NCD-3600 Piping Design

NCD-3610 General Requirements

NCD-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

NCD-3611.1 Allowable Stress Values.
Allowable stress values to be used for the design of piping systems are given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NCD-3611.2 Stress Limits.

(a) Design and Service. Loadings shall be specified in the Design Specification.

(b) Design Loadings. The sum of stresses due to design internal pressure, weight, and other sustained loads shall meet the requirements of eq. NCD-3652(8)

(c) Service Loadings. The following Service Limits shall apply to Service Loadings as designated in the Design Specification.

(1) Level A and B Service Limits. For Service Loadings for which Level A and B Service Limits are designated in the Design Specification, the requirements of NCD-3653 shall be met. When Level B Limits apply, the peak pressure $P_{\text{max}}$ alone shall not exceed 1.1 times the pressure $P_a$ calculated in accordance with eq. NCD-3641.1(5). The calculation of $P_a$ shall be based on the maximum allowable stress for the material at the coincident temperature.

(2) Level C Service Limits. For Service Loadings for which Level C Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of NCD-3654.

(3) Level D Service Limits. For Service Loadings for which Level D Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of NCD-3655.

(4) Test Conditions. Testing shall be in accordance with Article NCD-6000. Occasional loads shall not be considered as acting at time of test.

(d) External Pressure Stress. Piping subject to external pressure shall meet the requirements of NCD-3641.2.

(e) Allowable Stress Range for Expansion Stresses. The allowable stress range $S_A$ is given by eq. (1)
\[ S_A = f(1.25S_c + 0.25S_h) \]  

(1)

where

- \( S_A \) = stress range reduction factor for cyclic conditions for total number \( N \) of full temperature cycles over total number of years during which system is expected to be in service, from Table NCD-3611.2(e)-1
- \( f \) = temperature cycles over total number of years during which system is expected to be in service
- \( S_c \) = basic material allowable stress at minimum (cold) temperature, psi (MPa)
- \( S_h \) = basic material allowable stress at maximum (hot) temperature, psi (MPa)

1. In determining the basic material allowable stresses \( S_c \) and \( S_h \), joint efficiencies need not be applied.

2. Stress reduction factors apply essentially to noncorrosive service and to corrosion resistant materials, where employed to minimize the reduction in cyclic life caused by corrosive action.

3. If the range of temperature change varies, equivalent full temperature cycles may be computed as follows:

\[ N = N_E + r_1S_1 + r_2S_2 + \ldots + r_nS_n \]  

(2)

where

- \( N_E \) = number of cycles at full temperature change \( \Delta T_E \) for which expansion stress \( S_E \) has been calculated
- \( N_1, N_2, \ldots, N_n \) = number of cycles at lesser temperature changes, \( \Delta T_1, \Delta T_2, \ldots, \Delta T_n \)
- \( r_1, r_2, \ldots, r_n \) = the ratio of any lesser temperature cycles for which the expansion stress \( S_E \) has been calculated

(f) *Allowable Stress for Nonrepeated Stresses.* The allowable stress due to any single nonrepeated anchor movement (such as predicted building settlement) calculated in accordance with eq. NCD-3653.2(b)(10b) shall be \( 3.0S_c \).

### Table NCD-3611.2(e)-1 — Stress Range Reduction Factors

<table>
<thead>
<tr>
<th>Number of Equivalent Full Temperature Cycles, ( N )</th>
<th>( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>7,000 and less</td>
<td>1.0</td>
</tr>
<tr>
<td>7,000 to 14,000</td>
<td>0.9</td>
</tr>
</tbody>
</table>
**NCD-3611.3 Alternative Analysis Methods.**
The specific design requirements of NCD-3600 are based on a simplified engineering approach. A more rigorous analysis such as described in NB-3600 or NB-3200 may be used to calculate the stresses required to satisfy these requirements. These calculated stresses must be compared to the allowable stresses in this Subsection. In such cases, the designer shall include appropriate justification for the approach taken in the Certified Design Report.

**NCD-3612 Pressure–Temperature Ratings for Piping Products**

**NCD-3612.1 Piping Products Having Specific Ratings.**

(a) Pressure–temperature ratings for certain piping products have been established and are contained in some of the standards listed in Table NCA-7100-1. The pressure ratings at the corresponding temperatures given in the standards listed in Table NCA-7100-1 shall not be exceeded, and piping products shall not be used at temperatures in excess of those given in Section II, Part D, Subpart 1, Tables 1A and 1B for the materials of which the products are made.

(b) Where piping products have established pressure–temperature ratings that do not extend to the upper material temperature limits permitted by this Subsection, the pressure–temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Subsection.

**NCD-3612.2 Piping Products Not Having Specific Ratings.**

Should it be desired to use methods of manufacture or design of piping products not covered by this Subsection, it is intended that the manufacturer shall comply with the requirements of NCD-3640 and NCD-3690 and other applicable requirements of this Subsection for the Design Loadings involved. The manufacturer’s recommended pressure ratings shall not be exceeded.

**NCD-3612.4 Considerations for Local Conditions and Transients.**

(a) Where piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

<table>
<thead>
<tr>
<th>Number of Equivalent Full Temperature Cycles, ( N )</th>
<th>( f )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14,000 to 22,000</td>
<td>0.8</td>
</tr>
<tr>
<td>22,000 to 45,000</td>
<td>0.7</td>
</tr>
<tr>
<td>45,000 to 100,000</td>
<td>0.6</td>
</tr>
<tr>
<td>100,000 and over</td>
<td>0.5</td>
</tr>
</tbody>
</table>
(1) The requirements of the higher pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with NCD-7311 and NCD-7321.

(3) Assure compliance with all the conditions of (-a) through (-e) below.

(-a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(-b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed that will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the low pressure system.

(-c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(-d) Means shall be provided to assure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the low pressure system.

(-e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with NCD-7311 and NCD-7321, on the basis of the interconnecting valve being closed but leaking at a specified rate, when (-a) through (-e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in the Design Specification, and all other applicable requirements of Article NCD-7000 shall be met.

(b) Where pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower pressure system Design Pressure by more than 10% if the pressure reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time, the high pressure system is at a pressure higher than the Design Pressure of the low pressure system, the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.
(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size, unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping, unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

<table>
<thead>
<tr>
<th>Vessel Pressure, psi (MPa)</th>
<th>Design Pressure, psi (MPa)</th>
<th>Design Temperature, °F (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 (4.0) and below</td>
<td>250 (1.7)</td>
<td>410 (210)</td>
</tr>
<tr>
<td>Above 600 (4.0) to 900 (6.0)</td>
<td>400 (3.0)</td>
<td>450 (230)</td>
</tr>
<tr>
<td>Above 900 (6.0) to 1,500 (10.0)</td>
<td>600 (4.0)</td>
<td>490 (255)</td>
</tr>
<tr>
<td>Above 1,500 (10.0)</td>
<td>900 (6.0)</td>
<td>535 (280)</td>
</tr>
</tbody>
</table>

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. Where pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

(h) When a fluid passes through heat exchangers in series, the Design Temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.
NCD-3613 Allowances

NCD-3613.1 Corrosion or Erosion.
When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

NCD-3613.2 Threading and Grooving.
The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

NCD-3613.3 Mechanical Strength.
When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

NCD-3613.4 Pressure Design Weld Joint Efficiency for Butt Welds
For Class 2 piping, the joint efficiency factor, E, is equal to 1.0. For Class 3 piping, longitudinal weld joint efficiency factors for pressure design for butt welds as listed in Table NCD-3613.4-1 shall be applied to the allowable stress values given in Section II, Part D, Subpart 1, Tables 1A and 1B.

<table>
<thead>
<tr>
<th>Type of Longitudinal Joint</th>
<th>Weld Joint Efficiency Factor, E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc Weld</td>
<td></td>
</tr>
<tr>
<td>Single butt weld</td>
<td>0.80</td>
</tr>
<tr>
<td>Double butt weld</td>
<td>0.90</td>
</tr>
<tr>
<td>Single or double butt weld with 100% radiography per NCD-2560 for joints welded with filler metal or otherwise examined by ultrasonic methods per NCD-2550 for joints welded without filler metal, as applicable</td>
<td>1.00</td>
</tr>
<tr>
<td>Electric resistance weld</td>
<td>0.85</td>
</tr>
</tbody>
</table>

NCD-3613.5 Steel Casting Quality Factors.
The quality factors for castings required in Section II, Part D, Subpart 1, Tables 1A and 1B apply to castings that are designed using the stresses contained in this Subsection. The minimum examination required for these castings is that stipulated in the applicable material specification.
and in NCD-2570. Castings satisfying these minimum requirements shall be designed with a quality factor of 1.00.

NCD-3620 Design Considerations

NCD-3621 Design and Service Loadings

The provisions of NCD-3110 shall apply, except as modified in this subarticle.

NCD-3621.1 Cooling Effects on Pressure.
When the cooling of a fluid may reduce the pressure in the piping to below atmospheric, the piping shall be designed to withstand the external pressure or provision shall be made to break the vacuum.

NCD-3621.2 Fluid Expansion Effects.
When the expansion of a fluid may increase the pressure, the piping system shall be designed to withstand the increased pressure or provision shall be made to relieve the excess pressure.

NCD-3622 Dynamic Effects

NCD-3622.1 Impact.
Impact forces caused by either external or internal loads shall be considered in the piping design.

NCD-3622.2 Reversing Dynamic Loads.
Reversing dynamic loads are those loads that cycle about a mean value and include building filtered loads, and earthquake loads. A reversing dynamic load shall be treated as a nonreversing dynamic load in applying the rules of NCD-3600 when the number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20.

NCD-3622.3 Vibration.
Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

NCD-3622.4 Exposed Piping.
Exposed piping shall be designed to withstand wind loadings, using meteorological data to determine wind forces. When State, Province, or Municipal ordinances covering the design of building structures are in effect and specify wind loadings, these values shall be considered the minimum design values. However, it is not necessary to consider earthquake and wind loadings to be acting concurrently.

NCD-3622.5 Nonreversing Dynamic Loads.
Nonreversing dynamic loads are those loads that do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from
entrapped water in two-phase flow systems (see Figure NCD-3622-1). Reflected waves in a piping system due to flow transients are classified as nonreversing dynamic loads.

**Figure NCD-3622-1 — Examples of Reversing and Nonreversing Dynamic Loads**

NCD-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

**NCD-3623.1 Live Weight.**

The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

**NCD-3623.2 Dead Weight.**

The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.
NCD-3624 Thermal Expansion and Contraction Loads

NCD-3624.1 General Requirements.

(a) The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction and from the effects of expansion joints.

(b) Thermal expansion and contraction shall be provided for, preferably by pipe bends, elbows, offsets, or changes in direction of the piping.

(c) Hangers and supports shall permit expansion and contraction of the piping between anchors.

NCD-3624.2 Expansion Joints.

Expansion joints of the corrugated, slip sleeve, ball, or swivel types may be used if they conform to the requirements of NCD-3649.1 through NCD-3649.4, their structural and working parts are designed for the maximum pressure and temperature of the piping system, and their design prevents the complete disengagement of working parts while in service.

NCD-3640 Pressure Design of Piping Products

NCD-3641 Straight Pipe

NCD-3641.1 Straight Pipe Under Internal Pressure.

The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for the various materials listed in Section II, Part D, Subpart 1, Tables 1A and 1B, including allowances for mechanical strength, shall not be less than that determined by eq. (3) as follows:

\[
t_m = \frac{PD_b}{2(SE + Py)} + A
\]

(3)

\[
t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)}
\]

(4)

where

additional thickness, in. (mm):

(a) to compensate for material removed or wall thinning due to threading or grooving, required to make a mechanical joint. The values of \( A \) listed in Table NCD-3641.1(a)-1 are minimum values for material removed in threading.

(b) to provide for mechanical strength of the pipe. Small diameter, thin wall pipe or tubing is susceptible to mechanical damage due to erection, operation, and maintenance procedures. Accordingly, appropriate means must be employed to protect
such piping against these types of loads if they are not considered as Design Loads. Increased wall thickness is one way of contributing to resistance against mechanical damage.

(c) to provide for corrosion or erosion. Since corrosion and erosion vary widely from installation to installation, it is the responsibility of designers to determine the proper amounts that must be added for either or both of these conditions.

outside diameter of pipe, in. (mm). For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of \( t_m \).

\[
D_o = \text{outside diameter of pipe, in. (mm).}
\]

When calculating the allowable pressure of pipe on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.

\[
d = \text{inside diameter of pipe, in. (mm).}
\]

In using eq. (4) the value of \( d \) is for the maximum possible inside diameter allowable under the purchase specification.

\[
E = \text{joint efficiency for the type of longitudinal joint used, as given in Table NCD-3613.4-1, or casting quality factor determined in accordance with NCD-3613.5}
\]

\[
P = \text{internal Design Pressure, psi (MPa)}
\]

\[
S = \text{maximum allowable stress for the material at the Design Temperature, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A and 1B)}
\]

minimum required wall thickness, in (mm). If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness \( t_m \) is determined by eq. (4), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from standard thickness schedules such as contained in ASME B36.10M or from manufacturers’ schedules for other than standard thickness.

The allowable working pressure of pipe may be determined from the following equation:

\[
\frac{2SEt}{D_o - 2\pi} = \text{the calculated maximum allowable internal pressure, psi (MPa), for straight pipe that shall at least equal the Design Pressure.}
\]

\( Pa \) may be used for piping products with pressure ratings equal to that of straight pipe (see ASME B16.9).

\( Pa \) = (b) For standard flanged joints, the rated pressure shall be used instead of \( Pa \).

\( Pa \) = (c) For reinforced branch connections (NCD-3643) where part of the required reinforcement is in the run pipe, the Design Pressure shall be used instead of \( Pa \).

