(-b) If the total specified number of service cycles exceeds $10^6$ cycles, $S$ is the value of $S_a$ obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) Procedure for Analysis for Cyclic Loading. If the specified service loadings for the vessel do not meet the conditions of (d), the ability of the vessel to withstand the specified cyclic service without fatigue failure shall be determined as provided herein. The determination shall be made on the basis of the stresses at a point, and the allowable stress cycles shall be adequate for the specified service loadings at every point. Only the stress differences due to service cycles as specified in the Design Specifications need be considered. Compliance with these requirements means only that the component is suitable from the standpoint of possible fatigue failure; complete suitability for the specified Service Loadings is also dependent on meeting the general stress limits of NE-3221 and any applicable special stress limits of NE-3227.

(1) Stress Differences. For each condition of specified service, determine the stress differences and the alternating stress intensity $S_{alt}$ in accordance with NE-3216.

(2) Local Structural Discontinuities. These effects shall be evaluated for all Service Loadings using stress concentration factors determined from theoretical, experimental, or photoelastic studies, or stress analysis techniques. Experimentally determined fatigue strength reduction factors may be used when determined in accordance with the procedures of Section III Appendices, Mandatory Appendix I, II-1600, except for high strength alloy steel bolting for which the requirements of NE-3232.3(c) shall apply when using the design fatigue curve of Section III Appendices, Mandatory Appendix I, Figure I-9.4. Except for the case of crack-like defects, no fatigue strength reduction factor greater than 5 need be used.

(3) Design Fatigue Curves. Section III Appendices, Mandatory Appendix I contains the applicable fatigue design curves for the materials permitted by this Subsection. When more than one curve is presented for a given material, the applicability of each curve to materials of various strength levels is identified. Linear interpolation may be used for intermediate strength levels of these materials. As used herein, the strength level is the specified minimum room temperature value.

(4) Effect of Elastic Modulus. Multiply $S_{alt}$ (as determined in NE-3216.1 or NE-3216.2) 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. Enter the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I, at this value on the ordinate axis and find the corresponding number of cycles on the abscissa. If the service cycle being considered is the only one which produces significant fluctuating stresses, this is the allowable number of cycles.

(5) Cumulative Damage. If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 6 below.

**Step 1.** Designate the specified number of times each type of stress cycle of types 1, 2, 3, ..., $n$ will be repeated during the life of the component as $n_1$, $n_2$, $n_3$, ..., $n_n$, respectively.

**NOTE:** In determining $n_1$, $n_2$, $n_3$, ..., $n_n$, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles. For example, if one type of stress cycle produces 1000 cycles of a stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to −50,000 psi, the two types of cycle to be considered are defined by the following parameters:

(a) Type 1 cycle: $n_1 = 1,000$,

$$S_{alt1} = (60,000 + 50,000)/2 = 55,000 \text{ psi}$$

(b) Type 2 cycle: $n_2 = 9,000$

$$S_{alt2} = (50,000 + 0)/2 = 25,000 \text{ psi}$$

**Step 2.** For each type of stress cycle, determine the alternating stress intensity $S_{alt}$ by the procedures of NE-3216.1 or NE-3216.2 above. Call these quantities $S_{alt1}$, $S_{alt2}$, $S_{alt3}$, ..., $S_{altn}$.

**Step 3.** For each value $S_{alt1}$, $S_{alt2}$, $S_{alt3}$, ..., $S_{altn}$, use the applicable design fatigue curve to determine the maximum number of repetitions which would be allowable if this type of cycle were the only one acting. Call these values $N_1$, $N_2$, $N_3$, ..., $N_n$.

**Step 4.** For each type of stress cycle, calculate the usage factors $U_1$, $U_2$, $U_3$, ..., $U_n$ from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, $U_3 = n_3/N_3$, ..., $U_n = n_n/N_n$.

**Step 5.** Calculate the cumulative usage factor $U$ from $U = U_1 + U_2 + U_3 + ... + U_n$.

**Step 6.** The cumulative usage factor $U$ shall not exceed 1.0.

**NE-3221.6 Thermal Stress Ratchet.** It should be noted that under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as the result of ratchet action; that is, the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in this subparagraph and in NE-3227.3.

