Code Case Nxxx

Alternative Rules for Level D Service Limits of Class 1, 2, and 3 Piping Systems

Section III, Division 1

Inquiry: What rules may be used for the design of Class 1, 2, and 3 piping systems subjected to reversing and/or non-reversing dynamic loads as an alternative to the requirements of Nonmandatory Appendix F, Paragraph F-1341.2 or Mandatory Appendix XXVII, Paragraph XXVII -3340?

*Reply:*In the opinion of the committee, the following rules may be used as an alternative to the rules of Nonmandatory Appendix F, Paragraph F-1341.2 or Mandatory Appendix XXVII, Paragraph XXVII-3340 for the design of Class 1, 2, and 3 piping systems subjected to reversing and/or non-reversing dynamic loads determined using an inelastic analysis.

1.0 Strain-Based Acceptance Criteria

This Code Case provides strain-based acceptance criteria for evaluation of piping systems subjected to loadings for which Level D Service Limits are specified.

2.0 Basis and Limitations

2.1 Basis

The strain-based acceptance criteria establish plastic strain limits that maintain pressure boundary integrity in piping and piping components when subjected to non-reversing dynamic loads, reversing dynamic loads combined with non-reversing dynamic loads, and reversing dynamic loads alone. A limited number of proven ductile materials are allowed for which the strain limits have been established with sufficient margins of safety.

2.2 Criteria Limitations

A number of limitations are imposed that shall be satisfied in order to use these strain-based acceptance criteria. These limitations are specified in the paragraphs below.

2.2.1 Applicability Limitations

This Code Case is limited to the evaluation of the following dynamic events: Non-reversing dynamic loads or reversing dynamic loads combined with non-reversing dynamic loads as discussed in Section 4.2.2, and reversing dynamic loads by themselves as discussed in Section 4.2.3. A reversing dynamic load shall be classified as a non-reversing dynamic load and subject to the limits of Section 4.2.2 when the total number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20, per NB/NC/ND-3622.2 and Appendix XIII, Paragraph XIII-1300(aa). Earthquake loads shall be classified as reversing dynamic loads and subject to the limits of Section 4.2.3.

2.2.2 Material Limitations

The strain-based acceptance criteria shall only be applied to a limited set of materials. The permitted ASME material specifications (as restricted by Table 2A of Section II, Part D, Subpart 1) are listed in Table 2-1 below. Materials used shall have sufficient material properties determined in order to properly implement the strain-based acceptance criteria and these properties and their implementation in the analysis shall be justified in the final Design Report. True stress-strain curves are required. To obtain bounding strains, analyses with lower bound and with upper bound stress-strain curves are required. All weld materials for piping full penetration butt welds shall be compatible with the base metal as required by NB/NC/ND-4240. When ASME-specified material properties associated with the strain-based acceptance criteria are not available, the user must develop the necessary strain properties data for the base material and weld material. The properties used and the basis to establish these properties shall be provided in the final Design Report.

Table 2-1: Permitted Material Specifications and Products

Material Specification	Type/Grade	Product
SA-312 (Excluding HCW pipe)	TP304L, TP304, TP316L, TP316	Seamless pipe
SA-376	TP304, TP316	Seamless pipe
SA-403	304	Pipe fittings
SA-106	Grade B	Seamless pipe
SA-234	WPB	Pipe fittings

2.2.3 Temperature Limitations

The applicable temperature range for stainless steel materials shall be limited from 32°F to 800°F (0°C to 425°C). The maximum material temperature for carbon steel is 700°F (370°C) and the minimum material temperature for carbon steel is the RT_{NDT} +100°F (56°C), where RT_{NDT} is determined in accordance with NB-2330 for Class 1. For Class 2 and 3, the minimum material temperature for carbon steel shall be taken as defined for Class 1.

