NOTES L.8

SUBSECTION A

Requirements for Class A Vessels

ARTICLE 2

Introduction

N-210 SCOPE

Subsection A contains rules for the materials, design, fabrication, inspection and testing, and certification of Class A vessels.

N-220 TEMPERATURE LIMITS

The rules of this Subsection are not intended to be used:

(a) For vessels that are to operate at temperatures above those for which design stress values are given in Tables N-421, N-422, and N-423, at which temperatures creep and stress-rupture are significant factors.

Fatigue design curves and specified methods for fatigue analysis are not applicable above 700 F for materials covered by Fig. N-415*(a)* and above 800 F for materials covered by Fig. N-415*(b)*.

(b) For vessels that are to operate at temperatures below the nil-ductility-transition (NDT) temperature + 60 F of the material, at which temperatures brittle fracture may occur (see N-330).

dictional limit shall be considered in the stress analysis of the attachment.

N-160 NOMENCLATURE

The symbols used in this Section of the Code have the following meanings:

A = total required cross-sectional area of compensation, sq in.
D = inside diameter of shell or head, in.
D_o = outside diameter of shell or head, in.
d = inside diameter of nozzle, in.
d_o = outside diameter of nozzle, in.
E = modulus of elasticity, (Young's modulus), psi
h = minor semidiameter of ellipsoidal head, in.
K = stress concentration factor
F = calculated local or concentrated stress component[1], psi
m = gasket factor
N = allowable number of stress cycles at a given level
n = expected repetitions of a type of stress cycle
P_b = calculated primary bending stress component,[1] psi
P_L = calculated local primary membrane stress component,[1] psi
P_m = calculated general primary membrane stress component,[1] psi
p = internal pressure, psi
Q = calculated secondary stress component,[1] psi
R = inside radius of shell or head, in.
R_o = outside radius of shell or head, in.
r = intermediate radius of an internal point in the shell wall under consideration, in..
S = stress intensity (largest absolute value of S_{12}, S_{23}, and S_{31}) psi
S_a = allowable amplitude of alternating stress intensity, psi
S_{alt} = calculated amplitude of alternating stress intensity, psi
S_e = endurance limit (or endurance strength at 10^7 cycles), psi
S_m = design stress intensity value (see Tables N-421 and N-422), psi
S'_{mean} = basic value of the calculated mean stress intensity, psi
S_{mean} = adjusted value of the calculated mean stress intensity, psi
S_r = calculated range of alternating stress intensity, psi
S_u = ultimate tensile strength, psi
S_y = yield strength, (0.2 per cent offset) psi
S_{12} = algebraic difference between σ_1 and σ_2, psi
S_{23} = algebraic difference between σ_2 and σ_3, psi
S_{31} = algebraic difference between σ_3 and σ_1, psi
T_S = thickness of shell at nozzle, in.
t = thickness of shell, in.
t_c = throat dimension of fillet weld, in.
t_n = thickness of nozzle, in.
t_r = required thickness, in.
U = cumulative use factor
y = gasket unit seating load, psi
θ = angle of slope of nozzle (see Fig. I-613)
σ_t = tangential (circumferential) stress component, psi
σ_l = longitudinal (meridional) stress component, psi
σ_r = radial stress component, psi
$\sigma_1, \sigma_2, \sigma_3$ = principal stresses, psi
τ_{tl} = shear component in tl-plane, psi
τ_{lr} = shear component in lr-plane, psi
τ_{rt} = shear component in rt-plane, psi
α = coefficient of thermal expansion

[1]The symbols F, P_b, P_L, P_m, and Q do not represent single quantities, but sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{tl}, τ_{lr}, and τ_{rt}.

ARTICLE 4

Design

N-410 DESIGN CRITERIA

The requirements for the acceptability of a design are:

(a) The design shall be such that stresses will not exceed the limits described in N-414, N-415, N-416, and N-417 and tabulated in Tables N-421, N-422, and N-423.

(b) The design details shall conform to the rules given in N-440 to N-474.

(c) For configurations where compressive stresses occur, in addition to the requirements in *(a)* and *(b)* the critical buckling stress shall be taken into account. (For the special case of external pressure see N-417.3).

