MANDATORY APPENDIX 2
RULES FOR BOLTED FLANGE CONNECTIONS WITH RING TYPE GASKETS

2-1 SCOPE

(a) The rules in Mandatory Appendix 2 apply specifically to the design of bolted flange connections with gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle, and are to be used in conjunction with the applicable requirements in Subsections A, B, and C of this Division. The hub thickness of weld neck flanges designed to this Appendix shall also comply with the minimum thickness requirements in Subsection A of this Division. These rules are not to be used for the determination of the thickness of tubeshells integral with a bolting flange as illustrated in Figure UW-13.2 sketches (h) through (l) or Figure UW-13.3 sketch (c). Nonmandatory Appendix S provides discussion on Design Considerations for Bolted Flanged Connections.

These rules provide only for hydrostatic end loads and gasket seating. The flange design methods outlined in 2-4 through 2-8 are applicable to circular flanges under internal pressure. Modifications of these methods are outlined in 2-9 and 2-10 for the design of split and noncircular flanges. See 2-11 for flanges with ring type gaskets subject to external pressure, 2-12 for flanges with nut-stops, and 2-13 for reverse flanges. Rules for calculating rigidity factors for flanges are provided in 2-14. Recommendations for qualification of assembly procedures and assemblers are in 2-15. Proper allowance shall be made if connections are subject to external loads other than external pressure.

(b) The design of a flange involves the selection of the gasket (material, type, and dimensions), flange facing, bolting, hub proportions, flange width, and flange thickness. See Note in 2-5(c)(1). Flange dimensions shall be such that the stresses in the flange, calculated in accordance with 13-1, do not exceed the allowable flange stresses specified in 2-8. Except as provided for in 2-14(a), flanges designed to the rules of this Appendix shall also meet the rigidity requirements of 2-14. All calculations shall be made on dimensions in the corroded condition.

(c) It is recommended that bolted flange connections conforming to the standards listed in UG-44 be used for connections to external loads. These standards may be used for other bolted flange connections and dished covers within the limits of size in the standards and the pressure-temperature ratings permitted in UG-44. The ratings in these standards are based on the hub dimensions given or on the minimum specified thickness of flanged fittings of integral construction. Flanges fabricated from rings may be used in place of the hub flanges in these standards provided that their strength, calculated by the rules in this Appendix, is not less than that calculated for the corresponding size of hub flange.

(d) Except as otherwise provided in (c) above, bolted flange connections for unfired pressure vessels shall satisfy the requirements in this Appendix.

(e) The rules of this Appendix should not be construed to prohibit the use of other types of flanged connections, provided they are designed in accordance with good engineering practice and method of design is acceptable to the Inspector. Some examples of flanged connections which might fall in this category are as follows:

(1) flanged covers as shown in Figure 1-6;
(2) bolted flanges using full-face gaskets;
(3) flanges using means other than bolting to restrain the flange assembly against pressure and other applied loads.

2-2 MATERIALS

(a) Materials used in the construction of bolted flange connections shall comply with the requirements given in UG-4 through UG-14.

(b) Flanges made from ferritic steel and designed in accordance with this Appendix shall be full-annealed, normalized, normalized and tempered, or quenched and tempered when the thickness of the flange section exceeds 3 in. (75 mm).

(c) Material on which welding is to be performed shall be proved of good weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35%. All welding on flange connections shall comply with the requirements for postweld heat treatment given in this Division.

(d) Fabricated flanges with hubs shall be in accordance with the following:

(1) Flanges with hubs may be machined from a hot-rolled billet, forged billet, or forged bar. The axis of the finished flange shall be parallel to the long axis of the original billet or bar, but these axes need not be concentric.
MANDATORY APPENDIX 2
RULES FOR BOLTED FLANGE CONNECTIONS WITH RING TYPE GASKETS

GENERAL

2-1 SCOPE

(a) The rules in Mandatory Appendix 2 apply specifically to the design of bolted flange connections with gaskets that are entirely within the circle enclosed by the bolt holes and with no contact outside this circle, and are to be used in conjunction with the applicable requirements in Subsections A, B, and C of this Division. The hub thickness of weld neck flanges designed to this Appendix shall also comply with the minimum thickness requirements in Subsection A of this Division. These rules are not to be used for the determination of the thickness of supported or unsupported tubesheets integral with a bolting flange as illustrated in Figure UW-13.2 sketches (h) through (l) or Figure UW-13.3 sketch (c). Nonmandatory Appendix S provides discussion on Design Considerations for Bolted Flanged Connections.