\( Pa \) = (d) For other piping products where the pressure rating may be less than that of the
pipe (for example, flanged joints designed to Section III Appendices, Mandatory Appendix XI), the Design Pressure shall be used instead of $P_a$.

(e) $P_a$ may be rounded out to the next higher unit of 10 psi (0.1 MPa). the specified or actual wall thickness minus, as appropriate, material removed in threading, material removed in counterboring, in. (mm)
a coefficient having a value of 0.4, except that for pipe with a $D_o/t_m$ ratio less than 6, the value of $y$ shall be taken as

$$y = \frac{d}{d + D_b}$$  \hfill (6)

<table>
<thead>
<tr>
<th>Type of Pipe</th>
<th>$A$, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threaded steel and nonferrous pipe:</td>
<td></td>
</tr>
<tr>
<td>$\frac{3}{4}$ in. nominal (DN 20) and smaller</td>
<td>0.065 (1.5)</td>
</tr>
<tr>
<td>1 in. (DN 25) nominal and larger</td>
<td>Depth of thread</td>
</tr>
<tr>
<td>Grooved steel and nonferrous pipe</td>
<td>Depth of groove plus $\frac{1}{64}$ in. (0.4)</td>
</tr>
</tbody>
</table>

**NCD-3641.2 Straight Pipe Under External Pressure.**
For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in NCD-3133 shall be followed.

**NCD-3642 Curved Segments of Pipe**

**NCD-3642.1 Pipe Bends.**
Pipe bends shall be subject to the limitations in (a), (b), and (c) below.

(a) The minimum wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) The ovality shall meet the requirements of NCD-4223.2.

(c) The information in Section III Appendices, Nonmandatory Appendix GG is given to guide the designer when ordering pipe.

**NCD-3642.2 Elbows.**
Flanged elbows manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use at the pressure–temperature ratings specified by such standards. In
the case of standards under which butt welding elbows are made to a nominal wall thickness, the elbows shall be considered suitable for use with pipe of the same nominal thickness and of the same material.

**NCD-3643 Intersections**

**NCD-3643.1 General Requirements.**

(a) NCD-3643 gives acceptable rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, the angle between the axes of the branch and of the run is between 45 deg and 90 deg, inclusive, and no allowance is required for corrosion or erosion.

(b) Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg impose special design and fabrication problems. The rules given for angles between 45 deg and 90 deg, inclusive, may be used as a guide, but sufficient additional strength must be provided to assure safe service. Such branch connections shall be designed to meet the requirements of **NCD-3649**.

(c) Branch connections in piping may be made by using one of the products or methods given in (1) through (5) below:

1. flanged, butt welding, socket welding, or screwed fittings made in accordance with the applicable standards listed in Table NCA-7100-1;

2. welding outlet fittings, such as cast or forged nozzles; couplings including ASME B16.11 couplings, to a maximum of NPS 3 (DN 80); and adaptors or similar items having butt welding, socket welding, threaded, or flanged ends for attachment of the branch pipe. Such outlet fittings shall be attached to the main pipe

   (-a) by the full penetration weld; or

   (-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure **NCD-3643.2(b)-2**, sketch (e) or (f), provided the requirements of (1) through (4), as follows, are met:

   (-1) the nominal size of the branch shall not exceed 2 in. (50 mm) or one-quarter of the nominal size of the run, whichever is less;

   (-2) the minimum size of the weld, $x_{\text{min}}$, shall not be less than $1\frac{1}{4}$ times the fitting wall thickness in the reinforcement zone;

   (-3) the groove angle, $\theta$, shall be equal to or greater than 45 deg;

   (-4) except for attaching ASME B16.11 couplings, the requirements of **NCD-3643.3** shall be met.
(3) extruded outlets at right angles to the run pipe, in accordance with NCD-3643.4, where the attachment of the branch pipe is by butt welding;

(4) by attaching the branch pipe directly to the run pipe by welding or threading as stipulated in (-a) or (-b) below:

(-a) right angle branch connections may be made by attaching the branch pipe to the run pipe by socket welding, provided the requirements of (-1) through (-5) below are met:

(-1) the nominal size of branch does not exceed NPS 2 (DN 50) or one-fourth the nominal size of the run, whichever is less;

(-2) the depth of the socket in the run is at least equal to that shown in ASME B16.11 with a minimum shoulder of $\frac{1}{16}$ in. (1.5 mm) between the bottom of the socket and the inside diameter of the run pipe; weld metal may be deposited on the run pipe to provide the required socket depth and to provide any reinforcement required;

(-3) a minimum of $\frac{1}{16}$ in. (1.5 mm) clearance shall be provided between the bottom of the socket and the end of the inserted pipe;

(-4) the size of the fillet weld shall not be less than $1 \frac{1}{4}$ times the nominal branch wall thickness;

(-5) the requirements of NCD-3643.3 shall be met.

(-b) right angle branch connections may be made by attaching the branch pipe directly to the run by threading within the provisions of NCD-3671.3 and provided the requirements of (-1) and (-2) below are met:

(-1) the nominal size of the branch does not exceed NPS 2 (DN 50) or one-fourth the nominal size of the run, whichever is less;

(-2) minimum thread engagement shall be six full threads for 1/2 in., and 3/4 in. (DN 15 and DN 20) branches; seven for 1 in., 1 1/4 in., and 1 1/2 in. (DN 25, DN 32, and DN 40) branches; and eight for NPS 2 (DN 50) branches; weld metal may be deposited on the run pipe to provide sufficient thickness for required thread engagement;

(5) branch connections may be made by attaching the branch pipe directly to the run pipe

(-a) by a full penetration weld as shown in Figure NCD-3643.2(b)-1, with or without pad or saddle reinforcement as shown in Figure NCD-3643.3(c)(1)-1
or Figure NCD-3643.3(c)(1)-2, provided the requirements of NCD-3643.3 are met; or

(-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure NCD-3643.2(b)-2, sketches (a) through (d), provided the requirements of (-1) through (-4), as follows, are met:

(-1) the nominal size of the branch shall not exceed NPS 2 (DN 50) or one-quarter of the nominal size of the run, whichever is less;

(-2) the minimum size of the weld, \( x_{\text{min}} \), shall not be less than \( 1^{1/4} \) times the nominal branch wall thickness;

(-3) the groove angle, \( \theta \), shall be equal to or greater than 45 deg;

(-4) the requirements of NCD-3643.3 shall be met.

**NCD-3643.2 Branch Connections Not Requiring Reinforcement.**

Reinforcement need not be provided if the branch connection is made in accordance with the requirements of (a) through (c) below:

(a) by the use of a fitting manufactured in accordance with one of the standards listed in Table NCA-7100-1 and used within the limits of pressure–temperature ratings specified in such standards, a butt welding fitting made in accordance with ASME B16.9 or MSS SP-97 shall be of nominal thickness not less than the nominal thickness required for the adjoining pipe;

(b) by welding a coupling or half coupling directly to the run pipe, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the run, whichever is less; the wall thickness of the coupling is not less than that of the branch pipe; the coupling is joined to the run pipe by one of the methods shown in Figure NCD-3643.2(b)-1 sketch (c)(1) or Figure NCD-3643.2(b)-2 sketch (e); and in no case is the thickness of the coupling less than extra heavy or 3,000 lb nominal rating;

(c) by using an extruded outlet, provided the nominal diameter of the branch does not exceed 2 in. pipe size (DN 50) or one-fourth the nominal diameter of the pipe, whichever is less, and the minimum wall thickness at the abutting end of the outlet is not less than required for the branch pipe wall.
Figure NCD-3643.2(b)-1 — Typical Welded Branch Connections

(a) Typical Welded Branch Connection Without Additional Reinforcement

(b) Typical Welded Angular Branch Connection Without Additional Reinforcement

(c) Typical Branch Connections Made Using a Full Penetration Weld
**Figure NCD-3643.2(b)-2 — Typical Right Angle Branch Connections Made Using a Fillet Weld or a Partial Penetration Weld**

- (a) Calculations shall be made to determine the adequacy of reinforcement in branch connections except as exempted in NCD-3643.2.

- (b) A branch connection may be made by extruding an integrally reinforced outlet on the run pipe. The reinforcement requirements shall be in accordance with NCD-3643.4.
(c) A branch connection may be made by welding a pipe or fitting directly to the run pipe with or without added reinforcement, provided the pipe or fitting, deposited weldment, and other reinforcing devices meet the requirements of this subparagraph. This subparagraph gives rules covering the design of branch connections to sustain internal pressure in cases where the angle between the axes of the branch and of the run ranges from 45 deg to 90 deg. NCD-3643.5 gives rules governing the design of connections to sustain external pressure.

(1) **Nomenclature.** Figures NCD-3643.3(c)(1)-1 and NCD-3643.3(c)(1)-2 illustrate the notations used in the pressure–temperature design conditions of branch connections, which are as follows:

\[
\begin{align*}
\text{b} & = \text{ subscript referring to branch} \\
D_o & = \text{ outside diameter of pipe, in. (mm)} \\
d_1 & = \text{ inside diameter of branch for right angle connections, in. (mm); for connections at angles between 45 deg and 90 deg, } d_1 = \left( D_{ob} - 2T_b \right) / \sin \alpha \\
d_2 & = \text{ half width of reinforcing zone, in. (mm)} \\
& = \text{ the greater of } d_1 \text{ or } T_b + T_h + (d_1/2) \text{ but in no case more than } D_{ob} \\
h & = \text{ subscript referring to run or header} \\
L & = \text{ height of reinforcement zone outside of run, in. (mm)} \\
& = 2.5T_b + t_e \\
T & = \text{ nominal, actual by measurement, or minimum wall thickness of pipe, in. (mm), permissible under purchase specification} \\
t_e & = \text{ thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement, in. (mm) [Figure NCD-3643.3(c)(1)-2]} \\
t_m & = \text{ required minimum wall thickness, in. (mm), of pipe for pressure and temperature design conditions as determined by use of eq. NCD-3641.1(3) or eq. NCD-3641.1(4)} \\
\alpha & = \text{ angle between axes of branch and run, deg}
\end{align*}
\]

(2) **Requirements.** A pipe having a branch connection is weakened by the opening that must be made in it and, unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide additional reinforcement. The amount of reinforcement required shall be determined in accordance with (3) through (7), NCD-3643.4, or NCD-3643.5.

(3) **Reinforcement Area.** The required reinforcement area in in.$^2$ (mm$^2$) for branch connections shall be the quantity $t_{mh}d_1(2 - \sin \alpha)$.

(-a) For right angle connections, the required reinforcement becomes $t_{mh}(d_1)$. 

2019 Edition Version 0.0
(-b) The required reinforcement must be within the limits of the reinforcement zone as defined in (5).

**Figure NCD-3643.3(c)(1)-1 — Reinforcement of Branch Connections**

**GENERAL NOTES:**

(a) When metal is added as reinforcement (Example B), the value of reinforcing area may be taken in the same manner in which excess header metal is considered. Typical acceptable methods of meeting the above requirement are shown in Figure NCD-3643.3(c)(1)-2.

(b) Width to height of reinforcement shall be reasonably proportioned, preferably on a ratio as close as 4 to 1 as the available horizontal space within the limits of the reinforcing zone along the run and the outside diameter of the branch will permit, but in no case may the ratio be less than 1.

(c) This Figure is to be used only for definitions of terms, not for fabrication details.

(d) Use of reinforcing saddles and pads is limited as stated in NCD-3643.3(c)(7).
(4) *Area Contributing to Reinforcement*. Metal needed to meet reinforcement required by (c) must be within the limits of reinforcement zone determined in (5) and may include the following:

\[ A_1 = \text{area provided by excess pipe wall in the run, in.}^2 \text{ (mm}^2) \]
\[ = (2d_2 - d_1)[(T_h - \text{mill tolerance on } T_h) - tmh] \]
\[ A_2 = \text{area provided by excess pipe wall in the branch for a distance } L \text{ above the run}, \text{in.}^2 (\text{mm}^2) \]
\[ = \frac{2L}{\sin \alpha} \left[ (T_b - \text{mill tolerance on } T_b) - t_{mb} \right]. \]
\[ A_3 = \text{area provided by deposited weld metal beyond the outside diameter of the run and branch, in.}^2 (\text{mm}^2) \]
\[ A_4 = \text{area provided by reinforcement, in.}^2 (\text{mm}^2) \]

When the reinforcement area is composed of material with lower allowable stress than that of the run pipe, such reinforcement areas shall be increased by the inverse ratio of allowable stresses. No adjustment shall be made in reinforcement area for use of materials that have higher allowable stresses than the materials of the run pipe. Such reinforcement areas shall be decreased by the ratio of allowable stresses prior to any combination of areas to meet the reinforcement requirements of (c).

(5) Reinforcement Zone. The reinforcement zone is a parallelogram, the length of which shall extend a distance \(d_2\) on each side of the centerline of the branch pipe and the width of which shall start at the inside surface of the run pipe and extend to a distance \(L\) from the outside surface of the run pipe, when measured in the plane of the branch connection.

(6) Reinforcement of Multiple Openings

(-a) When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap, the two or more openings shall be reinforced in accordance with (3) with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(-b) When more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least \(1\frac{1}{2}\) times their average diameter and the area of reinforcement between them shall be at least equal to 50% of the total required for these two openings.

(7) Rings, Pads, and Saddles

(-a) Reinforcement provided in the form of rings, pads, or saddles shall not be appreciably narrower at the side than at the crotch.

(-b) A vent hole shall be provided at the ring, pad, or saddle to provide venting during welding and heat treatment.
(-c) Rings, pads, or saddles may be made in more than one piece, provided the joints between pieces have full thickness welds and each piece is provided with a vent hole.