N-411 Basis for Determining Stresses – The equivalent stress at any point in a vessel is the value of stress deduced from the stress condition at the point by means of a theory of failure for comparison with the mechanical properties of the material obtained in tests under uniaxial load. The theory of failure used in the rules of this Subsection for combining stresses is the maximum shear stress theory. The maximum shear stress at a point is equal to one-half the difference between the algebraically largest and the algebraically smallest of the three principal stresses at the point.

N-412 Terms Relating to Stress Analysis – Terms used in this Subsection relating to stress analysis are defined as follows:

(a) Stress Intensity – The "equivalent intensity of combined stress", or in short, the "stress intensity", is defined as twice the maximum shear stress. In other words, the stress intensity is the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tension stresses are considered positive and compression stresses are considered negative.

(b) Gross Structural Discontinuity – A source stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole.

Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles (except see N-451), and junctions between shells of different diameters or thicknesses.

(c) Local Structural Discontinuity – A source of stress or strain intensification which affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole.

Examples are small fillet radii, small attachments, and partial penetration welds.

(d) Normal Stress – The component of stress normal to the plane of reference. (This is also referred to as direct stress.)

Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components, one of which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration, and the other of which varies with the location across the thickness.

(e) Shear Stress – The component of stress tangent to the plane of reference.

(f) Membrane Stress – The component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

(g) Bending Stress – The variable component of the normal stress described in *(d)*. The variation may or may not be linear across the thickness.

(h) Primary Stress – A normal stress or a shear stress developed by the imposed loading which is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments.

The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure, or at least in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into "general" and "local" categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding.

Examples of primary stress are:

(1) General membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads.

(2) Bending stress in the central portion of a flat head due to pressure.

(i) Secondary Stress—A normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur, and failure from one application of the stress is not to be expected.

Examples of secondary stress are:

(1) General thermal stress (see *(m) (1)*).

(2) Bending stress at a gross structural discontinuity.

(j). Primary Local Membrane Stress – Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a primary and/or a discontinuity effect produces excessive distortion in the transfer of load to other portions of the structure. Conservatism requires that such a stress be classified as a primary local membrane stress even though it has some characteristics of a secondary stress.

A stressed region may be considered local if the distance over which the stress intensity exceeds 1.1 S_m does not extend in the meridional direction more then $0.5\sqrt{Rt}$ and if it is not closer in the meridional direction than $2.5\ \sqrt{Rt}$ to another region where the limits of general primary membrane stress are exceeded, where R is the mean radius of the vessel and t is the wall thickness at the location where the general primary membrane stress limit is exceeded.

An example of a primary local membrane stress is the membrane stress in a shell produced by external load and moment at a permanent support or at a nozzle connection.

(k) Peak Stress – The increment of stress which is additive to the primary plus secondary stresses by reason of stress concentrations or local thermal stress (see *(m) (2)*) including the effects (if any) of stress concentrations.

The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or a brittle fracture. A stress which is not highly localized falls into this category if it is of a type which cannot cause noticeable distortion. Examples of peak stress are:

(1) The thermal stress in the austenitic steel cladding of a carbon steel vessel.

(2) The thermal stress in the wall of a vessel or pipe caused by a rapid change in temperature of the contained fluid.

(3) The stress at a local structural discontinuity.

(l) Load Stress – The stress resulting from the application of a load, such as internal pressure or the effects of gravity, as distinguished from thermal stress.

(m) Thermal Stress – A self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature.

For the purpose of establishing allowable stresses, two types of thermal stress are recognized, depending on the volume or area in which distortion takes place, as follows:

(1) General thermal stress which is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds twice the yield strength of the material, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore this type is classified as secondary stress in Table N-413 and Fig. N-414.

Examples of general thermal stress are:

(a) Stress produced by an axial thermal gradient in a cylindrical shell,

(b) Stress produced by the temperature difference between a nozzle and the shell to which it is attached.

(2) Local thermal stress which is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall be considered only from the fatigue standpoint and are therefore classified as local stresses in Table N-413 and Fig. N-414. In evaluating local thermal stresses the procedures of N-417.5 (b) shall be used.

Examples of local thermal stress are:

(a) The stress in a small hot spot in a vessel wall.

(b) Stress from a radial temperature gradient in a cylindrical shell.

(c) The thermal stress in a cladding material which has a coefficient of expansion different from that of the base metal.