These rules provide only for hydrostatic end loads and gasket seating. The flange design methods outlined in 2-4 through 2-8 are applicable to circular flanges under internal pressure. Modifications of these methods are outlined in 2-9 and 2-10 for the design of split and noncircular flanges. See 2-11 for flanges with ring type gaskets subject to external pressure, 2-12 for flanges with nut-stops, and 2-13 for reverse flanges. Rules for calculating rigidity factors for flanges are provided in 2-14. Recommendations for qualification of assembly procedures and assemblers are in 2-15. Proper allowance shall be made if connections are subject to external loads other than external pressure.

(b) The design of a flange involves the selection of the material, type, and dimensions, flange facing, bolting, hub proportions, flange width, and flange thickness. See Note in 2-5(c)(1). Flange dimensions shall be such that the stresses in the flange, calculated in accordance with 2-7, do not exceed the allowable flange stresses specified in 2-8. Except as provided for in 2-14(a), flanges designed to the rules of this Appendix shall also meet the rigidity requirements of 2-14. All calculations shall be made on dimensions in the corroded condition.

(c) It is recommended that bolted flange connections conforming to the standards listed in UG-44 be used for connections to external piping. These standards may be used for other bolted flange connections and dished covers within the limits of size in the standards and the pressure–temperature ratings permitted in UG-44. The ratings in these standards are based on the hub dimensions given or on the minimum specified thickness of flanged fittings of integral construction. Flanges fabricated from rings may be used in place of the hub flanges in these standards provided that their strength, calculated by the rules in this Appendix, is not less than that calculated for the corresponding size of hub flange.

(d) Except as otherwise provided in (c) above, bolted flange connections for unfired pressure vessels shall satisfy the requirements in this Appendix.

(e) The rules of this Appendix should not be construed to prohibit the use of other types of flanged connections provided they are designed in accordance with good engineering practice and method of design is acceptable to the Inspector. Some examples of flanged connections which might fall in this category are as follows:

(1) flanged covers as shown in Figure 1-6;
(2) bolted flanges using full-face gaskets;
(3) flanges using means other than bolting to restrain the flange assembly against pressure and other applied loads.

2-2 MATERIALS

(a) Materials used in the construction of bolted flange connections shall comply with the requirements given in UG-4 through UG-14.

(b) Flanges made from ferritic steel and designed in accordance with this Appendix shall be full-annealed, normalized, normalized and tempered, or quenched and tempered when the thickness of the flange section exceeds 3 in. (75 mm).

(c) Material on which welding is to be performed shall be of good weldable quality. Satisfactory qualification of the welding procedure under Section IX is considered as proof. Welding shall not be performed on steel that has a carbon content greater than 0.35%. All welding on flange connections shall comply with the requirements for postweld heat treatment given in this Division.

(d) Fabricated hubbed flanges shall be in accordance with the following:

(1) Hubbed flanges may be machined from a hot rolled or forged billet or forged bar. The axis of the finished flange shall be parallel to the long axis of the...
### Figure 3.7
**Impact Test Exemption Curves — Parts Not Subject to PWHT (Cont’d)**

<table>
<thead>
<tr>
<th>Curve</th>
<th>Material Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e)</td>
<td>SA-516 Grades 55 and 60 if not normalized</td>
</tr>
<tr>
<td>(f)</td>
<td>SA-533 Types B and C, Class 1</td>
</tr>
<tr>
<td>(g)</td>
<td>SA-662 Grade A</td>
</tr>
<tr>
<td>(h)</td>
<td>SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered</td>
</tr>
<tr>
<td>(i)</td>
<td>All materials listed in (a) through (d) and in (j) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below</td>
</tr>
</tbody>
</table>

**D**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>SA-203</td>
</tr>
<tr>
<td>(b)</td>
<td>SA-299 if normalized</td>
</tr>
<tr>
<td>(c)</td>
<td>SA-508 Class 1</td>
</tr>
<tr>
<td>(d)</td>
<td>SA-516 if normalized</td>
</tr>
<tr>
<td>(e)</td>
<td>SA-524 Classes 1 and 2</td>
</tr>
<tr>
<td>(f)</td>
<td>SA-537 Classes 1, 2, and 3</td>
</tr>
<tr>
<td>(g)</td>
<td>SA-612 if normalized; except that the increased Cb limit in the footnote of Table 1 of SA-20 is not permitted</td>
</tr>
<tr>
<td>(h)</td>
<td>SA-662 if normalized</td>
</tr>
<tr>
<td>(i)</td>
<td>SA-738 Grade A</td>
</tr>
<tr>
<td>(j)</td>
<td>SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −29°C (−20°F)</td>
</tr>
<tr>
<td>(k)</td>
<td>SA-738 Grade B not colder than −29°C (−20°F)</td>
</tr>
<tr>
<td>(l)</td>
<td>SA/EN 10028-2 Grade P355GH if normalized [See General Note (d)(3)]</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) Castings not listed as Curve A and B shall be impact tested.

