Stress Categories and Limits of Stress Intensities for Service Level C

### Primary Stresses [Notes (1), (2), and (6)]

<table>
<thead>
<tr>
<th>Stress Category</th>
<th>Membrane, $P_m$</th>
<th>Membrane + Bending $(P_m + P_b)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits for Service Level C (NG-3224)</td>
<td>$1.5S_m$ Elastic analysis (NG-3224.1(a)(1)) or $2.25S_m$ Plastic analysis (NG-3224.1(c)(1))</td>
<td>$2.25S_n$ Elastic analysis (NG-3224.1(a)(2)) or $0.5S_n$ Plastic analysis (NG-3224.1(c)(2))</td>
</tr>
<tr>
<td>or $S_e$ Stress ratio analysis (NG-3224.1(d)(1))</td>
<td>$S_e$ Stress ratio analysis (NG-3224.1(d)(2))</td>
<td></td>
</tr>
</tbody>
</table>

### Primary Plus Secondary Stress Intensity, $Q$, and Fatigue [Note (1)]

<table>
<thead>
<tr>
<th>Peak Stress Intensity, $F$, and Fatigue [Note (1)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation not required (NG-3224.4)</td>
</tr>
<tr>
<td>Evaluation not required (NG-3224.5)</td>
</tr>
</tbody>
</table>

### Notes:

1. The symbols $P_m$, $P_b$, $Q$, and $F$ do not represent single quantities, but rather sets of six quantities representing the six stress components $\sigma_x$, $\sigma_y$, $\sigma_z$, $\tau_{xy}$, $\tau_{yz}$, and $\tau_{zx}$.
2. For configurations where compressive stresses occur, the stress limits shall be reviewed to take into account critical buckling stresses [NG-3221(i)].
3. Primary stress calculated from elastic-plastic analysis. Strain hardening of the material may be used for the actual monotonic stress-strain curve at the temperature of loading; any approximation to the stress-strain curve that everywhere has a lower stress for the same strain as the actual monotonic curve may also be used. Either the maximum shear stress theory or a strain energy of distortion theory shall be used to relate multiaxial yielding to the uniaxial case.
4. $S_u$ is tensile strength at temperature. Multiaxiality effect on the tensile strength shall be considered.
5. The greater of 2.25 $S_m$ or 0.5 $S_n$ may be used.
6. In lieu of satisfying these requirements of NG-3228.2 or experimental analysis in accordance with NG-3228.4, or both, a limit analysis in accordance with NG-3228.2 or experimental analysis in accordance with NG-3228.4 may be performed.

Add new paragraph "(b) For limit analysis, comply with NG-3228.2."

Renumber existing (b) and (c) accordingly.

dynamic pressures are involved, the permissible external pressure shall satisfy the preceding requirements or be limited to one-half the dynamic instability pressure.

**NG-3224.3 Special Stress Limits.** The permissible values for special stress limits shall be taken as 150% of the values given in NG-3227 and NG-3228.1.

**NG-3224.4 Secondary and Peak Stresses.** The requirements of NG-3222.2, NG-3222.4, NG-3222.5, and NG-3227.3 need not be satisfied.

**NG-3224.5 Fatigue Requirements.** Service Loads for which Level C Limits are designated need not be considered when applying the procedures of NG-3224.4(a) to determine whether or not a fatigue analysis is required.

**NG-3224.6 Deformation Limits.** Any deformation limits prescribed by the Design Specifications shall be considered.

**NG-3225 Level D Service Limits**

If the Design Specifications specify any Service Loadings for which Level D Limits are designated [NCA-2142.4(b)(4)], the rules contained in Section III Appendices, Mandatory Appendix XXVII shall be used in evaluating these loadings, independently of all other Design and Service Loadings. The following stipulations apply when using Section III Appendices, Mandatory Appendix XXVII:

(a) When the special stress limits of NG-3227 are applicable for Level D Limits, the calculated stresses shall not exceed twice the stress limits given in NG-3227 as applied for Level A and Level B Service Limits. The bearing and shear limits in XXVII-3500 do not apply to core support structures.

