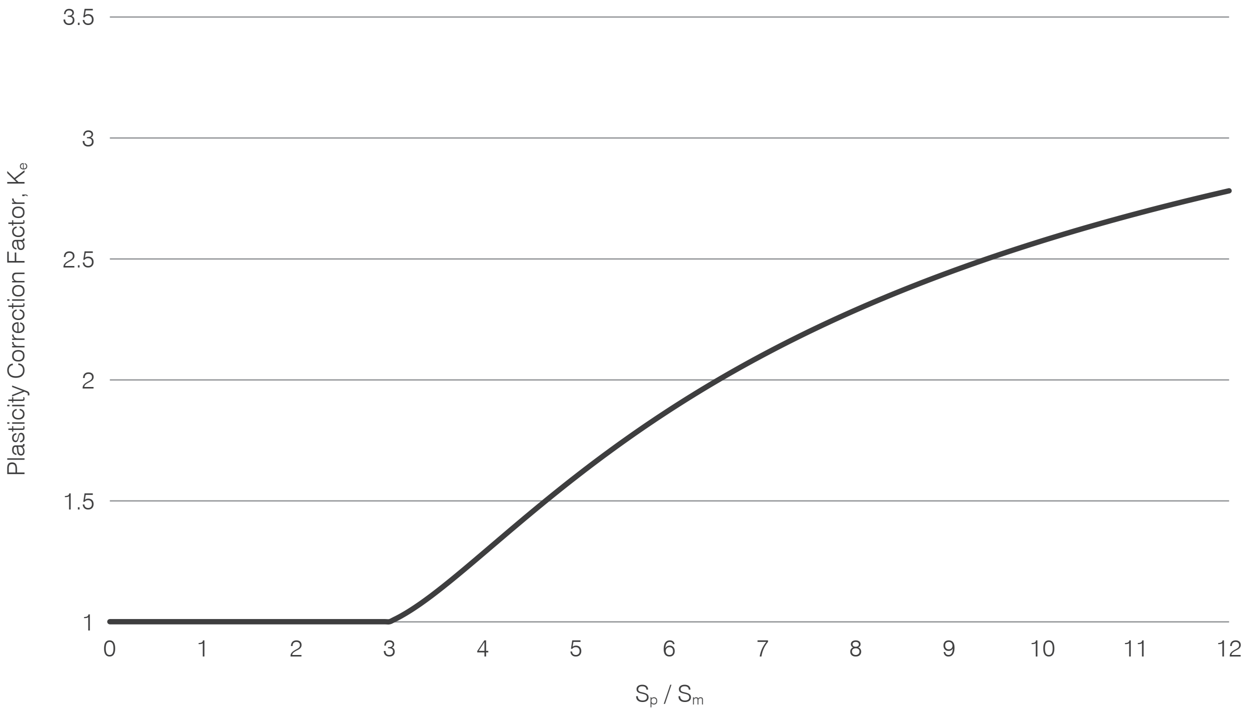

Figure 8-9. JSME Code Case NC-CC-005 K_e'' vs S_p / S_m Correction Curve Applicable to All Materials

8.4 Code K_e Factors vs K_e Derived by Elastic-Plastic FEA

This section presents a performance assessment of the plasticity correction (K_e) factors adopted by different Codes and Standards compared with the K_e factors obtained directly from elastic-plastic FE analysis. To enable a direct comparison between K_e methods that involve more than a single correction factor, an equivalent correction factor, $K_{e,eqv}$, must be determined. The purpose of $K_{e,eqv}$ is to reduce the combined effect of multiple plasticity correction factors to a single value whose effect on S_{alt} is equivalent, and it serves as the basis of comparison for all plasticity correction methods outlined in this report.

$K_{e,eqv}$ is calculated as follows:

$$K_{e,eqv} = \frac{2 \cdot S_{alt}}{S_p} \cdot \frac{E}{E_c}$$

Where S_{alt} is the alternating stress intensity after adjusting for plasticity and elastic modulus variation, and S_p is the elastically-calculated surface stress intensity range.