(b) For bolting see 3.11.6.

(c) When a class or grade is not shown in a material assignment, all classes and grades are indicated.

(d) The following apply to all material assignments:

(1) Cooling rates faster than those obtained in air, followed by tempering, as permitted by the material specification, are considered equivalent to normalizing and tempering heat treatments.

(2) Fine grain practice is defined as the procedures necessary to obtain a fine austenitic grain size as described in SA-20.

(3) Normalized rolling condition is not considered as being equivalent to normalizing.

(e) Data of Figures 3.7 and 3.7M are shown in Table 3.14.
### Curve Material Assignment

<table>
<thead>
<tr>
<th>Curve</th>
<th>Material Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f)</td>
<td>SA-533 Types B and C, Class 1</td>
</tr>
<tr>
<td>(g)</td>
<td>SA-662 Grade A</td>
</tr>
<tr>
<td>(h)</td>
<td>SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered</td>
</tr>
<tr>
<td>(i)</td>
<td>All materials listed in (a) through (d) and in (i) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below</td>
</tr>
<tr>
<td>(j)</td>
<td>All materials listed in (a) through (h) and in (j) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) Castings not listed as Curve A and B shall be impact tested.

(b) For bolting see 3.11.6.

(c) When a class or grade is not shown in a material assignment, all classes and grades are indicated.

(d) The following apply to all material assignments:

1. Cooling rates faster than those obtained in air, followed by tempering, as permitted by the material specification, are considered equivalent to normalizing and tempering heat treatments.
2. Fine grain practice is defined as the procedures necessary to obtain a fine austenitic grain size as described in SA-20.
3. Normalized rolling condition is not considered as being equivalent to normalizing.

(e) Data of Figures 3.7 and 3.7M are shown in Table 3.14.
**Figure 3.8**

**Impact Test Exemption Curves — Parts Subject to PWHT and Nonwelded Parts (Cont’d)**

<table>
<thead>
<tr>
<th>Curve</th>
<th>Material Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f)</td>
<td>SA-533 Types B and C, Class 1</td>
</tr>
<tr>
<td>(g)</td>
<td>SA-662 Grade A</td>
</tr>
<tr>
<td>(h)</td>
<td>SA/EN 10028-2 Grade 10CrMo9-10 if normalized and tempered</td>
</tr>
<tr>
<td>(i)</td>
<td>All materials listed in (a) through (h) and in (j) for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below D</td>
</tr>
</tbody>
</table>

- (a) SA-203
- (b) SA-299 if normalized
- (c) SA-508 Class 1
- (d) SA-516 if normalized
- (e) SA-524 Classes 1 and 2
- (f) SA-537 Classes 1, 2, and 3
- (g) SA-612 if normalized; except that the increased Cb limit in the footnote of Table 1 of SA-20 is not permitted
- (h) SA-662 if normalized
- (i) SA-738 Grade A
- (j) SA-738 Grade A with Cb and V deliberately added in accordance with the provisions of the material specification, not colder than −29°C (−20°F)
- (k) SA-738 Grade B not colder than −29°C (−20°F)
- (l) SA/EN 10028-2 Grade P355GH if normalized [See General Note (d)(3)]

**GENERAL NOTES:**
(a) Castings not listed as Curve A and B shall be impact tested.
(b) For bolting see 3.11.6.
(c) When a class or grade is not shown in a material assignment, all classes and grades are indicated.
(d) The following apply to all material assignments:
   1. Cooling rates faster than those obtained in air, followed by tempering, as permitted by the material specification, are considered equivalent to normalizing and tempering heat treatments.
   2. Fine grain practice is defined as the procedures necessary to obtain a fine austenitic grain size as described in SA-20.
   3. Normalized rolling condition is not considered as being equivalent to normalizing.
(e) Data of Figures 3.8 and 3.8M are shown in Table 3.15.
Figure 3.8M

Impact Test Exemption Curves — Parts Subject to PWHT and Nonwelded Parts (Cont’d)