(-d) Where saddles or pads are being employed for reinforcement, the potential for increased strain at the attachment welds that may occur as a result of rapid changes in differential metal temperatures between the saddle or pad and the run should be considered in the design evaluation.

**NCD-3643.4 Special Requirements for Extruded Outlets.**

The definitions, limitations, nomenclature, and requirements of (a) through (h) below are specifically applicable to extruded outlets.

(a) *Definition.* An extruded outlet header is a header in which the extruded lip at the outlet has a height above the surface of the run that is equal to or greater than the radius of the curvature of the external contoured portion of the outlet \( h_o \geq r_o \) [Figure NCD-3643.4(a)-1].
Figure NCD-3643.4(a)-1 — Reinforced Extruded Outlets

NOTES:
1 Sketch to show method of establishing $T_o$ when the taper encroaches on the crotch radius.
2 Sketch is drawn for condition where $K = 1.00$. 
(b) *Cases to Which Rules Are Applicable.* These rules apply only to cases where the axis of the outlet intersects and is perpendicular to the axis of the run.

(c) *Nomenclature.* The notation used herein is illustrated in Figure NCD-3643.4(a)-1.

\[
\begin{align*}
D &= \text{outside diameter of run, in. (mm)} \\
 d &= \text{outside diameter of branch pipe, in. (mm)} \\
 D_c &= \text{corroded internal diameter of run, in. (mm)} \\
 d_c &= \text{corroded internal diameter of branch pipe, in. (mm)} \\
 D_o &= \text{corroded internal diameter of extruded outlet measured at the level of the outside surface of the run, in. (mm)} \\
 h_o &= \text{height of the extruded lip, in. (mm); this must be equal to or greater than } r_o \text{ except as permitted in (d)(4)} \\
 L &= \text{height of reinforcement zone, in. (mm)} \\
 &= 0.7 \sqrt{D_o} \\
 &= \text{radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch, in. (mm); this is subject to the limitations given in (d) below} \\
 r_1 &= \text{half width of reinforcement zone, in. (mm)} = D_o \\
 T_b &= \text{actual thickness of branch wall, not including the corrosion allowance, in. (mm)} \\
 t_b &= \text{required thickness of branch pipe according to wall thickness eq. NCD-3641.1(3) or eq. NCD-3641.1(4), not including any thickness for corrosion, in. (mm)} \\
 T_o &= \text{corroded finished thickness of extruded outlet measured at a height equal to } r_o \text{ above the outside surface of the run, in. (mm)} \\
 T_r &= \text{actual thickness of run wall, not including the corrosion allowance, in. (mm)} \\
 t_r &= \text{required thickness of the run according to eq. NCD-3641.1(3) or eq. NCD-3641.1(4), not including any allowance for corrosion, in. (mm)}
\end{align*}
\]

(d) *Radii*

(1) The minimum radius shall not be less than \(0.05d\), except that on branch diameters larger than 30 in. (750 mm) it need not exceed \(1\frac{1}{2}\) in. (38 mm).

(2) The maximum radius for outlet pipe sizes 6 in. nominal (DN 150) and larger shall not exceed \(0.10d + 0.50\) in. (0.10\(d + 13\) mm). For outlet pipe sizes less than NPS 6 (DN 150), this dimension shall be not greater than \(1\frac{1}{4}\) in. (32 mm).

(3) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg shall meet the requirements of (1) and (2) above.

(4) Machining shall not be employed in order to meet the above requirements.

(e) *Required Area.* The required area is defined as
\[ A = K(t_r)(D_o) \]

where \( K \) shall be taken as follows:

1. for \( d/D \) greater than 0.60, \( K = 1.00 \)
2. for \( d/D \) greater than 0.15 and not exceeding 0.60, \( K = 0.6 + 2d/3D \)
3. for \( d/D \) equal to or less than 0.15, \( K = 0.70 \)

(f) **Reinforcement Area.** The reinforcement area shall be the sum of areas \( A_1 + A_2 + A_3 \) as defined in (1), (2), and (3) below:

1. Area \( A_1 \) is the area lying within the reinforcement zone resulting from any excess thickness available in the run wall
   \[ A_1 = D_0(t_r - t_r) \]
2. Area \( A_2 \) is the area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall
   \[ A_2 = 2L(t_b - t_b) \]
3. Area \( A_3 \) is the area lying within the reinforcement zone resulting from excess thickness available in the extruded outlet lip
   \[ A_3 = 2r_o(t_o - t_b) \]

(g) **Reinforcement of Multiple Openings.** When any two or more adjacent openings are so closely spaced that the reinforcement zones overlap, the two or more openings shall be reinforced in accordance with NCD-3643.4, with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(h) **Marking.** In addition to the above, the Certificate Holder shall be responsible for establishing and marking on the section containing extruded outlets, the Design Pressure and Temperature, and the Certificate Holder’s name or trademark.

**NCD-3643.5 Branch Connections Subject to External Pressure.**

(a) The reinforcement area in in.\(^2\) (mm\(^2\)) required for branch connections subject to external pressure shall be \( 0.54(t_{mh})(d_1)(2 - \sin \alpha) \). All terms defined in NCD-3643.3(c)(1), except \( t_{mh} \) is the minimum required wall thickness as determined by NCD-3641.2.
(b) Procedures established for connections subject to internal pressure shall apply for connections subject to external pressure.

**NCD-3643.6 Reinforcement of Other Designs.**

The adequacy of designs to which the reinforcement requirements of NCD-3643 cannot be applied shall be proven by burst or proof tests (NCD-3649) on scale models or on full-size structures, or by calculations previously substantiated by successful service of similar design.

**NCD-3644 Mitters**

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (e) below.

(a) The thickness of a segment of a miter shall be determined in accordance with NCD-3641.1. The required thickness thus determined does not allow for the discontinuity stresses that exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased. These discontinuity stresses may be neglected for miters in nonflammable, nontoxic, noncyclic services with incompressible fluids at pressures of 100 psi (700 kPa) and under, and for gaseous vents to atmosphere. Miters to be used in other services or at higher pressures shall meet the requirements of NCD-3649.

(b) The number of full pressure or thermal cycles shall not exceed 7,000 during the expected lifetime of the piping system.

(c) The angle $\theta$ in Table NCD-3673.2(b)-1 shall not be more than $22^{1}/2$ deg.

(d) The centerline distance between adjacent miters shall be in accordance with Table NCD-3673.2(b)-1.

(e) Full penetration welds shall be used in joining miter segments.

**NCD-3645 Attachments**

(a) External and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of NCD-3135.

(c) The effect of rectangular and circular cross-section welded attachments on straight pipes may be evaluated using the procedures in Section III Appendices, Nonmandatory Appendix Y.
NCD-3646 Closures

(a) Closures in piping systems shall be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table NCA-7100-1 and used within the specified pressure–temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table NCA-7100-1 may be made in accordance with the rules contained in NCD-3300 using the equation

\[ t_m = t + A \]

where

\[ A = \text{sum of mechanical allowances (NCD-3613), in. (mm)} \]
\[ t = \text{pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in Article NCD-3000, in. (mm)} \]
\[ t_m = \text{minimum required thickness, in. (mm)} \]

(c) Connections to closures may be made by welding, extruding, or threading. Connections to the closure shall be in accordance with the limitations provided in NCD-3643 for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening shall be designed as a reducer in accordance with NCD-3648.

(d) Other openings in closures shall be reinforced in accordance with the requirements of reinforcement for a branch connection. The total cross-sectional area required for reinforcement in any plane passing through the center of the opening and normal to the surface of the closure shall not be less than the quantity of \( d_st \), where

\[ d_s = \text{diameter of the finished opening, in. (mm)} \]
\[ t = \text{pressure design thickness for the closure, in. (mm)} \]

NCD-3647 Pressure Design of Flanged Joints and Blanks

NCD-3647.1 Flanged Joints.

(a) Flanged joints manufactured in accordance with the standards listed in Table NCA-7100-1, as limited by NCD-3612.1, shall be considered as meeting the requirements of NCD-3640.

(b) Flanged joints not included in Table NCA-7100-1 shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000.
NCD-3647.2 Permanent Blanks.

The minimum required thickness of permanent blanks (Figure NCD-3647.2-1) shall be calculated from the following equations:

\[ t_m = t + A \]

where

\[ A = \text{sum of mechanical allowances (NCD-3613), in. (mm)} \]

\[ t = \text{pressure design thickness calculated from the equation below, in. (mm)} \]

\[ t = d_6 \left( \frac{3P}{16S} \right)^{1/2} \]

\[ t = \text{where} \]

\[ d_6 = \text{the inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in. (mm)} \]

\[ P = \text{Design Pressure, psi (MPa)} \]

\[ S = \text{the allowable stress in accordance with Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)} \]

\[ t_m = \text{minimum required thickness, in. (mm)} \]
NCD-3647.3 Temporary Blanks.
Blanks to be used for test purposes only shall have a minimum thickness not less than the pressure design thickness $t$ calculated as in NCD-3647.2, except that $P$ shall not be less than the test pressure and the allowable stress $S$ may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Table Y-1).

NCD-3647.4 Flanges.
Flanges shall be integral or be attached to pipe by welding, brazing, threading, or other means within the applicable standards specified in Table NCA-7100-1.

NCD-3647.5 Gaskets.
(a) Gaskets shall be made of materials that are not injuriously affected by the fluid or by temperatures within the Design Temperature range.

(b) Only metallic or asbestos metallic gaskets may be used on flat or raised face flanges if the expected normal service pressure exceeds 720 psi (5 MPa) or the temperature exceeds 750°F (400°C). However, compressed sheet asbestos confined gaskets are not limited as to pressures, provided the gasket material is suitable for the temperatures.

(c) The use of metal or metal asbestos gaskets is not limited as to pressure, provided the gasket materials are suitable for the fluid Design Temperature.

NCD-3647.6 Bolting.
(a) Bolts, stud bolts, nuts, and washers shall comply with applicable standards and specifications listed in Table NCA-7100-1. Unless otherwise specified, bolting shall be in accordance with the latest edition of ASME B16.5. Bolts and stud bolts shall extend completely through the nuts.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least 1 1/2 diameters in length. Studs greater than 8 diameters in length may have an unthreaded portion that has the nominal diameter of the thread, provided the following requirements are met:

1. the threaded portions shall be at least 1 1/2 diameters in length;

2. the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion; and

3. a suitable transition shall be provided between the root diameter and unthreaded portions.

(c) Carbon steel bolts shall be square or heavy hexagon head bolts and shall have heavy semifinished hexagon nuts.
(d) Alloy steel stud bolts shall have heavy hexagon nuts. Headed alloy bolts are not recommended.

(e) It is recommended that all alloy bolts or stud bolts and accompanying nuts be threaded in accordance with ASME B1.1 Class 2A external threads and Class 2B internal threads.

NCD-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

NCD-3649 Pressure Design of Other Pressure-Retaining Piping Products

Other pressure-retaining piping products manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use in piping systems at the specified pressure–temperature ratings. Pressure-retaining piping products not covered by the standards listed in Table NCA-7100-1 and for which design equations or procedures are not given in this Subsection may be used where the design of similarly shaped, proportioned, and sized components has been proven satisfactory by successful performance under comparable service conditions. Where such satisfactory service experience exists, interpolation may be made to other sized piping products with a geometrically similar shape. In the absence of such service experience, the pressure design shall be based on an analysis consistent with the general design philosophy of this Subsection and substantiated by at least one of the following:

- proof tests as described in ASME B16.9;
- experimental stress analysis (Section III Appendices, Mandatory Appendix II).

NCD-3649.1 Expansion Joints — General Requirements.

Expansion joints of the bellows, sliding, ball, or swivel type may be used to provide flexibility for piping systems. The design of the piping systems and the design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and shall comply with the requirements of (a) through (e) below.

(a) Piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the expansion joints other than those for the absorption of which they are both suitable and intended. Bellows expansion joints are normally not designed for absorbing torsion. Sliding expansion joints are normally not designed for absorbing bending. In sliding and bellows expansion joints used for absorbing axial motion, the hydrostatic end force caused by fluid pressure and the forces caused by either friction resistance or spring force, or both, should be resisted by rigid end anchors, cross connections of the section ends, or other means. Where reaction to hydrostatic end forces acts on pipe, guides shall be provided to prevent buckling in any direction. For bellows expansion joints, the pipe guiding and anchorage shall conform to EJMA Standards.13
(b) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection and maintenance and for removal and replacement either directly or by other suitable means.

(c) Expansion joints employing mechanical seals shall be sufficiently leak-tight to satisfy safety requirements. The system designer shall specify the leak-tightness criteria for this purpose.

(d) Material shall conform to the requirements of Article NCD-2000, except that no sheet material in the quenched, aged, or air-hardened condition shall be used for the flexible elements of a bellows joint. If heat treatment is required, it shall be performed either after welding the element into a complete cylinder or after all forming of the bellows is completed, the only welding permissible after such treatment being that required to connect the element to pipe or end flanges.

(e) All welded joints shall comply with the requirements of NCD-4800.

NCD-3649.2 Bellows Expansion Joints.

Expansion joints of the bellows type may be used to provide flexibility for piping systems. The design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and the requirements of (a) through (f) below.

(a) The piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by pressure and the bellows spring force shall be accommodated by or resisted by rigid anchors, cross connections of the expansion joint ends, or other means. Where bellows are used in straight pipe sections to absorb axial motion and where the hydrostatic end force of the bellows acts on the pipe as a column, guides must be provided to prevent buckling of the pipe in any direction. The pipe guiding and anchorage shall conform to the requirements of the Design Specification for the attached piping.