2.2.4 Welded Joints Limitations

The applicability of these strain-based acceptance criteria to welds is limited to full-penetration butt welded joints only. Other categories of welds and their ~~heat-affected zones~~local region shall not use the strain-based acceptance criteria but the base material adjacent to those other types of welded joints and local region~~heat-affected zones~~ may use the strain-based acceptance criteria. The local region~~heat-affected zone~~ shall be the ~~zone~~ region on each side of the weld with a distance $\sqrt{D_o T_{nom}}$ from the edge of the weld. D_0 is the piping outside diameter and T_{nom} is the pipe nominal wall thickness.

2.2.5 Fabrication Strain Limitations

Any process may be used to hot or cold form or bend component material provided that the following requirements are met:

(a) Fabrication-induced strains less than or equal to 5% do not need to be addressed in the strain-based acceptance criteria nor are additional heat treatments required to reduce the effects of these strains.

The percent fabrication strain for pipe shall be established by the following equation:

$$\%\ fabrication\ strain = \frac{100r}{R}$$

where r is nominal radius of the pipe and R is nominal bending radius to the centerline of the pipe

(b) Fabrication strains that exceed 5%, but are not greater than 10%, shall require heat treatment per requirements in Section II, Part A, specification SA-106, SA-312, or SA-376. The use of this Code Case with fabrication strains that exceed 10% is not permitted.
(c) Residual stresses and the associated material strains in, or adjacent to, welds resulting from the welding process alone including repair welding and post-weld heat treatment processes, if any, shall not be considered in the determination of fabrication strains.

2.2.6 Exclusions

The strain-based acceptance criteria shall not be applied to the following locations:

(a) structural or non-structural attachments that are welded to the pipe
(b) flanges, bolted connections, clamped joints, bellows joints, and mitered elbows
(c) fillet or partial penetration welds and their heat-affected zones, including welds of attachments to the pipe boundary
(d) threaded connections, even if they are seal welded
(e) configurations where dominant loads cause compressive strain

3.0 Accurate Strain Determination

The strain-based acceptance criteria should be implemented using strains calculated from an analytical model with suitable convergence and sensitivity studies that demonstrate the accurate capability of the model. The analytical model should be created with acceptable elements, appropriate meshing, correct material property input (using true stress-strain curve), realistic boundary conditions and loading, acceptable calculation of Triaxiality Factor as defined in 4.3, and correct solution technique and strain outputs. The analysis should consider the effect of changes in geometry on stresses and strains and use a formulation that is consistent with the use of true stress and true strain.

4.0 Strain-Based Acceptance Criteria

4.1 Calculation of Applied Strain

The equivalent strain ε_{eq} is the combination of the initial elastic strain to the yield strain plus all inelastic strain after the yield strain is reached.

$$\varepsilon_{eq} = \varepsilon_{eq}^{e} + \varepsilon_{eq}^{P} \quad (1)$$

Where ε_{eq} is the equivalent strain, ε_{eq}^{e} is elastic strain before reaching the yield stress of the stress-strain curve used in the analysis, and the inelastic strain is defined as follows:

$$\varepsilon_{eq}^{P} = \int_{0}^{t} (\frac{2}{3} \dot{\varepsilon}_{ij}^{p} \dot{\varepsilon}_{ij}^{p})^{1/2} dt \quad (2)$$

$\dot{\varepsilon}_{ij}^{p}$ is the inelastic strain rate tensor with *ij* in tensor notation, i=1, 2, 3, and j =1, 2, 3, where 1, 2, 3 represent three orthogonal directions, and t is the time interval.

The ε_{eq}value shall be determined by the appropriate consideration of all simultaneously occurring loads including pressure and all sustained loads. When the non-reversing dynamic loads are combined with reversing dynamic loads, only a single analysis shall be used to calculate ε_{eq}. The final equivalent strain may be load path-dependent. The interaction between different loads shall be appropriately considered in the analysis method to determine the maximum equivalent strain that could occur.

4.2 Strain Limits

4.2.1 Strain Limits for Membrane plus Bending Strain due to Pressure and other Sustained Loads

The equivalent elastic membrane plus bending strain $(\varepsilon_{eq}^{e})_{SL}$ due to pressure and all sustained loads, calculated by elastic analysis and averaged across the pipe wall, shall be limited as follows:

$$(\varepsilon_{eq}^{e})_{SL} \leq \varepsilon_{y} \quad (3)$$

where

ε_y = the true strain value corresponding to the Code specified yield stress at a temperature consistent with the loading under consideration per Section II, Part D, Table Y-1

This shall be applied to Section 4.2.2 and 4.2.3.