(n) Operational Cycle – An operational cycle is defined as the initiation and establishment of new conditions followed by a return to the conditions that prevailed at the beginning of the cycle. Three types of operational cycles are considered:

(1) **Startup-shutdown cycle, defined as any** cycle which has atmospheric temperature and/or pressure as one of its extremes and normal operating conditions as its other extreme.

(2) The initiation of and recovery from any emergency or upset condition that must be considered in the design.

(3) Normal operating cycle, defined as any cycle between startup and shutdown which is required for the vessel to perform its intended purpose.

(o) Stress Cycle – A stress cycle is a condition in which the alternating stress difference (see N-415.2*(a)(2)*) goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. A single operational cycle may result in one or more stress cycles.

(p) Fatigue Strength Reduction Factor – 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 elsewhere in this Subsection. In the absence of experimental data, the theoretical stress concentration factor may be used.

(q) Shakedown – The absence of a continuing cycle of plastic deformation. A structure shakes down if after a few cycles of load application, the deformation stabilizes and subsequent structural response is elastic, excluding creep effects.

(r) Limit Analysis-Collapse Load

The methods of limit analysis are used to compute the maximum load a structure made of ideally plastic (non-strain hardening) material can carry. The deformations of an ideally plastic structure increase without bound at this load, which is termed the "collapse load." This concept is useful since deformations of structures made of real materials are in general of an elastic order of magnitude for any load below the collapse load.

(s) Collapse Load-Lower Bound

If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load.

N-413 Derivation of Stress Intensities – One requirement for the acceptability of a design (see N-410*(a)* is that the calculated stress intensities shall not exceed specified allowable limits. These limits differ depending on the stress category (primary, secondary, etc.) from which the stress intensity is derived. This paragraph describes the procedure for the calculation of the stress intensities which are subject to the specified limits. The steps in the procedure are as follows:

(a) At the point on the vessel which is being investigated, choose an orthogonal set of coordinates such as tangential, longitudinal, and radial, and designate them by the subscripts t, l, and r. The stress components in these directions are then designated σ_t, σ_r, and σ_l for direct stresses, and τ_{tl}, τ_{lr}, and τ_{rt} for shearing stresses.

(b) Calculate the stress components for each type of loading to which the part will be subjected and assign each set of stress values to one or a group of the following categories:[1]

(1) General primary membrane stress, P_m (see N-412*(f)* and *(h)*).

(2) Local primary membrane stress, P_L (see N-412*(j)*).

(3) Primary bending stress, P_b (see N-412 *(g)* and *(h)*).

(4) Secondary stress, Q^2 (see N-412*(i)*).

(5) Peak stress, F (see N-412*(k)*).

(c) Group the stress components in accordance with N-413*(b)*. Figure N-414 is to provide assistance in assigning the stress values to the appropriate category. At any rectangular box calculate the algebraic sum of the σ_t's which result from the different types of loadings and which have entered the box, and similarly for the other five stress components. The result is a set of six stress components in each box.

(d) Translate the stress components in the t, l, and r directions into principal stresses, σ_1, σ_2 and σ_3. (In many pressure vessel calculations, the t, l, and r directions may be so chosen that the shearing stress components are zero and σ_1, σ_2, and σ_3 are identical to σ_t, σ_l, and σ_r.)

[1] See Table N-413 and Note 4 of Fig. N-414.

[2] Subdivision of secondary stresses into membrane and bending components is not required because the same stress limits apply to both components.

(e) Calculate the stress differences S_{12}, S_{23}, and S_{31} from the relations

$$S_{12} = \sigma_1 - \sigma_2$$
$$S_{23} = \sigma_2 - \sigma_3$$
$$S_{31} = \sigma_3 - \sigma_1$$

The stress intensity, S, is the largest absolute value of S_{12}, S_{23} and S_{31}.

(Note: Membrane stress intensity is derived from the stress components averaged across the thickness of the section. The averaging shall be performed at the component level, in step *(b)* or *(c)* above.)

(f) The stress intensity calculated as in *(e)* from the stress components in any rectangle in Fig. N-414 shall not exceed the allowable values of N-414, which are shown in the circle adjacent to the rectangle in Fig. N-414.