(c) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length or offset to accommodate connected piping that is not properly aligned, unless such misalignments have been specified by the system designer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.
(f) Unless otherwise stated in the Design Specification, internal sleeves shall be provided when flow velocities exceed the following values:

(1) Air, Steam, and Other Gases

   (-a) up to 6 in. (150 mm) diameter — 4 ft/sec/in. (0.05 m/s/mm) of diameter

   (-b) 6 in. (150 mm) diameter and over — 25 ft/sec (7.6 m/s)

(2) Water and Other Liquids

   (-a) up to 6 in. (150 mm) diameter — 2 ft/sec/in. (0.024 m/s/mm) of diameter

   (-b) 6 in. (150 mm) diameter and over — 10 ft/sec (3 m/s)

**NCD-3649.3 Bellows Expansion Joint Material.**

Pressure-retaining material in the expansion joint shall conform to the requirements of Article NCD-2000.

**NCD-3649.4 Bellows Expansion Joint Design.**

Bellows may be of the unreinforced or reinforced convoluted type or of the toroidal type. The design shall conform to the requirements of Article NCD-3000 and to those of (a) through (j) below.

(a) The circumferential membrane stresses in both the bellows and reinforcing member, due to pressure, shall not exceed the allowable stresses given in Section II, Part D, Subpart 1, Tables 1A and 1B.

(b) The sum of the bellows meridional membrane and bending stresses due to internal pressure shall not exceed a value that results in a permanent decrease in the spaces between adjacent convolutions of 7% after a pressure test of 1½ times the Design Pressure, adjusted for temperature.

(c) The ratio of the internal pressure at which the bellows will become unstable (squirm) to the equivalent cold service pressure shall exceed 2.25. By definition, squirm shall be considered to have occurred if under internal pressure an initially symmetrical bellows deforms, resulting in a lack of parallelism or uneven spacing of adjacent convolutions at any point on the circumference. Unless otherwise specified, this deformation shall be construed as unacceptable squirm when the ratio of the maximum convolution pitch under internal pressure to the convolution pitch before application of pressure exceeds 1.15 for unreinforced and 1.20 for reinforced bellows. In the case of universal expansion joints, which consist of two bellows joined by a cylindrical section, compliance with these criteria shall be satisfied by the entire assembly. No external restraints on the bellows shall be employed during squirm testing other than those that will exist after installation.
(1) For single joints used in axial or lateral motion, the squirm test may be performed with the bellows fixed in the straight position at the maximum length expected in service; for rotation and universal joints, the bellows shall be held at the maximum design rotation angle or offset movement. In the case of single joints subjected to rotation movement or universal joints subjected to lateral offset movement, an instability condition as previously defined may or may not appear. Instead, movement of the convolutions may occur due to the superposition of the lateral internal pressure component on the applied rotation. In such cases, that portion of the bellows deformation due to the design rotation angle or offset movement shall not be included in the deformation used to define squirm.

(2) In the case of squirm tests, the equivalent cold service pressure is defined as the Design Pressure multiplied by the ratio $\frac{E_c}{E_h}$, where $E_c$ and $E_h$ are defined as the modulus of elasticity of the bellows material at room temperature and normal service temperature, respectively.

(d) The combination of meridional membrane and bending stresses $S$ in the bellows due to internal pressure and deflection, multiplied by a stress factor $K_s$ [see Section III Appendices, Mandatory Appendix II, II-1520(g)], shall not exceed the value defined by the following equation:

$$K_s S \leq S_f$$

where

$$K_s = (K_{sc})(K_{ss}), \text{ but not less than } 1.25$$

$$K_{sc} = \text{factor for differences in design fatigue curves at temperatures greater than } 100^\circ F \text{ (38°C)}$$

$$= 2S_c/(S_c + S_h)$$

$$K_{ss} = \text{factor for the statistical variation in test results}$$

$$= 1.470 - 0.044 \times \text{the number of replicate tests}$$

total combined meridional membrane and bending stress due to pressure and deflection, psi (MPa). The calculation of the individual stress components and their combination must be determined by the same method as used for determining $S$. In the case of single joints subjected to rotation movement and universal joints subjected to lateral offset movement, the increase in deflection stress caused by the lateral internal pressure component shall be included in determining the combined stress.

$$S_c = \text{basic material allowable stress value at room temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)}$$

total combined stress to failure at design cyclic life (number of cycles to failure)

$$S_f = \text{obtained from plots of stress versus cyclic life based on data from fatigue tests of a series of bellows at a given temperature (usually room temperature) evaluated by a best-fit continuous curve or series of curves, psi (MPa). The } S_f \text{ plot shall be}$$
parallel to the best-fit curve and shall lie below all of the data points.

\[ S_h = \text{basic material allowable stress value at normal service temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)} \]

(e) Compliance with (a) through (d) above shall be demonstrated by any one of the procedures of (1), (2), or (3) below.

(1) Calculation of the individual stresses, their combination, and their relation to fatigue life may be performed by any analytical method based on elastic shell theory. The resulting equations shall be substantiated by correlation with actual tests of a consistent series of bellows of the same basic design (unreinforced, reinforced, and toroidal bellows are considered as separate designs) by each manufacturer in order to demonstrate predictability of rupture pressure, meridional yielding, squirm, and cyclic life. A minimum of five burst tests on bellows of varying sizes, with not less than three convolutions, shall be conducted to verify that the analytical method will adequately satisfy (a) and (b) above. No specimen shall rupture at less than four times its equivalent cold pressure rating. A minimum of ten squirm tests on bellows of varying diameters and number of convolutions shall be conducted to verify that the analytical method will adequately satisfy (c) above. Since column instability is most likely to occur in bellows less than 20 in. (500 mm) diameter, where the convoluted bellows length is greater than its diameter, the test specimens shall reflect these considerations. In the case of universal expansion joints, two additional tests shall be conducted to verify that the analytical method will adequately satisfy (c) above. The cyclic life versus the combined stress plot used in evaluating (d) shall be obtained from the results of at least 25 fatigue tests on bellows of varying diameters, thicknesses, and convolution profiles. These curves may be used for diameter and convolution profiles other than those tested, provided that a variation in these dimensions has been included in the correlation with test data. Each group of five such tests on varying bellows may be considered the equivalent of one replicate test in determining \( K_s \).

(2) Individual expansion joint designs may be shown to comply by the testing of duplicate bellows. At least two test specimens are required, one to demonstrate pressure capacity in accordance with (a), (b), and (c) above and the second to demonstrate fatigue life in accordance with (d) above. In the case of rupture and fatigue tests, the specimens need not possess a duplicate number of convolutions provided the number of convolutions is not less than three and the diameter, thickness, depth, and pitch of the specimen are identical to the part to be furnished; squirm test specimens shall possess the total number of convolutions.

(-a) Any or all of the above tests of (1) or (2) may be conducted at room temperature, provided that cold service pressure is defined as the Design Pressure multiplied by the ratio of \( S_c/S_h \) for rupture specimens and \( E_c/E_h \) for squirm specimens.
(-b) The fatigue life of the test specimen shall exceed $K_s^{4.3}$ times the number of design cycles specified for the most significant cyclic movements. This test shall include the effect of internal pressure. If lateral and rotation movements are specified, these may be converted to equivalent axial motion for cyclic testing; the convolution deflection produced by the lateral component of the internal pressure force during the squirm test for single rotation joints and universal joints shall be added to the mechanical deflections in determining fatigue life. Where accelerated fatigue testing is employed, the deflection and number of cycles required shall be in accordance with Section III Appendices, Mandatory Appendix II. Cumulative fatigue requirements can be satisfied in accordance with (g) without additional testing by assuming that the slope of the fatigue curve is 4.3 and that the curve passes through the test point.

(3) An individual design may be shown to comply by a design analysis in accordance with NCD-3200. The stresses at every point in the bellows shall be determined by either elastic shell theory or by a plastic analysis, where applicable. Where an elastic analysis is employed, the stress intensity values of Section II, Part D, Subpart 1, Tables 2A and 2B, and fatigue curves of Section III Appendices, Mandatory Appendix I may be used to evaluate the design.

(-a) The stability requirements of (c) may be demonstrated by either

(-1) elastic stability calculations, provided that the ratio of the internal pressure at which the bellows is predicted to become unstable to the equivalent cold service pressure exceeds 10; or

(-2) the pressure test of NCD-6230, provided that the test is conducted at $2^{1/4}$ times the equivalent cold design pressure, and single rotation and universal joints are held at their design rotation angle or offset movement during the test, and the requirements of (b) are not exceeded by such a test.

(f) The Certificate Holder’s Data Report shall state which of the above procedures was utilized to verify the design.

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

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

Note: In determining $n_1, n_2, ..., n_n$, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference $S_1, S_2, ..., S_n$ greater than the stress difference of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of stress difference variation from 0 to +60,000 psi and another type of stress cycle produces 10,000
cycles of a stress difference variation from 0 to −50,000 psi, the two types of cycles to be considered are defined by the following parameters:

(a) Type 1 Cycle:

\[ n_1 = 1,000 \]
\[ S_1 = (60,000 + 50,000) = 110,000 \text{ psi} \]

(b) Type 2 Cycle:

\[ n_2 = 9,000 \]
\[ S_2 = (50,000 + 0) = 50,000 \text{ psi} \]

Step 2. For each value \( S_1, S_2, \ldots, S_n \), use the applicable design fatigue curve and corresponding method of analysis to determine the maximum number of stress cycles that would be allowable if this type of cycle were the only one acting. Call these values \( N_1, N_2, \ldots, N_n \). The fatigue curve used may be either the \( S_f \) lot defined in (d) or the curve consistent with (e)(2) or (e)(3). If the fatigue curve has been developed based on a total stress difference, then the full value of \( S_1, S_2, \ldots, S_n \) of Step 1 must be used to determine \( N \); however, if the curve is based on an alternating stress, then the values of \( S_1, S_2, \ldots, S_n \) shall be reduced by a factor of 2, in which case \( S_1, S_2, \ldots, S_n \) become the alternating stresses.

Step 3. For each type of stress cycle, calculate the usage factors \( U_1, U_2, \ldots, U_n \), from \( U_1 = n_1/N_1, U_2 = n_2/N_2, \ldots, U_n = n_n/N_n \).

Step 4. Calculate the cumulative usage factor \( U \) from \( U = U_1 + U_2 + \ldots + U_n \).

Step 5. The cumulative usage factor \( U \) shall not exceed 1.0.

(h) The Certificate Holder shall submit a report which demonstrates compliance with NCD-3649.

(i) Where necessary to carry the pressure, the cylindrical ends of the bellows may be reinforced by suitable collars. The design method used to assure that the stresses generated will not cause premature failure of the bellows material or weldment shall include the attachment weld between the bellows and end connections.

(j) The spring rates of the expansion joint assembly shall be provided by the Certificate Holder. The spring rates of a bellows can be defined by several methods due to the hysteresis loop that can occur during deflection; a restoring force may be required to return the bellows to the original neutral position after deflection. When applicable, the Design Specification shall state the maximum allowable force that can be imposed on the connecting parts or shall
require the Certificate Holder to determine the maximum force necessary to deflect the bellows a given distance, such as the maximum movement to be absorbed.

**NCD-3649.5 Metallic Braided Flexible Hoses.**
Metallic braided flexible hoses may be constructed in accordance with Section III Appendices, Nonmandatory Appendix BB.

**NCD-3650 Analysis of Piping Designs**

**NCD-3651 General Requirements**

(a) The design of the complete piping system shall be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads. The system design shall meet the limits of NCD-3650. The pressure portion of eqs. NCD-3652(8), NCD-3653.1(a)(9a), and NCD-3653.1(b)(9b) may be replaced with the expression

\[
S_{LP} = B_1 \frac{2PD^2}{D_o^2 - d^2}
\]

The pressure portion of eq. NCD-3653.2(c)(11) may be replaced by the expression

\[
S_{LP} = \frac{PD^2}{D_o^2 - d^2}
\]

where the terms are the same as in NCD-3652, except

- \(d\) = nominal inside diameter of pipe, in. (mm)
- \(P\) = \(P\) or \(P_{\text{max}}\), psi (MPa)

(b) When evaluating stresses in the vicinity of expansion joints, consideration must be given to actual cross-sectional areas that exist at the expansion joint. The pressure term in eqs. NCD-3652(8), NCD-3653.1(a)(9a), NCD-3653.1(b)(9b) and NCD-3653.2(c)(11) may not apply for bellows and expansion joints.

(c) For analysis of flanged joints, see NCD-3658.

**NCD-3652 Consideration of Design Conditions**

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of eq. (8)

\[
S_{SL} = B_1 \frac{PD_o}{2tr} + B_2 \frac{M_A}{Z} \leq 1.5S_{th} \quad (8)
\]
where

\( B_1 \) = primary stress indices for the specific product under investigation [Table NCD-3673.2(b)-1]

\( B_2 \) = outside diameter of pipe, in. (mm)

\( D_o \) = resultant moment loading on cross section due to weight and other sustained loads, in.-lb (N-mm) (NCD-3653.3)

\( P \) = internal Design Pressure, psi (MPa)

\( S_h \) = basic material allowable stress at Design Temperature, psi (MPa)

\( t_n \) = nominal wall thickness, in. (mm)

\( Z \) = section modulus of pipe, in.³ (mm³) (NCD-3653.3)

### NCD-3653 Consideration of Levels A and B Service Limits

#### NCD-3653.1 Occasional Loads.

The effects of pressure, weight, other sustained loads, and occasional loads, including reversing and nonreversing dynamic loads, for which Level B Service Limits are designated, must meet the requirements of either (a) or (b) below. Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.