<table>
<thead>
<tr>
<th>Curve D</th>
<th>Material Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f) SA-533 Types B and C, Class 1</td>
<td></td>
</tr>
<tr>
<td>(g) SA-662 Grade A</td>
<td></td>
</tr>
<tr>
<td>(h) SA/EN 10028-2 Grade 10CrMo9–10 if normalized and tempered</td>
<td></td>
</tr>
<tr>
<td>(i) All materials listed in (a) through (d) and in (g), for Curve B if produced to fine grain practice and normalized, normalized and tempered, or liquid quenched and tempered as permitted in the material specification, and not listed for Curve D below</td>
<td></td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) Castings not listed as Curve A and B shall be impact tested.
(b) For bolting see 3.11.6.
(c) When a class or grade is not shown in a material assignment, all classes and grades are indicated.
(d) The following apply to all material assignments:
   (1) Cooling rates faster than those obtained in air, followed by tempering, as permitted by the material specification, are considered equivalent to normalizing and tempering heat treatments.
   (2) Fine grain practice is defined as the procedures necessary to obtain a fine austenitic grain size as described in SA-20.
   (3) Normalized rolling condition is not considered as being equivalent to normalizing.
(e) Data of Figures 3.8 and 3.8M are shown in Table 3.15.
(d) Stiffening Rings - Stiffening rings may be used at the saddle support location, on either the inside or outside of the cylindrical shell. The stiffening rings may be mounted in the plane of the saddle (see Figure 4.15.3) or two stiffening rings may be mounted on each side of the saddle support equidistant from the saddle support (see Figure 4.15.4). In the later case, the spacing between the two stiffening rings, \( h \), as shown in Figure 4.15.4 shall not be greater than \( R_m \). If \( h \leq 1.56 \sqrt{R_m} \) as shown in Figure 4.15.3 sketch (c), then both of the stiffening rings shall be considered as a single stiffening ring situated in the plane of the saddle in the stress calculations.

4.15.3.2 Moment and Shear Force.

(a) If the vessel is composed of a cylindrical shell with a formed head (i.e., torispherical, elliptical, or hemispherical) at each end that is supported by two saddle supports equally spaced and with \( a \leq 0.25L \), then the moment at the saddle, \( M_1 \), the moment at the center of the vessel, \( M_2 \), and the shear force at the saddle, \( T \), may be computed using the following equations.

\[
M_1 = -Qd \left( 1 - \frac{a}{L} \frac{R_m^2 - h^2}{2ah} \right) \quad (4.15.3)
\]

\[
M_2 = \frac{QL}{4} \left( 1 + \frac{2(a^2 - h^2)}{L^2} - \frac{4a}{L} \right) \quad (4.15.4)
\]

\[
T = \frac{Q(L - 2a)}{L + \frac{4a^2}{3}} \quad (4.15.5)
\]

(b) If the vessel supports are not symmetric, or more than two supports are provided, then the highest moment in the vessel, and the moment and shear force at each saddle location shall be evaluated. The moments and shear force may be determined using strength of materials (i.e., beam analysis with a shear and moment diagram). If the vessel is supported by more than two supports, then differential settlement should be considered in the design.

4.15.3.3 Longitudinal Stress.

(a) The longitudinal membrane plus bending stresses in the cylindrical shell between the supports are given by the following equations.

\[
\sigma_1 = \frac{PR_m}{2t} - \frac{M_2}{\pi R_m^2} \quad \text{(top of shell)} \quad (4.15.6)
\]

\[
\sigma_2 = \frac{PR_m}{2t} + \frac{M_2}{\pi R_m^2} \quad \text{(bottom of the shell)} \quad (4.15.7)
\]

(b) The longitudinal stresses in the cylindrical shell at the support location are given by the following equations. The values of these stresses depend on the rigidity of the shell at the saddle support. The cylindrical shell may be considered as suitably stiffened if it incorporates stiffening rings at, or on both sides of the saddle support, or if the support is sufficiently close defined as \( a \leq 0.5R_m \) to a torispherical or elliptical head (a hemispherical head is not considered a stiffening element), a flat cover, or tubesheet.

(1) Stiffened Shell - The maximum values of longitudinal membrane plus bending stresses at the saddle support are given by the following equations.

\[
\sigma_3 = \frac{PR_m}{2t} - \frac{M_1}{\pi R_m^2} \quad \text{(top of shell)} \quad (4.15.8)
\]

\[
\sigma_4 = \frac{PR_m}{2t} + \frac{M_1}{\pi R_m^2} \quad \text{(bottom of shell)} \quad (4.15.9)
\]
failure by excessive deformation and elastic instability. Alternatively, saddle supports may be designed in accordance with Part 5.

b) Geometry – A typical horizontal vessel geometry is shown in Figure 4.15.1. Saddle supports for horizontal vessels shall be configured to provide continuous support for at least one-third of the shell circumference, or $\theta \geq 120^\circ$.

c) Reinforcing Plates – If a reinforcing plate is included in the design to reduce the stresses in the cylindrical shell at the saddle support, then the width of the reinforcing plate, $b_1$, shall satisfy Equation (4.15.1) and provide a supporting arc length that satisfies Equation (4.15.2). A typical reinforcing plate arrangement is shown in Figure 4.15.2.

$$b_1 = \min \left( b + 1.56 \sqrt{R_m t}, \frac{2a}{\theta} \right)$$  \hspace{1cm} (4.15.1)

$$\theta_1 = \theta + \frac{\theta}{12}$$  \hspace{1cm} (4.15.2)

d) Stiffening Rings – Stiffening rings may be used at the saddle support location, on either the inside or outside of the cylindrical shell. The stiffening rings may be mounted in the plane of the saddle (see Figure 4.15.3) or two stiffening rings may be mounted on each side of the saddle support equidistant from the saddle support (see Figure 4.15.4). In the latter case, the spacing between the two stiffening rings, $h$, as shown in Figure 4.15.4 shall not be greater than $R_m$. If $h \leq 1.56 \sqrt{R_m t}$ as shown in Figure 4.15.3 Sketch (c), then both of the stiffening rings shall be considered as a single stiffening ring situated in the plane of the saddle in the stress calculations.