N-414 Basic Stress Intensity Limits[1] – The five basic stress intensity limits which are to be satisfied are (see Fig. N-414):

N-414.1 General Primary Membrane Stress Intensity –(Derived from P_m in Fig. N-414.) –The stress intensity derived from the average value across the thickness of a section of the general primary stresses (see N-412*(h)*) produced by design internal pressure and other specified mechanical loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is S_m, as given in Table N-421, N-422, or N-423.

N-414.2 Local Membrane Stress Intensity – (Dervied from P_L in Fig. N-414.) The stress intensity derived from the average value across the thickness of a section of the local primary stresses (see N-412*(j)* produced by design pressure and specified mechanical loads but excluding all thermal and peak stresses. The allowable value of this stress intensity is 1.5 S_m.

N-414.3 Primary Membrane (General or Local) Plus Primary Bending Stress Intensity – (Derived from $P_L + P_b$ in Fig. N-414.) The stress intensity derived from the highest value across the thickness of a section of the general or local primary membrane stresses plus primary bending stresses produced by design pressure and other specified mechanical loads, but excluding all secondary and peak stresses. The allowable value of this stress intensity is 1.5 S_m.

[1] Design quantities are as defined in N-440

TABLE N-413 CLASSIFICATION OF STRESSES FOR SOME TYPICAL CASES

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	P_m Q
		Axial thermal gradient	Membrane Bending	Q Q
	Junction with head or flange	Internal pressure	Membrane Bending	P_L Q
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section. Stress component perpendicular to cross section	P_m
		External load or moment	Bending across full section. Stress component perpendicular to cross section	P_m
	Near nozzle or other opening	External load moment, or internal pressure	Local membrane Bending Peak (fillet or corner)	P_L Q F
	Any location	Temp. diff. between shell and head	Membrane Bending	Q Q
Dished head or conical head	Crown	Internal pressure	Membrane Bending	P_m P_b
	Knuckle or junction to shell	Internal pressure	Membrane Bending	P_L* Q
Flat head	Center region	Internal pressure	Membrane Bending	P_m P_b
	Junction to shell	Internal pressure	Membrane Bending	P_L Q
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (Av. thru cross section) Bending (Av. thru width of lig., but gradient thru plate) Peak	P_m P_b F
	Isolated or atypical ligament	Pressure	Membrane Bending Peak	Q F F
Nozzle	Cross section perpendicular to nozzle axis	Internal pressure or external load or moment	General membrane av. across full section. Stress component perpendicular to section	P_m (See N-417.9)
		External load or moment	Bending across nozzle section	P_m (See N-417.9)
	Nozzle wall	Internal pressure	General membrane Local membrane Bending Peak	P_m (See P_L N-417.9) Q F
		Differential expansion	Membrane Bending Peak	Q Q F
Cladding	Any	Differential expansion	Membrane Bending	F F
Any	Any	Thermal gradient thru plate thickness	Bending	F**
Any	Any	Any	Stress Concentration (notch effect)	F

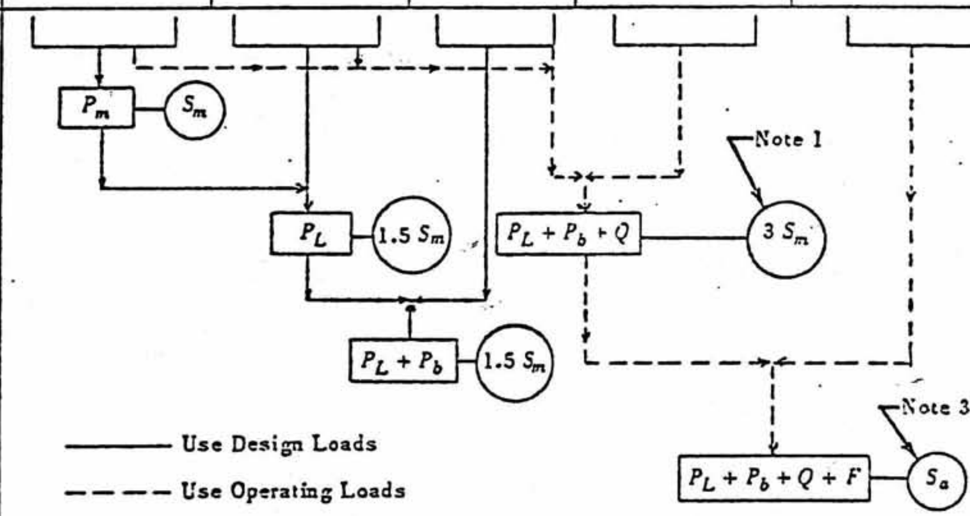
Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with large diameter-to-thickness ratio.