(a) The following requirements shall be met:

\[
S_{OL} = B_1 \frac{P_{max} \cdot D_o}{2t_n} + B_2 \left( \frac{M_A + M_B}{Z} \right) \leq 1.5S_y
\] (9a)

but not greater than 1.5\( S_y \). Terms are the same as in NCD-3652, except resultant moment loading on cross section due to occasional loads, such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and nonreversing dynamic loads, in.-lb (N-mm). For reversing and nonreversing dynamic loads, use only \( \frac{1}{2} \) the range. Effects of anchor displacement due to reversing and nonreversing dynamic loads may be excluded from eq. (9a) if they are included in either eq. NCD-3653.2(a)(10a) or eq. NCD-3653.2(c)(11).

\( P_{max} \) = peak pressure, psi (MPa)

\( S_h \) = material allowable stress at a temperature consistent with the loading under consideration, psi (MPa)

\( S_y \) = material yield strength at a temperature consistent with the loading under consideration, psi (MPa)

(b) As an alternative to (a), for piping fabricated from material designated as P-No. 1 through P-No. 9 in Section II, Part D, Subpart 1, Table 2A, and limited to \( \left( \frac{D_o}{t_n} \right) \leq 40 \), if Level B Service limits are specified, which include reversing dynamic loads (NCD-3622.4) that are...
not required to be combined with nonreversing dynamic loads are specified, the requirements below shall apply.

\[
S_{OL} = B_1\frac{P_{\text{max}}D_p}{2t_n} + B_2\left(\frac{M_A + M_B}{Z}\right) \leq 1.8S_b \quad (9b)
\]

but not greater than 1.5\(S_b\). Terms are the same as in NCD-3652, except

\[
B'2 = \text{as defined in NCD-3655(b)(3)}
\]

resultant moment loading on cross section due to reversing dynamic loads, in.-lb (N-mm). For reversing dynamic loads, use only \(1/2\) the range. Effects of anchor displacement due to reversing dynamic loads may be excluded from eq. (9b) if they are included in either eq. NCD-3653.2(a)(10a) or eq. NCD-3653.2(c)(11).

\[
P_{\text{max}} = \text{peak pressure, psi (MPa)}
\]

\[
S_b = \text{material allowable stress at a temperature consistent with the loading under consideration, psi (MPa)}
\]

\[
S_y = \text{material yield strength at a temperature consistent with the loading under consideration, psi (MPa)}
\]

**NCD-3653.2 Thermal Expansion.**

For Service Loadings for which Level A and B Service Limits are designated, the requirements of either (a)(10a) or (c)(11), and (b)(10b) must be met.

(a) The effects of thermal expansion must meet the requirements of eq. (10a)

\[
S_E = \frac{iM_C}{Z} \leq S_A \quad (10a)
\]

Terms are the same as in NCD-3652 and NCD-3653.1, except

\[
i = \text{stress intensification factor (NCD-3673.2)}
\]

range of resultant moments due to thermal expansion, in.-lb (N-mm); also include moment effects of anchor displacements due to reversing and nonreversing dynamic loads if anchor displacement effects were omitted from eq. NCD-3653.1(a)(9a) or eq. NCD-3653.1(b)(9b).

\[
S_A = \text{allowable stress range for expansion stresses (NCD-3611.2), psi (MPa)}
\]

(b) The effects of any single nonrepeated anchor movement shall meet the requirements of eq. (10b)

\[
\frac{iM_D}{Z} \leq 3.0S_c \quad (10b)
\]

Terms are the same as in NCD-3653.1(a), except
\[ M_D = \text{resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement), in.-lb (N mm)} \]

(c) The effects of pressure, weight, other sustained loads, and thermal expansion shall meet the requirements of eq. (11)

\[
S_{TE} = \frac{PD}{4m} + 0.75s\left(\frac{MA}{Z}\right) + i\left(\frac{MC}{Z}\right) \leq (S_b + S_A) \tag{11}
\]

For eq. (11) 0.75\(i\) shall not be less than 1.0.

**NCD-3653.3 Determination of Moments and Section Modulus.**

(a) For purposes of eqs. NCD-3652(8), NCD-3653.1(a)(9a), NCD-3653.1(b)(9b), NCD-3653.2(a)(10a), NCD-3653.2(b)(10b), and NCD-3653.2(c)(11), the resultant moment for straight through components, curved pipe, or welding elbows may be calculated as follows:

\[ M_j = \left(M_{xj}^2 + M_{yj}^2 + M_{zj}^2\right)^{1/2} \]

where

\[ j = A, B, B', C, \text{ or } D \] which are the subscripts of \(M_A, M_B, M'B, M_C, M_D\) defined in NCD-3652, NCD-3653.1, and NCD-3653.2

(b) For intersections (branch connections or tees), calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure NCD-3653.3-1) for full outlet intersections.

(c) For reduced outlets, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure NCD-3653.3-1), except that for \(r'm/R_m < 0.5\), the branch moments at the outside surface of the run pipe may be used for the branch leg.
(d) For intersections, the section modulus used to determine stresses shall be the effective section modulus

\[ Z = \pi (r'_{m})^2 T_{b} \text{ for the branch leg} \]

and

\[ Z = \pi (R_{m})^2 T_{r} \text{ for the run legs} \]

where

\[ R_{m} = \text{run pipe mean cross-sectional radius, in. (mm)} \]
\[ r'_{m} = \text{branch pipe mean cross-sectional radius, in. (mm)} \]
\[ T_{b} = \text{nominal branch pipe wall thickness, in. (mm)} \]
\[ T_{r} = \text{nominal wall thickness of run pipe, in. (mm)} \]

(e) For components and joints other than intersections, the section modulus used to determine stresses shall be the classic section modulus

\[ Z = \frac{2I}{D_{b}} \]

where

\[ I = \text{moment of inertia, in.}^4 (\text{mm}^4) \]
NCD-3654 Consideration of Level C Service Limits

NCD-3654.1 Permissible Pressure.
When Level C Service Limits [NCA-2142.4(b)(3) and NCD-3113(b)] are specified, the permissible pressure shall not exceed the pressure $P_a$, calculated in accordance with eq. NCD-3641.1(5), by more than 50%. The calculation of $P_a$ shall be based on the maximum allowable stress for the material at the coincident temperature.

NCD-3654.2 Analysis of Piping Components.
For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NCD-3113(b)] are designated, the following requirements shall apply:

(a) For Service Loadings for which Level C Service Limits are designated, except as permitted by (b) below, the conditions of eq. NCD-3653.1(a)(9a) shall be met using Service Level C coincident pressure $P$ and moment $(M_A + M_B)$, which result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_h$, but not greater than $1.8S_y$. $S_h$ and $S_y$ are defined in NCD-3653.1. In addition, if the effects of anchor motion, $M_{AM}$, from reversing dynamic loads are not considered in NCD-3653, then the requirements of NCD-3655(b)(4) shall be satisfied using 70% of the allowable stress given in NCD-3655(b)(4).

(b) As an alternative to (a), for Service Loadings for which Level C Service Limits are designated, which include reversing dynamic loads (NCD-3622.4) that are not required to be combined with nonreversing dynamic loads (NCD-3622.5), the requirements of NCD-3655(b) shall be satisfied using the allowable stress in NCD-3655(b)(2), 70% of the allowable loads in NCD-3655(b)(3), and 70% of the allowable loads in NCD-3655(b)(4).

NCD-3654.3 Deformation Limits.
Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

NCD-3655 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the following requirements shall apply:

(a) For Service Loadings for which Level D Service Limits are designated, except as permitted by (b) below, the requirements of (1), (2), and (3) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure $P_a$ calculated in accordance with eq. NCD-3641.1(5). The calculation of $P_a$ shall be based on the maximum allowable stress for the material at the coincident temperature.
(2) The conditions of eq. NCD-3653.1(a)(9a) shall be met using Service Level D coincident pressure $P$ and moment $(M_A + M_B)$, which result in the maximum calculated stress. The allowable stress to be used for this condition is $3.0 S_h$, but not greater than $2.0 S_y$. $S_h$ and $S_y$ are defined in NCD-3653.1.

(3) If the effects of anchor motion, $M_{AM}$, from reversing dynamic loads are not considered in NCD-3653, then the requirements of (b)(4) shall be satisfied.

(b) As an alternative to (a), for piping fabricated from material designated P-No. 1 through P-No. 9 in Section II, Part D, Subpart 1, Table 2A and limited to $D_o/t_n \leq 40$, if Level D Service Limits are designated, which include reversing dynamic loads (NCD-3622.4) that are not required to be combined with nonreversing dynamic loads (NCD-3622.5), the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading, $P_E$, shall not exceed the Design Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2l} M_W \leq 0.5 S_h$$

where

$M_W = \text{resultant moment due to weight effects, in.-lb (N\cdot\text{mm})}$

$S_h = \text{as defined in NCD-3653.1}$

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_E D_o}{2t_n} + B_2' \frac{D_o}{2l} M_E \leq 3 S_h$$

where

$B_2'$ from Table NCD-3673.2(b)-1, except as follows:

$B_2' = 1.33$ for girth butt welds between items that do not have nominally identical wall thicknesses

$B_2' = 0.87/h^{2/3}$ for curved pipe or butt welding elbows [$h$ as defined in Table NCD-3673.2(b)-1], but not less than 1.0

$B_2' = 0.27 \left(\frac{R_m}{T_r}\right)^{2/3}$ and $0.33 \left(\frac{R_m}{T_r}\right)^{2/3}$ for ASME B16.9 or MSS SP-87 butt welding tees

$B_2' = \text{[terms as defined in Table NCD-3673.2(b)-1], but neither less than 1.0}$
the amplitude of the resultant moment due to weight and the inertial loading resulting from reversing dynamic loads, in.-lb (N·mm). In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs are obtained, the most conservative combination shall be assumed.

\[ M_E = \] the pressure occurring coincident with the reversing dynamic load, psi (MPa)

\[ P_E = \]

\[ S_h = \] as defined in NCD-3653.1

(4) The range of the resultant moment \( M_{AM} \) and the amplitude of the longitudinal force \( F_{AM} \) resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

\[
\frac{C_2 M_{AM} D_0}{2I} < 6S_h \\
\frac{F_{AM}}{A_M} < S_h
\]

where

\[ A_M = \] cross-sectional area of metal in the piping component wall, in.\(^2\) (mm\(^2\))

\[ C_2 = \] secondary stress index from Table NB-3681(a)-1

\[ S_h = \] as defined in NCD-3653.1

(5) The use of the 6\( S_h \) limit in (4) assumes essentially linear behavior of the entire piping system. This assumption is sufficiently accurate for systems where plastic straining occurs at many points or over relatively wide regions, but fails to reflect the actual strain distribution in unbalanced systems where only a small portion of the piping undergoes plastic strain. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(-a) by the use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed.

(-b) by local reduction in size or cross section, or local use of a weaker material.

In the case of unbalanced systems the design shall be modified to eliminate the unbalance or the piping shall be qualified to the equations given in (4) with 6\( S_h \) taken as 3\( S_h \).

(6) Piping displacements shall satisfy Design Specification limitations.
(c) As an alternative to (a) and (b), the rules contained in Section III Appendices, Mandatory Appendix XIII, XIII-3144(a) and XIII-3144(b) or Mandatory Appendix XXVII with the stress value $S_m$ replaced by the stress value $S$ may be used in evaluating these service loadings independently of all other Design and Service Loadings. When using Section III Appendices, Mandatory Appendix XXVII, the exclusion of XXVII-1300 shall not apply to anchor motion effects and the secondary stresses resulting from anchor motion effects shall be considered if either of the following applies:

1. The loads under consideration are reversing dynamic loads in combination with nonreversing dynamic loads and the anchor motion effects were not considered in NCD-3653.

2. The loads under consideration are reversing dynamic loads not in combination with nonreversing dynamic loads.

### NCD-3657 Consideration of Test Limits

For loadings due to the Testing conditions defined in NCD-6221 and NCD-6321, the limits provided in (a) through (c) shall apply. The following nomenclature applies to (a) through (c):

- $P_{htest}$ = the actual hydrostatic test pressure, psi (MPa)
- $P_{ptest}$ = the actual pneumatic test pressure, psi (MPa)
- $M_{test}$ = the moments in the piping system during either the hydrostatic or pneumatic test, in.-lb (N-mm)

(a) The maximum pressure during a hydrostatic test ($P_{htest}$) shall not exceed the pressure $P_a$ calculated in accordance with eq. NCD-3641.1(5). In lieu of $S$ in eq. NCD-3641.1(5), 0.9$S_y$ may be used, where $S_y$ is taken at the test temperature.

(b) The maximum pressure during a pneumatic test ($P_{ptest}$) shall not exceed the pressure $P_a$ calculated in accordance with eq. NCD-3641.1(5). In lieu of $S$ in eq. NCD-3641.1(5), 0.8$S_y$ may be used, where $S_y$ is taken at the test temperature.

(c) The requirements of eq. NCD-3652(8) shall be met using the coincident test pressure $P_{htest}$ or $P_{ptest}$, as applicable, and test moment $M_{test}$, which result in the maximum calculated stress. In lieu of 1.5$S_h$, the larger of 1.5$S_h$ or 1.1$S_y$ may be used as the maximum stress permitted for eq. NCD-3652(8). Both $S_h$ and $S_y$ are to be taken at the test temperature.