4.15.3.2 Moment and Shear Force

a) If the vessel is composed of a cylindrical shell with a formed head (i.e. torispherical, elliptical, or hemispherical) at each end that is supported by two saddle supports equally spaced and with $a \leq 0.25L$, then the moment at the saddle, $M_1$, the moment at the center of the vessel, $M_2$, and the shear force at the saddle, $T$, may be computed using the following equations.

$$M_1 = -Qa \left( 1 - \frac{a}{L} \frac{R_m^2 - h_2^2}{2aL} \right) \left( 1 + \frac{4h_2}{3L} \right)$$  \hspace{1cm} (4.15.3)

$$M_2 = \frac{QL}{4} \left( \frac{2 \left( R_m^2 - h_2^2 \right)}{L^2} \frac{4h_2}{3L} - \frac{4a}{L} \right)$$  \hspace{1cm} (4.15.4)

$$T = \frac{Q(L - 2a)}{L + \frac{4h_2}{3}}$$  \hspace{1cm} (4.15.5)

b) If the vessel supports are not symmetric, or more than two supports are provided, then the highest moment in the vessel, and the moment and shear force at each saddle location shall be evaluated. The
### 4.19.14 SPECIFICATION SHEETS

**4.19.1 Metric Form Specification Sheet For ASME Section VIII, Division 2 Bellows Expansion Joints, Metric Units**

<table>
<thead>
<tr>
<th>Date: <strong><strong><strong>/</strong></strong></strong>/_______</th>
<th>Applicable ASME Code Edition: ____________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel Class: ______________</td>
<td>Vessel Manufacturer: ______________________</td>
</tr>
<tr>
<td>1. Item Number: ____________</td>
<td>Vessel Owner: ____________________________</td>
</tr>
<tr>
<td>2. Drawing/Tag/Serial/Job Number: ____________</td>
<td></td>
</tr>
<tr>
<td>3. Quantity: ______________</td>
<td>Installation Location: ____________________</td>
</tr>
<tr>
<td>4. Size: ______ OD ______ ID mm</td>
<td>Expansion Joint Overall Length: ________ mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Internal Pressure:</th>
<th>Design ______ MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Pressure:</td>
<td>Design ______ MPa</td>
</tr>
<tr>
<td>Vessel Manufacturer Hydrotest Pressure</td>
<td>Internal ______ MPa</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Design ______ °C</th>
<th>Operating ______ °C</th>
<th>Upset ______ °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Movements: Axial Compression: (-) ______ mm</td>
<td>Axial: Horizontal Vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specified Number of Cycles: ____________</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Torsion: Moment ______ N-mm</td>
<td>Twist Angle: ______ deg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shell Material: ____________</th>
<th>Bellows Material: ____________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Thickness: ______ mm</td>
<td>Shell Corrosion Allowance: Internal: ______ mm External: ______ mm</td>
</tr>
<tr>
<td>Shell Radiography:</td>
<td>Spot / Full</td>
</tr>
<tr>
<td>End Preparation:</td>
<td>Square Cut Outside Bevel Inside Bevel Double Bevel (Describe in Line 24 if special)</td>
</tr>
<tr>
<td>Heat Exchanger Tube Length Between Inner Tubeshell Faces: ______ mm</td>
<td></td>
</tr>
</tbody>
</table>

| Maximum Bellows Spring Rate: | No Yes – ______ N/mm |
| Internal Liner: | No Yes – Material: |
| Drain Holes in Liner: | No Yes – Quantity/Size: |
| Liner Flush with Shell ID: | No Yes – Telescoping Liners? No Yes |
| External Cover: | No Yes – Material: |
| Pre-Production Approvals Required: | No Yes – Drawings / Bellows Calculations / Weld Procedures |