(a) The limiting value of the maximum cyclic thermal stress permitted in a portion of an axisymmetric shell loaded by steady state internal pressure in order to prevent cyclic growth in diameter is as follows. Let:

$$x = \text{maximum general membrane stress due to pressure divided by the yield strength } S_y$$

$$y' = \text{maximum allowable range of thermal stress computed on an elastic basis divided by the yield strength } S_y$$

---

51
reinforcement, a $P_m$ classification is applicable to stress intensities resulting from pressure-induced general membrane stresses as well as the average stress across the nozzle thickness due to externally applied nozzle axial, shear, and torsional loads other than those attributable to restrained free end displacement of the attached pipe. Also, outside the limits of reinforcement a $P_L + P_b$ classification is applicable to the stress intensities which result from adding those stresses classified as $P_m$ to those due to externally applied bending moments, except for those attributable to restrained free end displacement of the pipe. Further, beyond the limits of reinforcement, a $P_L + P_b + Q$ classification is applicable to stress intensities resulting from all pressure, temperature, and external loads and moments, including those attributable to restrained free end displacements of the attached pipe. Beyond the limits of reinforcement, the $3S_m$ limit on the range of primary plus secondary stress intensity may be exceeded as provided in NE-3228.3, except that in the evaluation of NE-3228.3(a) stresses from restrained free end displacements of the attached pipe may also be excluded. The range of membrane plus bending stress intensity attributable solely to the restrained free end displacements of the attached piping shall be $\leq 3S_m$. The nozzle, outside the reinforcement limit, shall not be thinner than the larger of the pipe thickness or the quantity $t_p(S_{mp}/S_{mn})$ where $t_p$ is the nominal thickness of the mating pipe, $S_{mp}$ is the allowable stress intensity value for the pipe material, and $S_{mn}$ is the allowable stress intensity value for the nozzle material.

**NE-3227.6 Applications of Elastic Analysis for Stresses Beyond the Yield Strength.** Certain of the allowable stresses permitted in the criteria are such that the maximum stress calculated on an elastic basis may exceed the yield strength of the material. The limit on primary plus secondary stress intensity of $3S_m$ (NE-3221.4) has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle, except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore, the procedures of (a) and (b) below shall be used.

(a) In evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis.

(b) In evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses (NE-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:

$$v = 0.5 - 0.2 \frac{S_{alt}}{S_y} \text{ but not less than 0.3}$$

where:

- $S_{alt}$ = alternating stress intensity determined in NE-3221.5(e) prior to the elastic modulus adjustment in NE-3221.5(e)(4)
- $S_y$ = the yield strength of the material at the mean value of the temperature of the cycle

**NE-3228 Applications of Plastic Analysis**

The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the stress limits of NE-3221 which are allowed if plastic analysis is used.

**NE-3228.1 Plastic Analysis.** The limits on local membrane stress intensity (NE-3221.2), primary plus secondary stress intensity (NE-3221.4), thermal stress ratchet in shell (NE-3221.6), and progressive distortion of nonintegral connections (NE-3227.3) need not be satisfied at a specific location if, at the location, the procedures of (a) through (c) below are used.

(a) In evaluating stresses for comparison with the remaining stress limits, the stresses are calculated on an elastic basis.

(b) In lieu of satisfying the specific requirements of NE-3221.2, NE-3221.4, NE-3221.6, and NE-3227.3 at a specific location, the structural action is calculated on a plastic basis and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation) and if the deformations which occur prior to shakedown do not exceed specified limits.

(c) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range which occurs after shakedown shall be multiplied by one-half of the modulus of elasticity of the material (Section II, Part D, Subpart 2, Table TM) at the mean value of the temperature of the cycle.

**NE-3228.2 Limit Analysis.** The limits on local membrane stress intensity (NE-3221.2) and primary membrane plus primary bending stress intensity (NE-3221.3) need not be satisfied at a specific location if it can be shown by means of limit analysis or by tests that the specified loadings do not exceed two-thirds of the lower bound collapse load except for those materials of Section II, Part D, Subpart 1, Table 2A to which Note G7 is applicable and Section II, Part D, Subpart 1, Table 2B to which Note G1 is applicable. For these latter materials the specified loading shall not exceed the product of the applicable permanent strain limiting factor of Section II, Part D, Subpart 1, Table Y-2 times the lower bound collapse load.