### NCD-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by NCD-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of either NCD-3658.1, NCD-3658.2, or NCD-3658.3. In addition, the pipe-to-flange welds shall meet the requirements of NCD-3651 through NCD-3655 using appropriate stress intensification factors from Table NCD-3673.2(b)-1. The following nomenclature applies for NCD-3658:

- $A_b$ = total cross-sectional area of bolts at root of thread or section of least diameter under
stress, in.² (mm²)

\[ C = \text{bolt circle diameter, in. (mm)} \]

\[ D_f = \text{outside diameter of raised face, in. (mm)} \]

\[ G = \text{diameter at location of gasket load reaction as defined in Section III Appendices, Mandatory Appendix XI, XI-3130, in. (mm)} \]

bending or torsional moment (considered separately) as defined for \( M_{fs} \) but including

\[ M_{jd} = \text{dynamic loadings applied to the flanged joint during the design or service condition, in.-lb (N-mm)} \]

bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor movements, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service condition, in.-lb (N-mm). If cold springing is used, the moment may be reduced to the extent permitted by NCD-3673.5.

\[ P = \text{Design or Service Condition Pressure as defined in NCA-2140, psi (MPa)} \]

\[ P_{eq} = \text{equivalent pressure to account for the moments applied to the flange joint during the Condition, psi (MPa)} \]

\[ P_{fd} = \text{pressure concurrent with } M_{fd}, \text{ psi (MPa)} \]

\[ S = \text{allowable bolt stress for the bolt material, psi (MPa)} \]

\[ S_y = \text{yield strength, psi (MPa), of flange material at Design Temperature (Section II, Part D, Subpart 1, Table Y-1)} \]

**NCD-3658.1 Any Flanged Joint.**

Flanged joints may be analyzed and the stresses evaluated by using the methods given in Section III Appendices, Mandatory Appendix XI as modified by (a) or by (b). Alternatively, they may be analyzed in accordance with Section III Appendices, Mandatory Appendix XIII.

(a) If the flanged joint conforms to one of the standards listed in Table NCA-7100-1, and if each \( P' \), as calculated by (b) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of NCD-3658 are satisfied.

(b) The Design Pressure used for the calculation of \( H \) in Section III Appendices, Mandatory Appendix XI shall be replaced by a flange design pressure

\[ P' = P + P_{eq} \]

The equivalent pressure \( P_{eq} \) shall be determined by the greater of

\[ P_{eq} = \frac{16M_{fs}}{\pi G^3} \]

or

\[ P_{eq} = \frac{8M_{jd}}{\pi G^3} \]
NCD-3658.2 Standard Flanged Joints at Moderate Pressures and Temperatures.
Flanged joints conforming to ASME B16.5, ASME B16.47, or ANSI/AWWA C207 Class E [275 psi (1.9 MPa)], and used where neither the Design nor Service Pressure exceeds 100 psi (0.7 MPa) and neither the Design nor Service Temperature exceeds 200°F (95°C), meet the requirements of NCD-3658, provided the following equations are satisfied:

\[ M_{fs} \leq A_b CS / 4 \]

and

\[ M_{fd} \leq A_b CS / 2 \]

NCD-3658.3 ASME B16.5, Flanged Joints With High Strength Bolting.
Flanged joints using flanges, bolting, and gaskets as specified in ASME B16.5 and using bolting material having an \( S \) value at 100°F (38°C) not less than 20,000 psi (140 MPa) may be analyzed in accordance with the following rules:

(a) Design Limits and Levels A and B Service Limits

(1) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(2) The limitations given by eqs. (12) and (13) shall be met

\[ (U.S. \ Customary \ Units) \]

\[ M_{fs} \leq 3, 125 \left( \frac{S_y}{36,000} \right) C A_b \]  \hspace{1cm} (12) \]

\[ (SI \ Units) \]

\[ M_{fs} \leq 21.7 \left( \frac{S_y}{250} \right) C A_b \]

\[ (U.S. \ Customary \ Units) \]

\[ M_{fd} \leq 6, 250 \left( \frac{S_y}{36,000} \right) C A_b \]  \hspace{1cm} (13) \]

\[ (SI \ Units) \]
where the value of $S_y/36,000$ or $(S_y/250)$ shall not be taken as greater than unity.

(b) **Level C Service Limits**

1. The pressure shall not exceed 1.5 times the rated pressure.
2. The limitation given by eq. (17) shall be met

\[
M_{fd} \leq [78.1A_b - (\pi/16)D_p^2P_{fd}^{1/3}C(S_y/250)]
\]  

(SI Units)

\[
M_{fd} \leq [11,250A_b - (\pi/16)D_p^2P_{fd}^{1/3}C(S_y/36,000)]
\]  

(U.S. Customary Units)

where the value of $S_y/36,000$ or $(S_y/250)$ shall not be taken as greater than unity.

(c) **Level D Service Limits**

1. The pressure shall not exceed 2.0 times the rated pressure.
2. The limitation given by eq. (b)(2)(17) shall be met, where $P_{fd}$ and $M_{fd}$ are pressures, psi (MPa), and moments, in.-lb (N·m), occurring concurrently.

(d) **Test Loadings.** Analysis for test loadings is not required.

**NCD-3660 Design of Welds**

**NCD-3661 Welded Joints**

**NCD-3661.1 General Requirements.**
Welded joints shall be in accordance with the requirements of NCD-4200 and NCD-4420, except as limited herein.

**NCD-3661.2 Butt-Welded Joints.**

(a) Girth welds shall be Type 1, 2, or 3 (NCD-4245).

(b) Longitudinal welds shall be Type 1 (NCD-4245).
NCD-3661.2 Socket Welded Joints.

(a) Socket welded piping joints shall be limited to pipe sizes of NPS 2 (DN 50) and less.

(b) Socket welds shall comply with the requirements of NCD-4427. Socket welds shall not be used where the existence of crevices could result in accelerated corrosion.

NCD-3661.3 Fillet Welds and Partial Penetration Welds for Branch Connections.

(a) Fillet welds and partial penetration welds may be used within the limitations of NCD-3643.1(c).

(b) For fillet welds, the size of the weld shall be specified on the design drawings.

(c) For partial penetration welds, the size of the weld, the depth of the weld groove, and the groove angle shall be specified on the design drawings.

Fillet and partial penetration welds should not be used where severe vibration is expected.

NCD-3670 Special Piping Requirements

NCD-3671 Selections and Limitations of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled.

NCD-3671.1 Flanged Joints.
Flanged joints shall conform to NCD-3647 and NCD-3658.

NCD-3671.2 Expanded or Rolled Joints.
Expanded or rolled joints may be used when experience or test (NCD-3649) has demonstrated that the joint is suitable for the Design Loadings and when adequate provisions are made to prevent separation of the joint.

NCD-3671.3 Threaded Joints.
Threaded joints may be used within the limitations specified in (a), (b), and (c) below.

(a) All threads on piping products shall be taper pipe threads in accordance with the applicable standard listed in Table NCA-7100-1. Threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seal weld or a seating surface other than the threads and when experience or test (NCD-3649) has demonstrated that such threads are suitable.
(b) Threaded joints shall not be used when severe erosion, crevice corrosion, shock, or vibration is expected to occur. Size limits for steam and hot water service above 220°F (100°C) shall be as follows:

<table>
<thead>
<tr>
<th>Maximum Nominal Size, in. (DN)</th>
<th>Maximum Pressure, psi (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 (80)</td>
<td>400 (2.8)</td>
</tr>
<tr>
<td>2 (50)</td>
<td>600 (4.1)</td>
</tr>
<tr>
<td>1 (25)</td>
<td>1,200 (8.3)</td>
</tr>
<tr>
<td>3/4 (20) and less</td>
<td>1,500 (10.3)</td>
</tr>
</tbody>
</table>

(c) Pipe with a wall thickness less than that of standard weight of ASME B36.10M steel pipe shall not be threaded, regardless of service. When steel pipe is threaded and used in steam service over 250 psi (1.7 MPa) or water service above 100 psi (700 kPa) and 220°F (100°C), the pipe shall be seamless and at least Schedule 80.

NCD-3671.4 Flared, Flareless, and Compression Joints.

Flared, flareless, and compression type tubing fittings may be used for tube sizes not exceeding 2 in. (50 mm) O.D. within the limitations of applicable standards and specifications in Table NCA-7100-1 and as specified in (a) through (e) below.

(a) Fittings and their joints shall be compatible with the tubing with which they are to be used and shall conform to the range of wall thicknesses and method of assembly recommended by the manufacturer.

(b) Fittings shall be used at pressure–temperature ratings not exceeding the recommendations of the manufacturer. Service Conditions, such as vibration and thermal cycling, shall be considered in the application.

(c) All threads on piping products shall be taper pipe threads in accordance with applicable standards listed in Table NCA-7100-1. Exceptions are that threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seating surface other than the threads and when experience or tests (NCD-3649) have demonstrated that such threads are suitable.

(d) In the absence of standards or specifications, the designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the following requirements.

1. The pressure design shall meet the requirements of NCD-3649.

2. Prototypes of the fittings to be used shall successfully meet performance tests (NCD-3649) to determine the safety of the joint under simulated Service Loadings. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are expected, the applicable conditions shall be incorporated in the test.
(e) Flareless fittings shall be of a design in which the gripping member or sleeve shall grip or bite into the outer surface of the tube with sufficient strength to hold the tube against pressure but without appreciably distorting the inside tube diameter. The gripping member shall also form a pressure seal against the fitting body.

(1) When using bite-type fittings, a spot check shall be made for adequate depth of bite and condition of tubing by disassembling and reassembling selected joints.

(2) Grip-type fittings that are tightened in accordance with manufacturer’s instructions need not be disassembled for checking.

NCD-3671.5 Caulked Joints.
Caulked or leaded joints shall not be used.

NCD-3671.6 Brazed and Soldered Joints.

(a) Brazed Joints. Brazed joints shall be socket type, and the minimum socket depth shall be sufficient for the intended service, but in no case less than that specified in Figure NCD-4511-1.

(b) Soldered Joints. Soldered joints shall be socket type and shall be made in accordance with applicable standards listed in Table NCA-7100-1.

(c) Limitations of Brazed and Soldered Joints

(1) Brazed socket-type joints shall not be used in systems containing flammable or toxic fluids, or in areas where fire hazards are involved.

(2) Soldered socket-type joints shall be limited to systems containing nonflammable and nontoxic fluids.

(3) Soldered socket-type joints shall not be used in piping subject to mechanical or thermal shock, or vibration.

(4) Brazed or soldered joints depending solely upon a fillet, rather than primarily upon brazing or soldering material between the pipe and socket, are not acceptable.

(5) Soldered joints shall be pressure and temperature rated in accordance with the applicable standards in Table NCA-7100-1, except that they shall not be used at pressures in excess of 175 psi (1.2 MPa) or at temperatures in excess of 250°F (120°C).

NCD-3671.7 Sleeve-Coupled and Other Patented Joints.
Mechanical joints for which no ASME standards exist, and other patented joints may be used, provided the requirements below are met.
(a) The pressure design shall meet the requirements of NCD-3649. Manufacturer’s pressure and temperature ratings may be used if established in accordance with the Code.

(b) Either (1), (2), or (3) below is satisfied:

(1) Prototype joints have been subjected to performance tests to determine the safety of the joint under simulated service conditions. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are anticipated, the applicable conditions shall be incorporated in the tests. The mechanical joints shall be sufficiently leak tight to satisfy the requirement of the Design Specifications. A minimum of three specimens of each joint shall be tested. The results may be extrapolated to one-half and 1.5 times the NPS of the tested fitting.

(2) The supplier has furnished evidence of successful service experience or testing to an alternate Standard, and review of the experience or testing confirms that the service conditions are equivalent to the anticipated conditions in the Design Specification.

(3) The joints are designed in accordance with the rules of Section III Appendices, Mandatory Appendix XIII.

(c) The piping system stress analysis shall include appropriate stress intensification factors, flexibility factors, and fatigue strength reduction factors for the joint based on (b) above, and developed in accordance with Section III Appendices, Mandatory Appendix II and the rules of this Subsection.

NCD-3672 Expansion and Flexibility

NCD-3672.1 General Requirements.

(a) In addition to the design requirements for pressure, weight, and other loadings, piping systems subject to thermal expansion or contraction or to similar movements imposed by other sources shall be designed in accordance with the requirements for the evaluation and analysis of flexibility and stresses specified in this paragraph.

(b) Piping shall meet the expansion and flexibility requirements of this subarticle except that, where Class 3 piping is connected to Class 1 piping, the requirements for expansion and flexibility for Class 1 piping shall apply to the Class 3 piping out to the first anchor on the Class 3 piping. However, the effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with NCD-3650. Other exceptions as stated in the following subparagraphs shall apply.

NCD-3672.2 Properties.

Thermal expansion data and moduli of elasticity shall be determined from Section II, Part D, Subpart 2, Tables TE and TM, which cover more commonly used piping materials. For material
not included in these Tables, reference shall be to authoritative source data such as publications of the National Institute of Standards and Technology.

**NCD-3672.3 Thermal Expansion Range.**
The thermal expansion range shall be determined from Section II, Part D, Subpart 2, Table TE as the difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service and shutdown conditions.

**NCD-3672.4 Moduli of Elasticity.**
The cold and hot moduli of elasticity $E_c$ and $E_h$ shall be as shown in Section II, Part D, Subpart 2, Table TM for the material based on the temperatures established in NCD-3672.3.

**NCD-3672.5 Poisson’s Ratio.**
Poisson’s ratio, when required for flexibility calculations, shall be taken as 0.3 at all temperatures for all materials.

**NCD-3672.6 Stresses.**
Calculations for the stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal dimensions at the location of local strain. Calculations for the expansion stress $S_E$ shall be based on the modulus of elasticity at room temperature $E_c$.