** Consider possibility of thermal stress ratchet (see N-417.3).

FIG. N-414 STRESS CATEGORIES AND LIMITS OF STRESS INTENSITY

Stress Category	Primary: General Membrane	Primary: Local Membrane	Primary: Bending	Secondary Membrane plus Bending	Peak
Description (For examples, see Table N-413)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.	(1) Increment added to primary or secondary stress by a concentration. (notch) (2) Certain thermal stresses which may cause fatigue but not distortion of vessel shape.
Symbol (Note 4)	P_m	P_L	P_b	Q	F

Combination of stress Components and Allowable Limits of Stress Intensities.



NOTE 1 – This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the S_m values tabulated in Tables N-421, N-422, and N-423 for the highest and the lowest temperature of the metal during the transient. When part or all of the secondary stress is due to mechanical load, the value of S_m shall be taken as the S_m value for the highest temperature of the metal during the transient.

NOTE 2 – The stresses in Category Q are those parts of the total stress which are produced by thermal gradients, structural discontinuities, etc., and do not include primary stresses which may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of $P_L + P_b + Q$ and not Q alone. Similarly, if the stress in Category F is produced by a stress concentration, the quantity F is the additional stress produced by the notch, over and above the nominal stress. For example, if a plate has a nominal stress intensity, $P_m = S$, $P_b = 0$, $Q = 0$ and a notch with a stress concentration K is introduced, then $F = P_m (K - 1)$ and the peak stress intensity equals $P_m + P_m (K - 1) = KP_m$. However, P_L is the total membrane stress which results from mechanical loads including discontinuity effects, rather than a stress increment. Therefore the P_L value always includes the P_m contribution.

NOTE 3 – S_a is obtained from the fatigue curves, Fig. N-415. The allowable stress intensity for the full range of fluctuation is $2\ S_a$.

NOTE 4 – The symbols P_m, P_L, P_b, Q, and F do not represent single quantities, but rather sets of six quantities representing the six stress components σ_t, σ_l, σ_r, τ_{tl}, τ_{lr}, and τ_{rt}.

N-414.4 Primary Plus Secondary Stress Intensity — (Derived from $P_L + P_b + Q$ in Fig. N-414.) (See Note 2 of Fig. N-414.) The stress intensity derived from the highest value at any point across the thickness of a section of the general or local primary membrane stresses plus primary bending stresses plus secondary stresses produced by specified operating pressure and other specified mechanical loads and by general thermal effects. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. The allowable value for the maximum range of this stress intensity is 3 S_m (See Note 1 of Fig. N-414).

N-414.5 Peak Stress Intensity — (Derived from $P_L - P_b + Q + F$ in Fig. N-414.) (See Note 2 of Fig. N-414.) The stress intensity derived from the highest value at any point across the thickness of a section of the combination of all primary, secondary, and peak stresses produced by specified operating pressures and other mechanical loads and by general and local thermal effects and including the effects of gross and local structural discontinuities. The allowable value of this stress intensity is dependent on the range of the stress difference from which it is derived and on the number of times it is to be applied. The stress intensity to be compared to the allowable value is obtained by the methods of analysis for cyclic operation described in N-415 through the use of the fatigue curves, Fig. N-415.