Additional Recommendations (i.e., bellows pre-set, ultrasonic examination, etc.):
4.19.14  SPECIFICATION SHEETS

| 4.19.1 Metric Form Specification Sheet For ASME Section VIII, Division 2 Bellows Expansion Joints, Metric Units |
|---|---|
| Date: ________/_______/_______ | Applicable ASME Code Edition: __________ |
| 1. Item Number: __________ | Vessel Manufacturer: __________ |
| 2. Drawing/Tag/Serial/Job Number: __________ | Vessel Owner: __________ |
| 3. Quantity: __________ | Installation Location: __________ |
| 4. Size: _______ OD _______ ID mm | Expansion Joint Overall Length: _______ mm |
| 5. Internal Pressure: Design _______ MPa | |
| 6. External Pressure: Design _______ MPa | |
| 7. Vessel Manufacturer Hydrotest Pressure | Internal _______ MPa | External _______ MPa |
| 8. Temperature | Design _______ °C | Operating _______ °C | Upset _______ °C |
| 10. Design Movements: Axial Compression: (-) _______ mm Axial Extension: (+) _______ mm Lateral: _______ mm Angular: _______ deg |
| 11. Specified number of Cycles: __________ |
| 12. Design Torsion: Moment _______ N-mm or Twist Angle: _______ deg |
| 13. Shell Material: __________ | Bellows Material: __________ |
| 14. Shell thickness _______ mm Shell Corrosion Allowance: Internal: _______ mm External: _______ mm |
| 15. Shell Radiography: Spot / Full |
| 16. End Preparation: Square Cut Outside Bevel Inside Bevel Double Bevel (Describe in Line 24 if special) |
| 17. Heat Exchanger Tube Length Between Inner Tubesheet Faces: _______ mm |
| 18. Maximum Bellows Spring Rate: | No | Yes – _______ N/mm |
| 19. Internal Liner: | No | Yes – Material: __________ |
| 20. Drain Holes in Liner: | No | Yes – Quantity/Size: __________ |
| 21. Liner Flush with Shell ID: | No | Yes – Telescoping Liners? No Yes |
| 22. External Cover: | No | Yes – Material: __________ |
| 23. Pre-Production Approvals Required: | No | Yes – Drawings / Bellows Calculations / Weld Procedures |
| 24. Additional Recommendations: (i.e. bellows pre-set, ultrasonic examination, etc.) |

Temporary shipping bars are required to maintain assembly length during shipping and vessel fabrication only, and ARE NOT to be used during vessel hydrotest for expansion joint pressure restraint (see paragraph 4.19.3.1(c) and 4.19.3.1(d)).

[07/15]
Table KD-230.5
Tabular Values for Coefficients

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature</th>
<th>(m_2)</th>
<th>(m_3)</th>
<th>(m_4)</th>
<th>(m_5)</th>
<th>(\epsilon_p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferritic steel [Note (1)]</td>
<td>480°C (900°F)</td>
<td>0.60 (1.00 - R)</td>
<td>2 ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>2.2</td>
<td>2.0 E-5</td>
</tr>
<tr>
<td>Austenitic stainless steel and nickel-based alloys</td>
<td>480°C (900°F)</td>
<td>0.75 (1.00 - R)</td>
<td>3 ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>0.6</td>
<td>2.0 E-5</td>
</tr>
<tr>
<td>Duplex stainless steel</td>
<td>480°C (900°F)</td>
<td>0.70 (0.95 - R)</td>
<td>2 ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>2.2</td>
<td>2.0 E-5</td>
</tr>
<tr>
<td>Precipitation hardening, nickel based</td>
<td>540°C (1,000°F)</td>
<td>1.90 (0.93 - R)</td>
<td>ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>2.2</td>
<td>2.0 E-5</td>
</tr>
<tr>
<td>Aluminum</td>
<td>120°C (250°F)</td>
<td>0.52 (0.98 - R)</td>
<td>1.3 ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>2.2</td>
<td>5.0 E-6</td>
</tr>
<tr>
<td>Copper</td>
<td>65°C (150°F)</td>
<td>0.50 (1.00 - R)</td>
<td>2 ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>2.2</td>
<td>5.0 E-6</td>
</tr>
<tr>
<td>Titanium and zirconium</td>
<td>260°C (500°F)</td>
<td>0.50 (0.90 - R)</td>
<td>1.3 ln [1 + ((E_{100}/100))]</td>
<td>ln [100/(100 - RA)]</td>
<td>2.2</td>
<td>2.0 E-5</td>
</tr>
</tbody>
</table>

NOTE:
(1) Ferritic steel includes carbon, low alloy, and alloy steels, and ferritic, martensitic, and iron-based age-hardening stainless steels.

\[m_5 = \text{value listed in Table KD-230.5}\]
\[R = S_y/S_u\]
\[RA = \text{minimum specified reduction of area, \%}\]
\[\sigma_{1, k} = \text{principal stress in the } k^{th}\text{ direction at the point of interest for the } k^{th}\text{ load increment}\]
\[\sigma_{2, k} = \text{principal stress in the } k^{th}\text{ direction at the point of interest for the } k^{th}\text{ load increment}\]
\[\sigma_{3, k} = \text{principal stress in the } k^{th}\text{ direction at the point of interest for the } k^{th}\text{ load increment}\]
\[\sigma_{e, k} = \text{von Mises equivalent stress at the point of interest}\]
\[S_y = \text{yield strength at the analysis temperature (see Section II, Part D, Subpart 1, Table Y-1)}\]
\[S_u = \text{tensile strength at the analysis temperature (see Section II, Part D, Subpart 1, Table U)}\]