4.2.2 Strain Limits for Non-Reversing Dynamic Loads or Non-Reversing Dynamic Loads Combined with Reversing Dynamic Loads

The following requirements shall apply:

(a) The requirements of Section 4.2.3 (b) and (c) shall be met for any Reversing Dynamic Loads.

(b) All average equivalent strain $(\varepsilon_{eq})_{ave}$ across the pipe wall shall be limited as follows:

$$(TF)(\varepsilon_{eq})_{ave} \leq 0.35n \quad (4)$$

where

TF = Triaxiality Factor, see Section 4.3

n = strain hardening exponent per Mandatory Appendix XIII, Table XIII-3450-1 for the applicable material

(c) The maximum equivalent strain $(\varepsilon_{eq})_{max}$ of the pipe shall be limited as follows:

$$\left\{\frac{\sinh\left[\frac{\sqrt{3}}{3}(1-n)(TF)\right]}{\sinh\left[\frac{\sqrt{3}}{3}(1-n)\right]}\right\}(\varepsilon_{eq})_{max} \leq 0.45\varepsilon_f \quad (5)$$

where

TF = Triaxiality Factor, see Section 4.3

ε_f = the true strain at fracture, defined in Nonmandatory Appendix EE

n = strain hardening exponent as in Section 4.2.2(b).

4.2.3 Strain Limits for Reversing Dynamic Loads Not Required to be Combined with Non-Reversing Dynamic Loads

The following requirements shall apply:

(a) The number of cycles of reversing dynamic load exclusive of earthquake shall be equal to or less than 20. Earthquake loads shall be considered as reversing dynamic loads, per NB/NC/ND-3622.2 and Appendix XIII, Paragraph XIII-1300(aa).

(b) The equivalent elastic membrane plus bending strain $(\varepsilon^e_{eq})_{DWT}$ of the piping due to deadweight shall be limited as follows:

$$(\varepsilon^e_{eq})_{DWT} \leq {}^1\!/_3\,\varepsilon_y \quad (6)$$

where:

ε_y = as defined in Section 4.2.1

(c) The maximum equivalent strain $(\varepsilon_{eq})_{max}$ of the pipe shall be limited as follows:

$$(TF)(\varepsilon_{eq})_{max} \leq \varepsilon_a \quad (7)$$

$$\varepsilon_a = \frac{[S_a(N)]a}{E} \quad (8)$$

where

ε_a = the allowable true strain amplitude as defined in equation (8)

TF = Triaxiality factor, see Section 4.3

E = Young's modulus, can be obtained from Figure I-9.1 or I-9.2 of Section III Appendices, Mandatory Appendix I as applicable

$S_a(N)$ = allowable stress amplitude S_a for N cycles of load and can be obtained from Figure I-9.1 or I-9.2 of Section III Appendices, Mandatory Appendix I; N shall not be less than 10

N = Number of cycles of dynamic load

a = 2.3 for S_a values from Figure I-9.1

$a = 1.5$ for S_a values from Figure I-9.2

4.3 Triaxiality Factor

The Triaxiality Factor is determined in accordance with Nonmandatory Appendix FF, Paragraph FF-1143. The maximum TF is conservatively used in the analysis to determine the strain limit for average equivalent strain in Section 4.2.2(b) regardless of time and location. For maximum equivalent strain in Section 4.2.2(c) and Section 4.2.3(c), the corresponding TF where the maximum strain occurs shall be used for evaluation.

4.4 Other Requirements

4.4.1 Analysis Incorporation in the Design Report

Analysis complying with this Code Case shall be included in the Design Report for the piping system.

4.4.2 Identification of use of this Code Case

Use of this Code Case shall be identified in the Design Specification, Design Report and on the N-5 Data Report Form.