(b) For experimental analysis, comply with NG-3228.4.

(c) Component inelastic analysis may be combined with elastic system analysis as defined in Section III Appendices, Mandatory Appendix XXVII. For this analysis, the maximum stress limit shall be 0.67 $S_u$ for primary membrane stress intensity, and shall be equal to the greater of 0.67 $S_{ut}$ and $[S_y + (\gamma_b)(S_{ut} - S_y)]$, but not to exceed 0.95 $S_u$ for primary primary stress intensity, where $S_{ut}$ is defined as the value of ultimate stress obtained from the true stress–strain curve and $S_u$ is defined as the value of ultimate stress from an engineering stress–strain curve.

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strain curve. In this case, the elastic system analysis shall be checked, accounting for component plastic deformation.

**NG-3227 Special Stress Limits**

The following deviations from the basic stress limits are provided to cover special Service Loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. Rules governing application of these special stress limits for Level C and Level D Service Limit applications are contained in NG-3224.3 and NG-3225, respectively. In cases of conflict between these requirements and the basic stress limits, the rules of NG-3227 take precedence for the particular situations to which they apply. NG-3227 does not apply to threaded structural fasteners (NG-3230).

**NG-3227.1 Bearing Loads.**

(a) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of Design Loadings or of Service Loadings for which Level A Limits are designated, shall be limited to $S_y$ at temperature, except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of $1.5S_y$ at temperature is permitted. For clad surfaces the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(b) When bearing loads are applied near free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. In the case of load-controlled stress only (NG-3213.11), the average shear stress shall be limited to $0.6S_m$. In the case of load-controlled stress plus secondary stress (NG-3213.9), the average shear stress shall not exceed the following:

1. For material 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, the lower of $0.5S_y$ at $100^\circ F$ (38°C) and $0.675S_y$ at temperature;
2. For all other material, $0.55S_y$ at temperature.

(c) For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(d) When considering bearing stresses in pins and similar members, the $S_y$ at temperature value is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

**NG-3227.2 Pure Shear.**

(a) The average primary shear stress across a section loaded in pure shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated (e.g., keys, shear rings), shall be limited to $0.6S_m$.

(b) The maximum primary shear, experienced as a result of Design Loadings or Service Loadings for which Level A Limits are designated exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) Primary plus secondary and peak shear stresses shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of NG-3222.2 and NG-3222.4(b).

**NG-3227.3 Progressive Distortion of Nonintegral Connections.** Screwed on caps, screwed in plugs, shear ring closures, and breechlock closures are examples of nonintegral connections which are subject to failure by bell mouting or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (NG-3222.2) which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion shall be limited to the value $S_y$ (Section II, Part D, Subpart 1, Table Y-1).

**NG-3227.4 Triaxial Stresses.** The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of $S_m$.

**NG-3227.5 Nozzle Piping Transition.** The $P_m$ classification of stresses in nozzle resulting from pressure difference, external loads, and moments is applicable for that length of nozzle which lies within the limits of reinforcement given by NG-3132, whether or not nozzle reinforcement is provided. Beyond the limits of reinforcement, a $P_m$ classification shall be applied to the general primary membrane stress intensity averaged across the section (not thickness) resulting from combined pressure difference and external mechanical loads; $P_m + P_b$ classification shall be applied to primary membrane plus primary bending stress intensities that result from Design Pressure Difference and external mechanical loads; and a $P_m + P_b + Q$ classification shall be applied to primary plus secondary stress intensities resulting from all loads including external load or moment attributable to restrained free end displacement 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 NG-3228.3 except that in the
evaluation of NG-3228.3(a), stresses from attached pipe thermal expansion loads and moments may also be excluded. The range of membrane plus bending stress intensity attributable solely to thermal expansion of the attached piping shall be 3 $S_m$. The nozzle, outside the re- 

strictions limit, shall not be thinner than the larger of the pipe $t_p$ is the the allowable and $S_m$ nozzle materials.