8.4.1 Bettis Stepped Pipe

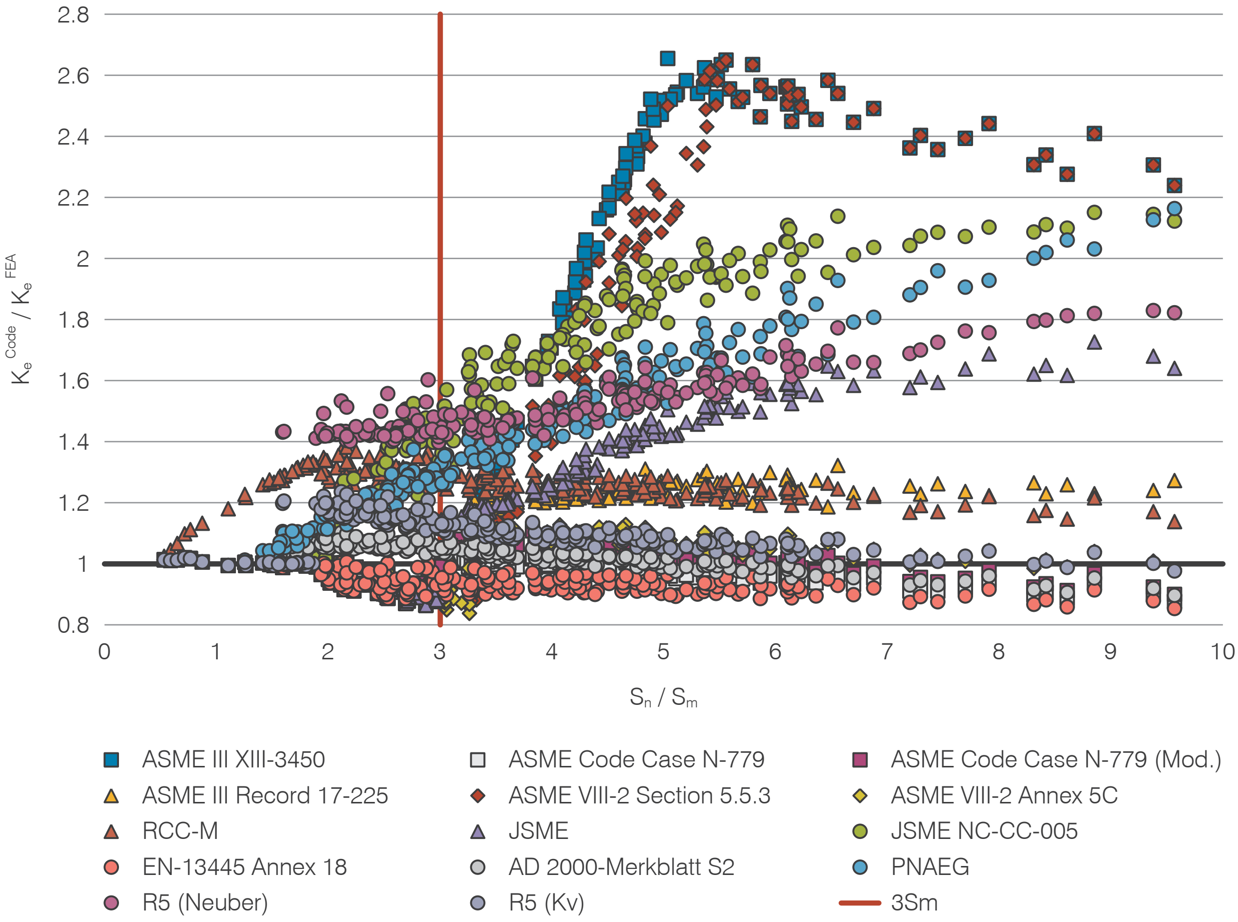

Figure 8-10. Conservatism of Code K_e vs S_n / S_m Correction Curves for Austenitic Stainless Steels Compared to Direct K_e Calculation by Elastic-Plastic FE Analysis. Clarkson, D.M., Bell, C.D., Mackenzie, D. [7]

9 References

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[2] ASME Boiler & Pressure Vessel Code, Section III - Rules for Construction of Nuclear Facilities Components, Subsection NB Class 1 Components, ASME, 2017 Edition

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This report, the first of a planned series of four, reviews and compares the current code and standard requirements of major nuclear design codes in the area of fatigue analysis and design rules based on the S-N approach. The focus of this comparison is Class 1 vessels of Light Water Reactor (LWR) plants.

The Cooperation in Reactor Design Evaluation and Licensing (CORDEL) Working Group promotes the development of a worldwide regulatory environment where internationally standardized reactor designs can be widely deployed without major design changes due to national regulations.