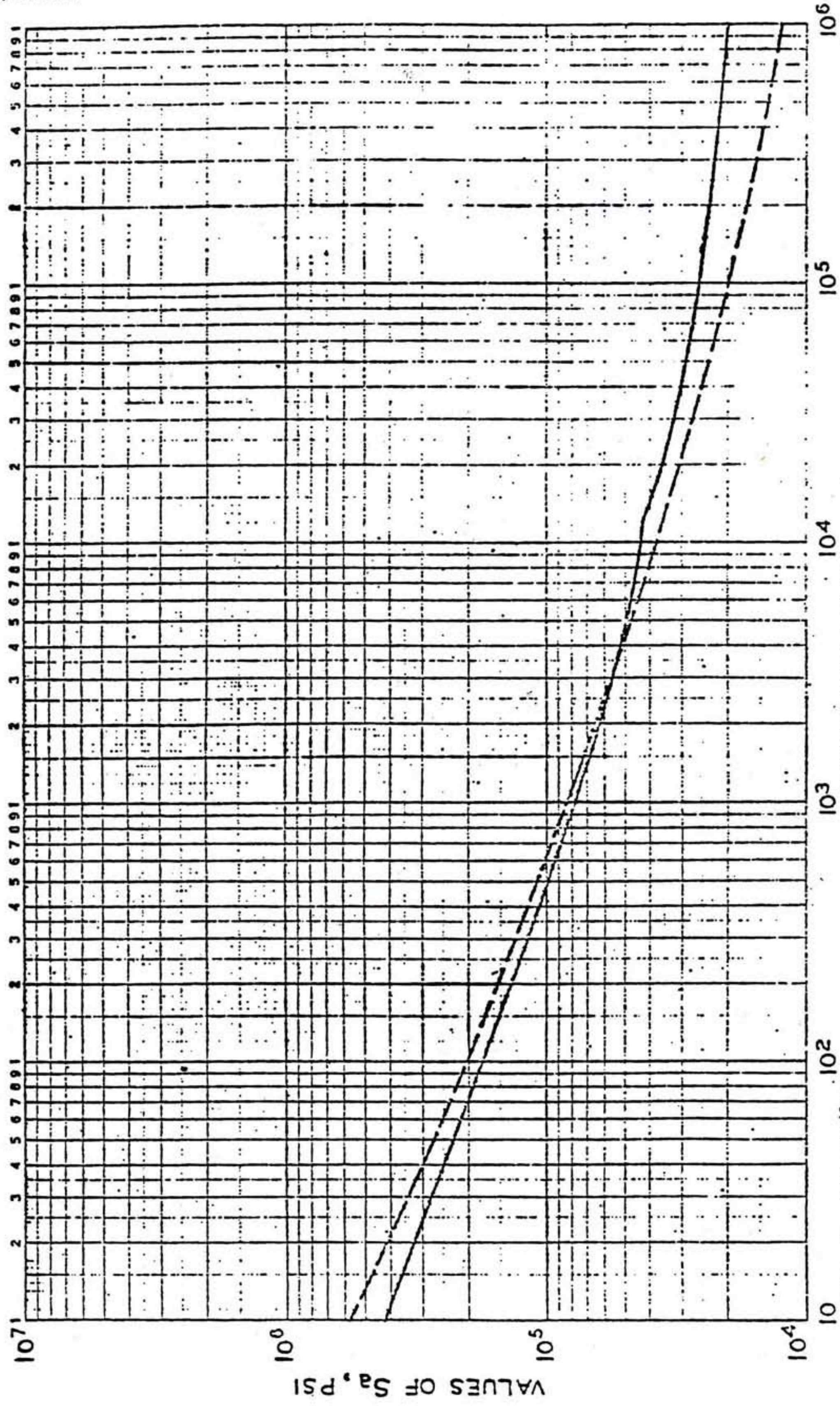
N-415 Analysis for Cyclic Operation — The suitability of a vessel component for specified operating conditions involving cyclic application of loads and thermal conditions shall be determined by the methods described herein, except that the suitability of high-strength bolts shall be determined by the methods of N-416.2 and the possibility of thermal stress ratchet shall be investigated in accordance with N-417.3. If the specified operation of the vessel meets all of the conditions of N-415.1, no analysis for cyclic operation is required, and it may be assumed that the peak stress limit discussed in N-414.5 has been satisfied by compliance with the applicable requirements for materials, design, fabrication, testing, and inspection of this Subsection. If the operation does not meet all the conditions of N-415.1, a fatigue analysis shall be made in accordance with N-415.2 or a fatigue test shall be made in accordance with I-1080.