NG-3228 Applications of Plastic Analysis

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

NG-3228.1 Plastic Analysis. The limits on primary plus secondary stress intensity (NG-3222.2), thermal stress ratchet in shell (NG-3222.5), and progressive distortion of nonintegral connections (NG-3227.3) need not be satisfied at a specific location if, at the location, the procedures of (a) through (c) 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 NG-3222.2, NG-3222.5, and NG-3227.3 at a specific location, the structural action is calculated on a plastic basis, all be considered to be acceptable if the service loadings do not exceed the requirements of (1) or (2) below for the lower bound limit load $L_L$ (NG-3213.21). The lower bound limit load $L_L$ may be determined by analysis or by test (test collapse load per Section III Appendices, Mandatory Appendix II, II-1430), using a material yield point equal to 1.5 times the allowable stress intensity $S_m$ at temperature, where $S_m$ is given in Section II, Part D, Subpart 1, Tables 2A and 2B.

(1) Except for the materials identified in (2) below, the specified loadings shall not exceed 2/3 of $L_L$.

(2) For materials of Section II, Part D, Subpart 1, Table 2A to which Note G7 applies and Table 2B to which Note G1 applies, the specified loadings shall not exceed the product of $L_L$ and the applicable permanent strain limiting factor of Section II, Part D, Subpart 1, Table Y-2.

(c) For Level D Service Loadings with materials identified in (a) (2) above, the specified loadings shall not exceed 2 times the limits of (a) (2), with $L_L$ determined as described in (a). For all other materials, the limit analysis shall comply with Section III Appendices, Mandatory Appendix XXVII.

\[
\nu = 0.5 - 0.2 \frac{S_y}{S_{ult}} \quad \text{but not less than} \quad 0.2
\]

where

$S_{ult} = $ alternating stress intensity determined in NG-3224.2(e) prior to the elastic modulus adjustment in NG-3224.2(e)(4)

$S_y = $ the yield strength of the material at the mean value of the temperature of the cycle
(d) The lower bound limit load, \( L_L \) (NG-3213.21) may be determined by analysis or by test (test collapse load per Section III Appendices, Mandatory Appendix II, II-1430), using a material yield point equal to 1.5 times the allowable stress intensity \( S_m \) at temperature, where \( S_m \) is given in Section II, Part D, Subpart 1, Tables 2A and 2B. For materials of Section II, Part D, Subpart 1, Table 2A to which Note G7 is applicable and Table 2B to which Note G1 is applicable, the specified loadings shall not exceed the product of the applicable permanent strain limiting factor of Section II, Part D, Subpart 1, Table Y-2 times \( L_L \) for (a) above, 1.5\( L_L \) for (b) above, or \( 2L_L \) for (c) above.

**NG-3228.3 Simplified Elastic-Plastic Analysis.** The 3\( S_m \) limit on the range of primary plus secondary stress intensity (NG-3222.2) may be exceeded, provided that the requirements of (a) through (f) below are met

(a) The range of primary plus secondary membrane plus bending stress intensity, excluding thermal bending stresses, shall be \( \leq 3S_m \).

(b) The value of \( S_n \) used for entering the design fatigue curve is multiplied by the factor \( K_e \) where

\[
K_e = 1.0 \text{ for } S_n \leq 3S_m \\
= 1.0 + \frac{(1 - n)}{n(m - 1)} \left( \frac{S_n}{3S_m} - 1 \right) \text{ for } 3S_m < S_n < 3mS_m \\
= 1.0/n \text{ for } S_n \geq 3S_m
\]

\( S_n = \) 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 follows:

<table>
<thead>
<tr>
<th>Material</th>
<th>( m )</th>
<th>( n )</th>
<th>( T_{max} ) °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low alloy steel</td>
<td>2.0</td>
<td>0.2</td>
<td>700 (370)</td>
</tr>
<tr>
<td>Martensitic stainless steel</td>
<td>2.0</td>
<td>0.2</td>
<td>700 (370)</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>3.0</td>
<td>0.2</td>
<td>700 (370)</td>
</tr>
<tr>
<td>Austenitic stainless steel</td>
<td>1.7</td>
<td>0.3</td>
<td>800 (425)</td>
</tr>
<tr>
<td>Nickel-chromium-iron</td>
<td>1.7</td>
<td>0.3</td>
<td>800 (425)</td>
</tr>
<tr>
<td>Nickel-copper</td>
<td>1.7</td>
<td>0.3</td>
<td>800 (425)</td>
</tr>
</tbody>
</table>

(c) The rest of the fatigue evaluation stays the same as required in NG-3222.4, except that the procedure of NG-3227.6 need not be used.