(a) **Stress Range.** Stresses caused by thermal expansion, when of sufficient initial magnitude, relax in the hot condition as a result of local yielding or creep. A stress reduction takes place and usually appears as a stress of reversed sign when the component returns to the cold condition. This phenomenon is designated as self-springing of the line and is similar in effect to cold springing. The extent of self-springing depends on the material, the magnitude of the initial expansion and fabrication stress, the hot service temperature, and the elapsed time. While the expansion stress in the hot condition tends to diminish with time, the sum of the expansion strains for the hot and cold conditions during any one cycle remains substantially constant. This sum is referred to as the strain range; however, to permit convenient association with allowable stress, stress range is selected as the criterion for the thermal design of piping.

(b) **Local Overstrain.** All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems in which plastic straining occurs at many points or over relatively wide regions but fails to reflect the actual strain distribution in unbalanced systems in which only a small portion of the piping undergoes plastic strain or in which, for piping operating in the creep range, the strain distribution is very uneven. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(1) by use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed;
by local reduction in size or cross section, or local use of a weaker material;

(3) in a system of uniform size, by use of a line configuration for which the neutral axis or thrust line is situated close to the major portion of the line itself, with only a very small offset portion of the line absorbing most of the expansion strain.

(c) Conditions of this type shall be avoided, particularly where materials of relatively low ductility are used; if unavoidable, they shall be mitigated by the judicious application of cold spring.

(d) It is recommended that the design of piping systems of austenitic steel materials be approached with greater overall care as to general elimination of local stress raisers, examination, material selection, fabrication quality, and erection.

NCD-3672.7 Flexibility.

Piping systems shall be designed to have sufficient flexibility to prevent pipe movements from causing failure from overstress of the pipe material or anchors, leakage at joints, or detrimental distortion of connected equipment resulting from excessive thrusts and moments. Flexibility shall be provided by changes of direction in the piping through the use of bends, loops, or offsets; or provisions shall be made to absorb thermal movements by utilizing expansion, swivel, or ball joints or corrugated pipe.

NCD-3672.8 Expansion, Swivel, or Ball Joints.

Expansion, swivel, or ball joints, if used, shall conform to the requirements and limitations of NCD-3649.

NCD-3673 Analysis

NCD-3673.1 Method of Analysis.

All systems shall be analyzed for adequate flexibility by a structural analysis unless one of the following conditions is met:

(a) The system can be judged technically adequate by an engineering comparison with previously analyzed systems.

(b) The operating temperature of the piping system is at or below 150°F (65°C) and the piping is laid out with inherent flexibility, as provided in NCD-3672.7.

(c) The operating temperature of the piping system is at or below 250°F (120°C) and the piping is analyzed for flexibility using simplified methods of calculation such as handbooks or charts.

NCD-3673.2 Basic Assumptions and Requirements.

(a) When calculating the flexibility of a piping system between anchor points, the system between anchor points shall be treated as a whole. The significance of all parts of the line and
of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors found to exist in piping products or joints other than straight pipe. Credit may be taken where extra flexibility exists in such products or joints. Flexibility factors and stress intensification factors for commonly used piping products and joints are shown in Table NCD-3673.2(b)-1 [see also Figure NCD-3673.2(b)-2]. The stress intensification factors and flexibility factors in Table NCD-3673.2(b)-1 shall be used unless specific experimental or analytical data exist that would warrant lower stress intensification factors or higher flexibility factors.

(c) Flexibility factors are identified herein by $k$ with appropriate subscripts. The general definition of a flexibility factor is

$$k = \frac{\theta_{ab}}{\theta_{nom}}$$

where

$\theta_{ab} = \text{rotation of end } a, \text{ with respect to end } b, \text{ due to a moment load } M \text{ and in the direction of the moment } M$

$\theta_{nom} = \text{the nominal rotation assuming the component acts as a beam with the properties of nominal pipe. For an elbow, } \theta_{nom} \text{ is the nominal rotation assuming the elbow acts as a curved beam}$

The flexibility factor $k$ is defined in detail for specific components in Table NCD-3673.2(b)-1.

(d) Stress intensification factors are identified herein by $i$. The definition of a stress intensification factor is based on fatigue bend testing of mild carbon steel fittings and is

(U.S. Customary Units)

$$iS = 245,000N^{-0.2}$$

(SI Units)

$$iS = 1700N^{-0.2}$$

where

$$i = \text{stress intensification factor} = \text{ratio of the bending moment producing fatigue in a given number of cycles in a straight pipe with a girth butt weld to that producing failure in the same number of}$$
cycles in the fitting or joint under consideration.

\[ N = \text{number of cycles to failure} \]
\[ S = \text{amplitude of the applied bending stress at the point of failure, psi (MPa)} \]

(e) For piping products or joints not listed in Table NCD-3673.2(b)-1, flexibility or stress intensification factors shall be established by experimental or analytical means.

(f) Experimental determination of flexibility factors shall be in accordance with Section III Appendices, Mandatory Appendix II, II-1900. Experimental determination of stress intensification factors shall be in accordance with Section III Appendices, Mandatory Appendix II, Article II-2000.

(g) Analytical determination of flexibility factors shall be consistent with the definition above.

(h) Analytical determination of stress intensification factors may be based on the empirical relationship

\[ i = \frac{C_2 K_2}{2}, \text{ but not less than 1.0} \]

where \( C_2 \) and \( K_2 \) are stress indices for Class 1 piping products or joints from NB-3681(a)-1, or are determined as explained below.

Analytical determination of stress intensification factors shall be correlated with experimental fatigue results. Experimental correlation may be with new test data or with test data from similar products or joints reported in literature. Finite element analyses or other stress analysis methods may be used to determine \( C_2 \); however, test or established stress concentration factor data should then be used to determine \( K_2 \).

(i) For certain piping products or joints the stress intensification factor may vary depending on the direction of the applied moment, such as in an elbow or branch connection. For these cases, the stress intensification factor used in eqs. NCD-3653.2(a)(10a), NCD-3653.2(b)(10b) and NCD-3653.2(c)(11) shall be the maximum stress intensification factor for all loading directions as determined in accordance with (f) or (h) above.

(j) Stress intensification factors determined in accordance with (f) above shall be documented in accordance with Section III Appendices, Mandatory Appendix II, II-2050. The test report may be included and certified with the Design Report (NCA-3551.1 and NCA-3555) for the individual piping system or a separate report furnished (Section III Appendices, Mandatory Appendix II, II-2050).

(k) Stress intensification factors determined in accordance with (h) above shall be documented in a report with sufficient detail to permit independent review. The review shall be performed by an engineer competent in the applicable field of design in accordance with
Section III Appendices, Mandatory Appendix XXIII. The report shall be included and certified as part of the design report for the piping system (NCA-3551.1 and NCA-3555).

(l) The total expansion range as determined from NCD-3672.3 shall be used in all calculations, whether or not the piping is cold sprung. Expansion of the line, linear and angular movements of the equipment, supports, restraints, and anchors shall be considered in the determination of the total expansion range.

(m) Where simplifying assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(n) Dimensional properties of pipe and fittings used in flexibility calculations shall be based on nominal dimensions.

(o) When determining stress intensification factors by experimental methods, NCD-3653.3(d) shall not apply. The nominal stress at the point under consideration (crack site, point of maximum stress, etc.) shall be used.
### Table NCD-3673.2(b)-1 — Stress Indices, Flexibility, and Stress Intensification Factors

<table>
<thead>
<tr>
<th>Description</th>
<th>Primary Stress Index</th>
<th>Flexibility Characteristic, $h$</th>
<th>Flexibility Factor, $k$</th>
<th>Stress Intensification Factor, $i$</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding elbow or pipe bend [Note (1)], [Note (2)]</td>
<td>$B_1$ 0.4, $h-0.1 \leq 0.5$ and $&gt; 0$</td>
<td>$B_2$ $\frac{1.30}{\sqrt{h^{2}/3}}$</td>
<td>$\frac{t_n R}{r^2}$</td>
<td>$\frac{1.65}{h}$, $\frac{0.9}{\sqrt{h^{2}/3}}$</td>
<td><img src="image1" alt="Sketch" /></td>
</tr>
<tr>
<td>Closely spaced miter bend [Note (1)] $s &lt; r (1 + \tan \theta)$</td>
<td>$B_1$ 0.5</td>
<td>$B_2$ $\frac{1.30}{\sqrt{h^{2}/3}}$</td>
<td>$\frac{t_n \cot \theta}{2r^2}$</td>
<td>$\frac{1.52}{h^{5/6}}$, $\frac{0.9}{\sqrt{h^{2}/3}}$</td>
<td><img src="image2" alt="Sketch" /></td>
</tr>
<tr>
<td>Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r (1 + \tan \theta)$</td>
<td>$B_1$ 0.5</td>
<td>$B_2$ $\frac{1.30}{\sqrt{h^{2}/3}}$</td>
<td>$\frac{t_n (1 + \cot \theta)}{2r}$</td>
<td>$\frac{1.52}{h^{5/6}}$, $\frac{0.9}{\sqrt{h^{2}/3}}$</td>
<td><img src="image3" alt="Sketch" /></td>
</tr>
<tr>
<td>Welding tee per ASME B16.9 [Note (4)]</td>
<td>$B_1$ 0.5</td>
<td>Branch end: $b_{2b} = \frac{0.4 (r/n)}{r/n}$</td>
<td>$\frac{4.4 t_n}{r}$</td>
<td>1</td>
<td><img src="image4" alt="Sketch" /></td>
</tr>
<tr>
<td>Run end: $b_{2r} = \frac{0.5 (r/n)}{r/n}$</td>
<td>For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}$, $\frac{T_r}{T_r}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reinforced fabricated tee [Note (4)], [Note (5)], [Note (7)]</td>
<td>$B_1$ 0.5</td>
<td>Branch end: $b_{2b} = 0.75 \left( \frac{r}{n} \right)^{1/3} \left( \frac{T_r}{n} \right)^{1/2} \left( \frac{T_m}{T_n} \right) \left( \frac{r}{T_m} \right) \geq 1.0 \frac{t_n + \frac{r}{T_m}}{r(n)^{3/2}}$</td>
<td>1</td>
<td>$\frac{0.9}{h^{2/3}} \geq 2.1$</td>
<td><img src="image5" alt="Sketch" /></td>
</tr>
</tbody>
</table>
### ASME BPVC Section III NCD-3600 Consolidation

(Note: ND was used as base document, Red text denotes changes)

<table>
<thead>
<tr>
<th>Description</th>
<th>Primary Stress Index</th>
<th>Flexibility Characteristic, $h$</th>
<th>Flexibility Factor, $k$</th>
<th>Stress Intensification Factor, $i$</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Note (6)]</td>
<td>$B_1$</td>
<td>$B_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For branch leg of a reduced outlet, use $0.9 \frac{T_k}{T_r} \geq 2.1$</td>
<td></td>
</tr>
<tr>
<td>Run end:</td>
<td>$B_{2r} = \frac{0.675(r / t_a)^{2/3}}{1 + (r / 2t_a)^{5/3}} \geq 1.0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[Note (8)]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Primary Stress Index</th>
<th>Flexibility Factor, $k$</th>
<th>Stress Intensification Factor, $i$</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Note (4)], [Note (6)], [Note (9)]</td>
<td>0.5</td>
<td></td>
<td></td>
<td>Figure NCD-3673.2(b)-2</td>
</tr>
<tr>
<td>Branch connection or unreinforced fabricated tee</td>
<td>$B_{2B} = 0.75 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{r_m}{R_m} \right)^{1/2} \left( \frac{t_m}{t_p} \right)$</td>
<td>$i_p = 1.5 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{r_m}{R_m} \right)^{1/2} \left( \frac{T_k}{T_r} \right) \geq 1.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) = 1.0$</td>
<td></td>
<td>for $(r_m^'/R_m) = 1.0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) \leq 0.9$</td>
<td></td>
<td>for $(r_m^'/R_m) \leq 0.9$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $0.9 &lt; (r_m^'/R_m) &lt; 1.0$, use linear interpolation</td>
<td></td>
<td>for $0.9 &lt; (r_m^'/R_m) &lt; 1.0$, use linear interpolation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run legs:</td>
<td>$B_{2r} = 0.75 \left( \frac{r_m}{t_p} \right)^{0.3}$</td>
<td>$i_p = 0.9 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{r_m}{R_m} \right) \geq 1.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>but not &lt; 1.0</td>
<td></td>
<td>but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_k/T_r)(t_k/d_l)^{0.5}$ but not &gt; 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Branch leg:</td>
<td>$B_{2B} = 0.45 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{r_m}{R_m} \right)$</td>
<td>$i_p = 1.5 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{r_m}{R_m} \right)^{1/2} \left( \frac{T_k}{T_r} \right) \geq 1.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) = 1.0$</td>
<td></td>
<td>for $(r_m^'/R_m) = 1.0$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) \leq 0.9$</td>
<td></td>
<td>for $(r_m^'/R_m) \leq 0.9$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $0.9 &lt; (r_m^'/R_m) &lt; 1.0$, use linear interpolation</td>
<td></td>
<td>for $0.9 &lt; (r_m^'/R_m) &lt; 1.0$, use linear interpolation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run legs:</td>
<td>$B_{2r} = 0.75 \left( \frac{r_m}{t_p} \right)^{0.3}$</td>
<td>$i_p = 0.9 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{r_m}{R_m} \right) \geq 1.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>but not &lt; 1.0</td>
<td></td>
<td>but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_k/T_r)(t_k/d_l)^{0.5}$ but not &gt; 0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td>for $(r_m^'/R_m) &gt; 0.5$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Description Primary Stress Index Flexibility Factor, \( k \) Stress Intensification Factor, \( i \) Sketch