(d) Determine the strain limit damage for the \(k^{th}\) load step increment using the following equations:

\[
\Delta \epsilon_{\text{peq}, k} = \frac{\sqrt{2}}{3} \left[ \left( \Delta \sigma_{p,11,k} - \Delta \sigma_{p,22,k} \right)^2 + \left( \Delta \sigma_{p,22,k} - \Delta \sigma_{p,33,k} \right)^2 + \left( \Delta \sigma_{p,33,k} - \Delta \sigma_{p,11,k} \right)^2 \right]
+ 0.5 \left[ \Delta \sigma_{p,12,k}^2 + \Delta \sigma_{p,23,k}^2 + \Delta \sigma_{p,31,k}^2 \right]^{0.5}
\]

\[\text{Eq. (KD-232.3)}\]

\[D_{e,k} = \Delta \epsilon_{\text{peq}, k} / \epsilon_{e,k}\]

\[\text{Eq. (KD-232.4)}\]

(e) Add the damage occurring during the \(k^{th}\) load step increment, \(D_{e,k}\), to the sum of the incremental damage occurring at each previous increment to obtain the accumulated damage, \(D_{e}\).

(f) Repeat the process in (b) through (e) for all load step increments in the analysis.

(g) If the component has not been cold-formed or if heat treatment has been performed after forming, the damage from forming, \(D_{e,\text{form}}\), may be assumed to be zero.

\[D_{e,\text{form}} = c_{\text{cf}} / \left( \epsilon_{e,\text{cf}} \left[ 1 - 0.67 \left( m_2 / (1 + m_2) \right) \right] \right)\]

\[\text{Eq. (KD-232.5)}\]

where
\[D_{e,\text{form}} = \text{damage occurring during forming at the location in the component under consideration}\]
\[\epsilon_{e,\text{cf}} = \text{forming strain at the location in the component under consideration}\]

(h) Add the damage from forming to the accumulated damage during loading to obtain the total accumulated damage, \(D_{e,t}\):

\[D_{e,t} = D_{e,\text{form}} + D_{e}\]

\[\text{Eq. (KD-232.6)}\]

(i) The total accumulated damage, \(D_{e,t}\), shall be calculated for the case of the local criteria in Table KD-230.4 and for the sequence of applied loads defined in KD-234 that will be applied to the component. This calculated \(D_{e,t}\) value shall be no greater than 1.0, indicating the local failure criteria to be specified (see KD-232).

The designer is cautioned that excessive distortion in the structure of the vessel may lead to failure of the pressure boundary. This could be in the form of buckling or bellmouthing (see KD-631.5).
**KD-232 PROTECTION AGAINST LOCAL FAILURE**

In addition to demonstrating protection against plastic collapse as defined in KD-231, the local failure criteria below shall be satisfied.

(15) **KD-232.1 Elastic–Plastic Analysis Procedure.** The following procedure shall be used to evaluate protection against local failure.

(a) Perform an elastic–plastic stress analysis based on the local criteria of Table KD-230.4 and the ratcheting criteria for a series of applied loads in KD-234. Nonlinear geometry shall be used in the analysis.

(b) For a location in the component subject to evaluation, determine the principal stresses, \( \sigma_1, \sigma_2, \sigma_3 \), the equivalent stress, \( \sigma_e \), using eq. (KD-232.1) below, and the total equivalent plastic strain, \( \varepsilon_{peq} \).

\[
\sigma_e = \frac{1}{\sqrt{2}} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]^{\frac{1}{2}}
\]  

(KD-232.1)

(c) Determine the limiting triaxial strain \( \varepsilon_{L,k} \) for the \( k^{th} \) load step increment using the equation below, where \( \varepsilon_{L,u} \), \( m_2 \), and \( m_3 \) are determined from the coefficients given in Table KD-230.5.

\[
\varepsilon_{L,k} = \varepsilon_{L,u} e^{1 + \frac{m_2}{2} \left( \frac{\sigma_{1,k} + \sigma_{2,k} + \sigma_{3,k}}{3\sigma_{e,k}} - \frac{1}{3} \right)}
\]  