(d) The structure meets the thermal ratcheting requirement of NG-3222.5.

(e) The temperature does not exceed those listed in the above table for the various classes of materials.

(f) The material shall have a specified minimum yield strength to specified minimum tensile strength ratio of less than 0.80.

**NG-3228.4 Experimental Analysis.**

(a) For Level A and Level B Service Loadings, the primary stress limits of NG-3222.1 need not be satisfied in a structure if it can be shown from the test of a prototype or model that the specified loadings (dynamic or static equivalent) do not exceed 44% of \( L_u \) (NG-3213.23), and (d) below is satisfied.

(b) For Level C Service Loadings, the primary stress limits of NG-3224.1(a) need not be satisfied if it can be shown from the test of a prototype or model that the specified loadings (dynamic or static equivalent) do not exceed 60% of \( L_u \) (NG-3213.23), and (d) below is satisfied.

(c) For Level D Service Loadings, the specified dynamic or equivalent static loads shall not exceed 80% of the ultimate collapse load as obtained from test \( P_c \). \( P_c \) is defined as the load at which the horizontal tangent to the load deformation curve occurs, or 80% of a load combination used in the test of a prototype or model. Paragraph (d) below shall also be satisfied.

(d) In using this method, account shall be taken of the size effect and dimensional tolerances that may exist between the actual part and test part or parts, as well as differences that may exist in the ultimate strength or other governing material properties of the actual part and the tested parts to ensure that the loads obtained from the test are a conservative representation of the load-carrying capability of the actual structure under the postulated Service Loadings.

**NG-3229 Design Stress Values**

The design stress intensity values \( S_m \) are given in Section II, Part D, Subpart 1, Tables 2A and 2B for core support structure material. Values for intermediate temperatures may be found by interpolation. These form the basis for the various stress limits. Values of yield strength are given in Section II, Part D, Subpart 1, Table Y-1. Values of the coefficient of thermal expansion are in Section II, Part D, Subpart 2, Table TE, and values of the modulus of elasticity are in Section II, Part D, Subpart 2, Table TM. The basis for establishing stress values is given in Section III Appendices, Mandatory Appendix III. The design fatigue curves used in conjunction with NG-3222.4 are those of Section III Appendices, Mandatory Appendix I.

**NG-3230 Stress Limits for Threaded Structural Fasteners**

**NG-3231 Design Conditions**

(a) The rules of this paragraph apply to mechanical connections joining parts in core support structures located within a pressure-retaining boundary. Devices which are used to assemble structural elements of core support structures are referred to as threaded structural fasteners. The design stress intensity values \( S_m \) and yield strength values \( S_y \) for threaded structural fasteners shall be the values given in Section II, Part D, Subpart 1, Tables 2A and 2B and in Section II, Part D, Subpart 1, Table Y-1, respectively.
(19) **NG-3232.2 Maximum Stress.**

(a) The maximum primary membrane and bending plus secondary membrane and bending stress intensities, including stress from preload but excluding effects of stress concentrations, shall be no greater than 1.33 times the limits of NG-3232.1(a).

(b) For torquing during installation of fasteners, the maximum value of membrane stress intensity shall be no greater than 1.2 times the limits of NG-3232.1(a), and the maximum value of membrane plus bending stress intensity shall be no greater than 1.2 times the limits of (a) at installation temperature.