<table>
<thead>
<tr>
<th>Description</th>
<th>( B_1 )</th>
<th>( B_2 )</th>
<th>( i_r = 0.8 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{T_m}{R_m} \right)^{1/2} \geq 2.1 )</th>
<th>( i_r = 0.8 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{T_m}{R_m} \right)^{1/2} \geq 2.1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]</td>
<td>0.5</td>
<td></td>
<td>Branch leg: ( B_{2b} = 2.25 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{T_m}{R_m} \right)^{1/2} \geq 1.5 )</td>
<td>Branch leg: ( B_{2b} = 2.25 \left( \frac{R_m}{T_r} \right)^{2/3} \left( \frac{T_m}{R_m} \right)^{1/2} \geq 1.5 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Run legs: ( B_{2r} = 1.3 \left( \frac{T_m}{R_m} \right)^{1/4} \geq 1.5 )</td>
<td>Run legs: ( B_{2r} = 1.3 \left( \frac{T_m}{R_m} \right)^{1/4} \geq 1.5 )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Figure NCD-3643.2(b)-2</td>
<td>Figure NCD-3643.2(b)-2</td>
</tr>
<tr>
<td>Girth butt weld</td>
<td>0.5</td>
<td>1.0</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Circumferential fillet welded or socket welded joints [Note (11)]</td>
<td>0.75 ( \left( \frac{T_m}{R_m} \right) \geq 0.5 )</td>
<td>1</td>
<td>For ( C_x \geq 1.09 ), ( i = 1.3 )</td>
<td>For ( C_x \geq 1.09 ), ( i = 1.3 )</td>
</tr>
<tr>
<td></td>
<td>1.5 ( \left( \frac{T_m}{R_m} \right) \geq 1.5 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Figure NCD-4427-1 sketches (c-1), (c-2), and (c-3)</td>
<td>Figure NCD-4427-1 sketches (c-1), (c-2), and (c-3)</td>
</tr>
<tr>
<td>Brazed joint</td>
<td>0.5</td>
<td>1.6</td>
<td>1</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Figure NCD-4511-1</td>
<td>Figure NCD-4511-1</td>
</tr>
<tr>
<td>30 deg tapered transition (ASME B16.25) ( t_n &lt; 0.237 \text{ in. (6 mm)}</td>
<td>0.5</td>
<td>1.0</td>
<td>( (U.S. \text{ Customary Units}) )</td>
<td>( (SI \text{ Units}) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( 1.3 + 0.0036 \frac{D}{t_n} + 0.113/t_n \leq 1.9 )</td>
<td>( 1.3 + 0.0036 \frac{D}{t_n} + 2.87/t_n \leq 1.9 )</td>
</tr>
</tbody>
</table>

30 deg tapered transition (ASME B16.25) \( t_n \geq 0.237 \) in. (6 mm)
### Description

<table>
<thead>
<tr>
<th>Description</th>
<th>Primary Stress Index</th>
<th>Flexibility Factor, $k$</th>
<th>Stress Intensification Factor, $i$</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentric and eccentric reducers (ASME B16.9) [Note (12)]</td>
<td>0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg $&lt; \alpha \leq 60$ deg</td>
<td>1.0</td>
<td>1.0</td>
<td><img src="image" alt="Sketch" /></td>
</tr>
<tr>
<td>Threaded pipe joint or threaded flange</td>
<td>0.75 1.7</td>
<td>1.0</td>
<td>2.3</td>
<td></td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) The following nomenclature applies:

- $D_o$ = nominal outside diameter, in. (mm)
- $d_i$ = nominal inside diameter of branch, in. (mm)
- $r$ = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
- $r_{m}'$ = mean radius of branch pipe, in. (mm)
- $R$ = nominal bend radius of elbow or pipe bend, in. (mm)
- $R_m$ = mean radius of run pipe, in. (mm)
- $\vartheta$ = one-half angle between adjacent miter axes, deg
- $s$ = miter spacing at center line, in. (mm)
- $t_b$ = thickness in reinforcement zone of branch, in. (mm)
- $t_e$ = pad or saddle thickness, in. (mm)
- $t_n$ = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
- $T_{b}'$ = nominal wall thickness of branch pipe, in. (mm)
- $T_r$ = nominal wall thickness of run pipe, in. (mm)

For Figure NCD-3673.2(b)-2, sketches (a) and (b):
ASME BPVC Section III NCD-3600 Consolidation
(Note: ND was used as base document, Red text denotes changes)

\[ t_b = \begin{cases} 
T_b & \text{if } L_1 \geq 0.5(2r_mT_b)^{1/2} \\
T_b' & \text{if } L_1 < 0.5(2r_mT_b)^{1/2} 
\end{cases} \]

For Figure NCD-3673.2(b)-2, sketch (c):

\[ t_b = \begin{cases} 
T_b' + (2/3)y & \text{if } \theta_n \leq 30 \text{ deg} \\
T_b' + 0.385L_1 & \text{if } \theta_n > 30 \text{ deg} 
\end{cases} \]

For Figure NCD-3673.2(b)-2, sketch (d):

\[ t_b = T_b' = T_b \]

For branch connection nomenclature, refer to Figs. NCD-3643.2(b)-2 and NCD-3673.2(b)-2.

(b) The flexibility factors \( k \), stress intensification factors \( i \), and stress indices \( B_2 \) apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to \( D_o/t_n \leq 50 \) and stress intensification factors are applicable to \( D_o/t_n \leq 100 \). For products and joints with \( 50 < D_o/t_n \leq 100 \), the \( B_1 \) index in Table NCD-3673.2(b)-1 is valid. The \( B_2 \) index shall be multiplied by the factor \( 1/(XY) \), where:

\[ \begin{align*}
X &= 1.3 - 0.006(D_o/t_n), \text{ not to exceed } 1.0 \\
Y &= 1.033 - 0.000337T \text{ for Ferritic Material, not to exceed } 1.0; T = \text{Design temperature (°F)} \\
Y &= 1.0224 - 0.000594T \text{ for Ferritic Material, not to exceed } 1.0; T = \text{Design temperature (°C)} \\
Y &= 1.0 \text{ for other materials}
\end{align*} \]

NOTES:

(1) Where flanges are attached to one or both ends, the values of \( k \) and \( i \) shall be corrected by the factor \( c \) given below.

(a) One end flanged, \( c = h^{1/6} \)

(b) Both ends flanged, \( c = h^{1/3} \)
But after such multiplication, values of $k$ and $i$ shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi (r_m)^2 T_b$$

For checking run leg stress:

$$Z = \pi (r_m)^2 T_r$$

(5) When $t_e > 1.5 \ t_n$, $h = 4.05 t_n/r$.

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of NCD-3643 are met.

(b) The axis of the branch pipe is normal to the surface of the run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.

(d) The run pipe is a straight pipe.

(7) $r_m'/r$ shall be taken as 0.5 for $r_m'/r > 0.5$.

$r_m'/r_{ps}$ shall not be taken as less than 0.5.
The definition of \( r_{ps} \) is:
\[
r_{ps} = \frac{(r_m' + r_e)}{2} \text{ for } t_e \geq 0.8 t_n
\]
\[
r_{ps} = r_m' + \frac{T_b'}{2} \text{ for } t_e < 0.8 t_n
\]

(8) The definition of \( t_e' \) is:
\[
t_e' = t_e \left[ \frac{r_e}{r_m'} - 1 \right] \text{ but not greater than } 1.0 t_n
\]

(9) If an \( r_2 \) radius is provided [Figure NCD-3673.2(b)-2] that is not less than the larger of \( T_b/2, (T_b' + y)/2 \) [sketch (c)], or \( T_s/2 \), then the calculated values of \( i_b \) and \( i_r \) may be divided by 2, but with \( i_b \geq 1.5 \) and \( i_r \geq 1.5 \). For \( r_m'/R_m \leq 0.5 \), the \( i \) factors for checking run ends are independent of whether \( r_2 \) is provided or not.

(10) The equations apply only if \( r_m'/R_m \leq 0.5 \).

(11) In Figure NCD-4427-1 sketches (c-1) and (c-2), \( C_x \) shall be taken as \( X_{\text{min}} \) and \( C_x \geq 1.25 t_n \). In Figure NCD-4427-1 sketch (c-3), \( C_x \geq 0.75 t_n \). For unequal leg lengths, use the smaller leg length for \( C_x \).

(12) The equation applies only if the following conditions are met:

(o) Cone angle \( \alpha \) does not exceed 60 deg.

(p) The larger of \( D_1/t_1 \) and \( D_2/t_2 \) does not exceed 100.

(q) The wall thickness is not less than \( t_1 \) throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than \( t_2 \).

(r) For eccentric reducers, \( \alpha \) is the maximum cone angle.
Figure NCD-3673.2(b)-2 — Branch Connection Nomenclature

Legend:

- $d_o$ = outside diameter of branch pipe, in. (mm)
- $L_1$ = height of nozzle reinforcement for branch connection, in. (mm)
- $r_2$ = designated radius for reinforced branch connection, in. (mm)
- $R_m$ = mean radius of run pipe, in. (mm)
- $r'_m$ = mean radius of branch pipe, in. (mm)
- $r_p$ = outside radius of reinforced branch connection, in. (mm)
$T_b = \text{nominal thickness of branch pipe, in. (mm)}$

$T_r = \text{nominal thickness of run pipe, in. (mm)}$

$\Theta_n = \text{transition angle of branch reinforcement, deg}$

$T_b = \text{nominal thickness of the reinforced pipe, in. (mm)}$

$y = \text{slope offset distance, in. (mm)}$

NCD-3673.3 Cold Springing.

The beneficial effect of judicious cold springing in assisting a system to attain its most favorable position is recognized. Inasmuch as the life of a system under cyclic conditions depends on the stress range rather than the stress level at any one time, no credit for cold spring is allowed with regard to stresses. In calculating end thrusts and moments acting on equipment, the actual reactions at any one time, rather than their range, shall be used. Credit for cold springing is allowed in the calculations of thrusts and moments, provided the method of obtaining the designed cold spring is specified and used.

NCD-3673.4 Movements.

Movement caused by thermal expansion and loadings shall be determined for consideration of obstructions and design of proper supports.

NCD-3673.5 Computing Hot and Cold Reactions.

(a) In a piping system with no cold spring or an equal percentage of cold springing in all directions, the reactions of $R_h$ and $R_c$, in the hot and cold conditions, respectively, shall be obtained from the reaction $R$ derived from the flexibility calculations based on the modulus of elasticity at room temperature $E_c$ using (14) and (15).

$$R_h = \left(1 - \frac{2}{3}C\left(\frac{E_h}{E_c}\right)\right)R \quad (14)$$

$$R_c = CR \quad (15)$$

$$= \left[1 - \left(\frac{S_h}{S_E}\right)\left(\frac{E_c}{E_h}\right)\right]R$$

whichever is greater, and with the further condition that

$$\left(\frac{S_h}{S_E}\right)\left(\frac{E_c}{E_h}\right) < 1$$

where

$$C = \text{cold spring factor varying from zero for no cold spring to 1.00 for 100\% cold spring}$$
ASME BPVC Section III NCD-3600 Consolidation
(Note: ND was used as base document, Red text denotes changes)

$E_c = \text{modulus of elasticity in the cold condition, psi (MPa)}$

$E_h = \text{modulus of elasticity in the hot condition, psi (MPa)}$

$R = \text{maximum reaction for full expansion range based on } E_c \text{ that assumes the most severe condition (100% cold spring, whether such is used or not), lb (N)}$

$R_c, R_h = \text{maximum reactions estimated to occur in the cold and hot conditions, respectively, lb (N)}$

$S_E = \text{computed expansion stress, psi (MPa) [NCD-3653.2(a)]}$

(b) If a piping system is designed with different percentages of cold spring in various directions, (a)(14) and (a)(15) are not applicable. In this case, the piping system shall be analyzed by a comprehensive method. The calculated hot reactions shall be based on theoretical cold springs in all directions not greater than two-thirds of the cold springs as specified or measured.

NCD-3673.6 Reaction Limits.
The reactions computed shall not exceed limits that the attached equipment can safely sustain.

NCD-3674 Design of Pipe Supports
Pipe supports shall be designed in accordance with the requirements of Subsection NF.

NCD-3677 Pressure Relief Piping

NCD-3677.1 General Requirements.
Pressure relief piping within the scope of this subarticle shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

NCD-3677.2 Piping to Pressure-Relieving Safety Devices.

(a) Piping that connects a pressure relief device to a piping system shall comply with all the requirements of the Class of piping of the system that it is designed to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices, except as provided for in NCD-7142.

NCD-3677.3 Discharge Piping From Pressure-Relieving Safety Devices.

(a) Discharge piping from pressure relief devices shall comply with the requirements of the Class of piping applicable to the conditions under which it operates.

(b) There shall be no intervening stop valves between the protective device or devices and the point of discharge, except as provided for in NCD-7142.
(c) When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel.

(d) It is recommended that individual discharge lines be used. For requirements on discharge piping, see NCD-7141(f).

(e) Discharge lines from pressure-relieving safety devices within the scope of this subarticle shall be designed to facilitate drainage.

(f) When the umbrella or drip pan type of connection is used, the discharge piping shall be so designed as to prevent binding due to expansion movements. Drainage shall be provided to remove water collected above the safety valve seat.

**NCD-3678 Temporary Piping Systems**

Prior to service of piping systems and associated equipment, certain temporary piping may be installed to accommodate cleaning by blowing out with steam or air, or by acid or caustic fluid circulation, or other flushing methods. Such temporary piping shall be designed to safeguard against rupture or other failure that could become a hazard to health or safety.

**NCD-3690 Dimensional Requirements for Piping Products**

**NCD-3691 Standard Piping Products**

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NCA-7100-1.

**NCD-3692 Nonstandard Piping Products**

The dimensions of nonstandard piping products shall be such as to provide strength and performance equivalent to standard products, except as permitted in NCD-3641.