The conditions and procedures of N-415.1 and N-415.2 are based on a comparison of peak stresses with strain-cycling fatigue data. The strain-cycling fatigue data are represented by the design fatigue-strength curves of Fig. N-415.[1] These curves show the allowable amplitude, S_a, of the alternating stress component (one-half of the alternating stress range) plotted against the number of cycles. This stress amplitude is calculated on the assumption of elastic behavior, 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 amplitude directly comparable. The curves have been adjusted where necessary to include the maximum effects of mean stress, which is the condition where the stress fluctuates about a mean value which is different from zero. As a consequence of this procedure, it is essential that the requirements of N-414.5 and N-417.5 be satisfied at all times with transient stresses included, and that the calculated value of the alternating stress intensity be proportional to the actual strain amplitude. To evaluate the effect of alternating stresses of varying amplitudes, a linear damage relation is assumed in N-415.2*(d)*.

The loadings to be considered shall include those loads that are due to testing of the vessel when such testing is in addition to that required by this Subsection.

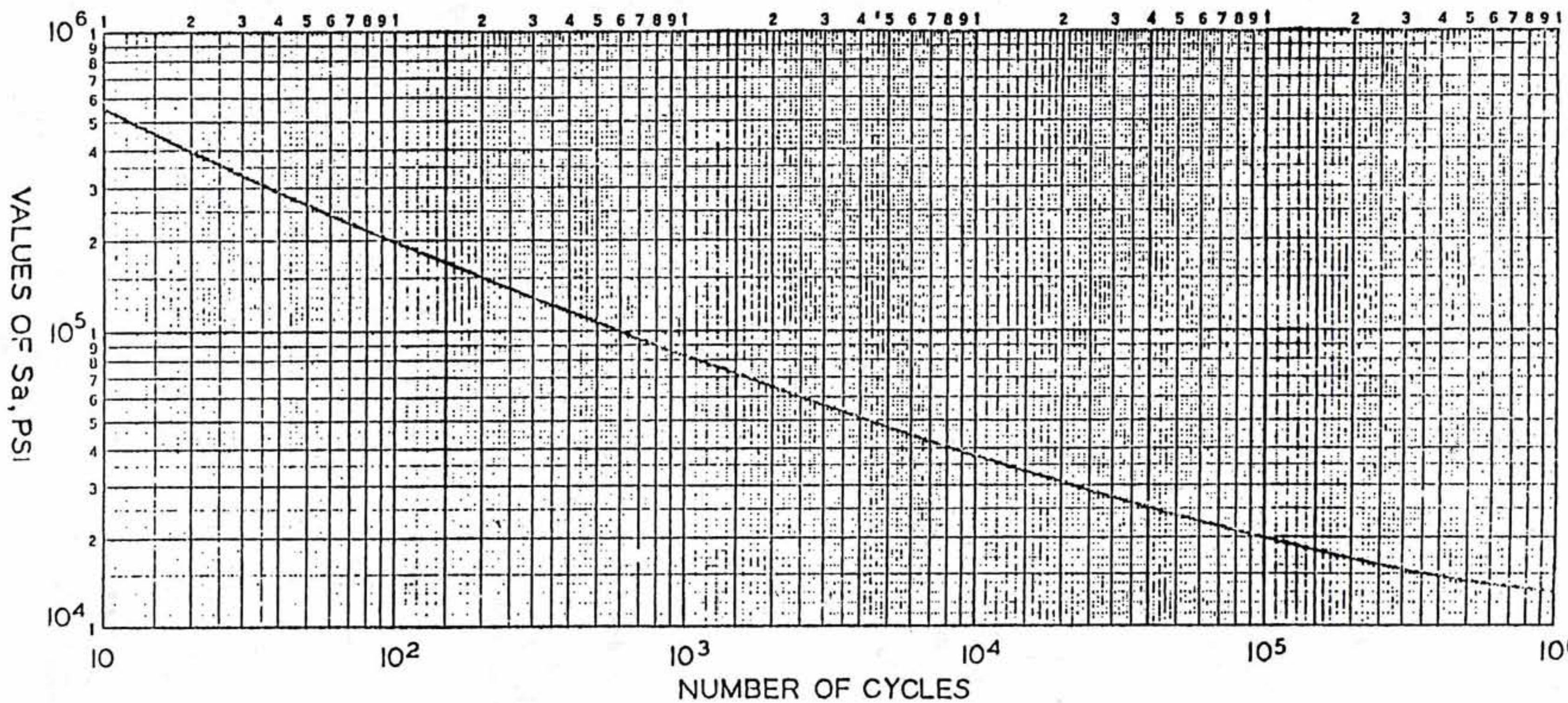
N-415.1 Vessels Not Requiring Analysis for Cyclic Operation — An analysis for cyclic operation is not required, and it may be assumed that the peak stress limit discussed in N-414.5 has been satisfied for a vessel or part thereof by compliance with the applicable requirements for materials, design, fabrication, testing, and inspection of this Subsection, provided the specified