(19) **NG-3232.3 Fatigue Analysis of Threaded Structural Fasteners.** Unless threaded structural fasteners meet the conditions of NG-3222.4(d) and thus require no fatigue analysis, the suitability of threaded structural fasteners for cyclic service shall be determined in accordance with the procedures of (a) through (e) below.

(a) **Threaded Structural Fasteners Having Less Than 100 ksi (690 MPa) Tensile Strength.** Fasteners made of material which has specified minimum tensile strength of less than 100 ksi (690 MPa) shall be evaluated for cyclic service by the methods of NG-3222.4(e), using the applicable design fatigue curves of Section III Appendices, Mandatory Appendix I and an appropriate fatigue strength reduction factor [see (c)].

(b) **High-Strength Threaded Structural Fasteners.** High-strength fasteners may be evaluated for cyclic service by the methods of NG-3222.4(e) using the applicable design fatigue curve of Section III Appendices, Mandatory Appendix I, provided

1. The maximum value of primary and secondary stresses, including preload, at the periphery of the fastener cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall not exceed 0.95_, where _S_ is determined at service temperature.

2. Threads shall have a minimum thread root radius no smaller than 3 mils (0.08 mm)

3. Fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.06

(c) **Fatigue Strength Reduction Factor (NG-3213.16).** Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor used in the fatigue evaluation of threaded members shall not be less than 4 for the threaded region. However, when applying the rules of (b) for high-strength fasteners, the value used shall not be less than 4 for the threaded region.

(d) **Effect of Elastic Modulus.** Multiply _S_(alt) (NG-3216.1 or NG-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 at this value on the ordinate 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.

(e) **Cumulative Damage.** The fasteners shall be acceptable for the specified cyclic application of loads and thermal stress provided the cumulative usage factor _U_ as determined in NG-3222.4(e)(5) does not exceed 1.

**NG-3233 Level B Service Limits**
Level A Service Limits (NG-3232) apply.

**NG-3234 Level C Service Limits (NG-3232) apply.**

**NG-3235 Level D Service Limits for Threaded Structural Fasteners**

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of NG-3224 are satisfied for the Service Loadings for which Level D Limits are designated in the Design Specifications. For high-strength structural fasteners [specified minimum tensile strength _S_ ≥ 100 ksi (690 MPa)], the limits of NG-3232.1 and NG-3232.2(a) also apply for these Service Loadings. Any deformation limit prescribed in the Design Specifications shall be considered.

Replace with "XXVII-2310(b) and XXVII-3000" and Add ", with _L_ determined in accordance with NG-3228.2."
NG-3300  CORE SUPPORT STRUCTURE

**NG-3310  GENERAL REQUIREMENTS**

The requirements for acceptability of a core support structure design are given in (a) through (c).

(a) The design shall be such that the requirements of NG-3100 and NG-3200 are satisfied.

(b) The requirements of NG-3300 are satisfied. In case of conflict between NG-3200 and NG-3300, the requirements of NG-3300 shall govern.

(c) The requirements of this subarticle apply to internal structures, NG-1122, only as specifically stipulated by the Certificate Holder; however, the Certificate Holder shall certify that the design used for the internal structures shall not adversely affect the integrity of the core support structure.

**NG-3320  DESIGN CONSIDERATIONS**

**NG-3321  Design and Service Loadings**

The provisions of NG-3110 apply.

**NG-3322  Special Considerations**

The provisions of NG-3120 apply.

**NG-3323  General Design Rules**

The provisions of NG-3130 apply, except when they conflict with rules of this subarticle. In case of conflict, this subarticle governs in the design of core support structures.

**NG-3350  DESIGN FOR WELDED CONSTRUCTION**

**NG-3351  Welded Joint Categories**

(a) The term *category* as used herein defines the location of a joint. The categories established by this paragraph are for use elsewhere in this Subsection to identify special restrictions regarding type of joint permitted for the location. Figures NG-3351(a)-1 and NG-3351(a)-2 illustrate locations of some typical welded joints in each category. Joints whose design functions are neither to restrain nor support the core do not fall into any category.

(b) The *types* of joints that may be used at the various locations are defined in NG-3352.