[1] The tests on which the design curves are based did not include tests at temperatures in the creep range or in the presence of unusually corrosive environments, either of which might accelerate fatigue failure. Therefore, as noted in N-202 these curves are not applicable at operating temperatures for which creep is a significant factor. In addition, the designer shall evaluate separately any effects on fatigue life which might result from an unusually corrosive environment.



NOTE $E = 30 \times 10^6$ PSI
– – – UTS ≤ 80,000 PSI
——— UTS 115–130,000 PSI
INTERPOLATE FOR UTS 80–115,000 PSI

FIG. N-415(A) DESIGN FATIGUE CURVES FOR CARBON, LOW ALLOY, AND HIGH TENSILE STEELS
(FOR METAL TEMPERATURES NOT EXCEEDING 700 F)



NOTE: $E = 26 (10)^6$ psi.

FIG: N-415(B) ALLOWABLE AMPLITUDE OF ALTERNATING STRESS INTENSITY, S_a, FOR 18-8 STAINLESS STEELS, NICKEL-CHROMIUM-IRON ALLOY, NICKEL-IRON CHROMIUM ALLOY AND NICKEL COPPER ALLOY (FOR METAL TEMPERATURE NOT EXCEEDING 800 F).

operation of the vessel or part thereof meets all of the following conditions:

(a) The specified number of times (including startup and shutdown) that the pressure will be cycled from atmospheric pressure to operating pressure and back to atmospheric pressure does not exceed the number of cycles on the applicable fatigue curve (Fig. N-415) corresponding to an S_a value of 3 times the S_m value of Table N-421, N-422, or N-423, for the material at operating temperature.

(b) The specified full range of pressure fluctuations during normal operation[1] does not exceed the quantity (1/3) x design pressure x (S_a/S_m) where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant pressure fluctuatious and S_m is the stress from Table N-421, N-422, or N-423, for the material at operating temperature. If the total specified number of significant pressure fluctuations exceeds 10^6, the S_a value at $N = 10^6$ may be used. Significant pressure fluctuations are those for which the total excursion exceeds the quantity:

$$\text{Design Pressure} \times \frac{1}{3} \times \frac{S}{S_m}$$

where S = the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(c) The temperature difference in deg F between any two adjacent points[2] of the vessel during normal operation and during startup and shutdown operation does not exceed $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the specified number of startup-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points as given by Table N-426 and E is taken from Table N-427 at the mean value of the temperature at the two points.

(d) The temperature difference in deg F between any two adjacent points[2] of the vessel does not change[3] during normal operation[1] by more than the quantity $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature-difference fluctuations. A temperature-difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/2E\alpha$ where S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(e) For components fabricated from materials of differing moduli of elasticity and/or coefficients of thermal expansion, the total algebraic range of temperature fluctuation in deg F experienced by the vessel during normal operation does not exceed the magnitude $S_a/[2(E_1\alpha_1 - E_2\alpha_2)]$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value involved for the two materials of construction. (See Tables N-426 and N-427.) A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/2(E_1\alpha_1 - E_2\alpha_2)$ where S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph.

(f) The specified full range of mechanical loads, excluding pressure but including pipe reactions, does not result in load stresses whose range exceeds the S_a value obtained from the applicable design fatigue curve for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuation exceeds 10^6, the S_a value at $N = 10^6$ may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

N-415.2 Design for Cyclic Loading — If the specified operation of the vessel does not meet the conditions of N-415.1, the ability of the ves-

[1] Normal operation is defined as any set of operating conditions other than startup and shutdown which are specified for the vessel to perform its intended function (see N-412 *(n)(2)* and *(3)*).

[2] Adjacent points are defined as points which are spaced less than the distance $2\sqrt{Rt}$ from each other, where R and t are the mean radius and thickness, respectively, of the vessel, nozzle, flange, or other component in which the points are located.

[3] The algebraic range of the difference shall be used.