(KD-232.2)

where

\[ \varepsilon_{peq} = \text{total equivalent plastic strain} \]
\[ e = 2.7183, \text{approximate value of the base of the natural logarithm} \]
\[ EI = \text{minimum specified elongation, percent} \]
\[ \varepsilon_{L,k} = \text{maximum permitted local total equivalent plastic strain at any point at the } k^{th} \text{ load increment} \]
\[ \varepsilon_{L,u} = \text{maximum of } m_2, m_3, \text{and } m_4 \]
\[ ln = \text{natural logarithm} \]
\[ m_2 = \text{value calculated from Table KD-230.5} \]

\( m_3 = \text{value calculated from Table KD-230.5} \)
\( m_4 = \text{value calculated from Table KD-230.5} \)
\( m_5 = \text{value listed in Table KD-230.5} \)
\( R = \frac{S_y}{S_u} \)
\( RA = \text{minimum specified reduction of area, percent} \)
\( R\sigma = \text{yield strength at the analysis temperature (see Section II, Part D, Subpart 1, Table Y-1)} \)
\( S_u = \text{tensile strength at the analysis temperature (see Section II, Part D, Subpart 1, Table U)} \)

(d) Determine the strain limit damage for the \( k^{th} \) load step increment using the following equation:

\[
D_{e,k} = \frac{\Delta \varepsilon_{peq,k}}{\varepsilon_{L,k}}
\]  

(KD-232.3)

where

\( D_{e,k} = \text{strain limit damage for the } k^{th} \text{ loading condition} \)
\( \Delta \varepsilon_{peq,k} = \text{equivalent plastic strain range for the } k^{th} \text{ loading condition or cycle} \)

(e) Add the damage occurring during the \( k^{th} \) load step increment, \( D_{e,k} \), to the sum of the incremental damage occurring at each previous increment to obtain the accumulated damage, \( D_{e} \).

(f) Repeat the process in (b) through (e) for all load step increments in the analysis.

(g) If the component has been cold-formed without subsequent heat treatment, calculate the damage from forming, \( D_{e,\text{form}} \), using the equation below. If the

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**NOTE:**
(1) Ferritic steel includes carbon, low alloy, and alloy steels, and ferritic, martensitic, and iron-based age-hardening stainless steels.
Table KD-320.1
Tabulated Values of $S_a$, ksi, From Figures Indicated (Cont'd)

GENERAL NOTES (CONT'D):
Table continued

$S_u \geq 38$ ksi

\[
N = \left[ - \left( 7.125 \times 10^{-4} \right) + \left( 4.4692 \times 10^{-4} \right) (S_u^2) \ln(S_u) + \left( 3.561 \times 10^{-3} \right) / S_u^{0.5} \right]^{-1}
\]

12.5 ksi < $S_u < 38$ ksi

\[
N = \exp \left[ \frac{18.0353 - 1.3526 S_u - (1.549 E - 02) S_u^2}{1 - (4.031 E - 02) S_u - (3.854 E - 03) S_u^2} \right]
\]

$S_u \leq 12.5$ ksi

\[
N = \exp \left[ -20.0 \ln(S_u) / 24.94 \right]
\]

(4) Figure KD-320.2, UTS = 115–130 ksi

\[
S_{ult} = 43\text{ ksi} \quad N = \exp \left[ \frac{9.363 - 3.004 E - 01 (S_{ult}) + 1.488 E - 04 (S_{ult}^2)}{1 - 2.4133 E - 02 (S_{ult}) - 1.6829 E - 04 (S_{ult}^2)} \right]
\]

20 ksi < $S_{ult} < 43$ ksi

\[
N = \left( 1 - 1974.51 + 1063.7 (S_{ult})^{0.5} - 146.64 (S_{ult}) / (1 - 6.73933 E - 01 (S_{ult}) + 1.51483 E - 01 (S_{ult})^{1.5}) \right)
\]

$S_{ult} \leq 20$ ksi

\[
N = \exp \left[ -20.0 \ln(S_{ult}) / 39.91 \right]
\]

(5) Figure KD-320.3, austenitic stainless steel

345 ksi ≥ $S_a$ ≥ 55.7 ksi

\[
N = \exp \left[ \frac{3.03 E - 02 - 0.7531 S_a - (1.968 E - 04) S_a^2}{1 - (7.23 E - 02) S_a - (4.075 E - 04) S_a^2} \right]
\]

55.7 ksi > $S_a$ ≥ 28 ksi

\[
N = \exp \left[ \frac{2.445 E - 04 + 1.656 E - 03 S_a - (3.416 E - 02) S_a^2}{1 - (6.062E02) S_a - (4.29E04) S_a^2 - (4.049 E - 05) S_a^2} \right]
\]

(6) Figure KD-320.4, 17-4PH/15-5PH stainless steel

129 ksi ≤ $S_u$ < 207 ksi

\[
N = \left( 1 - 10.60 \ln \left( S_u \right) \right)^3 + 80.024 \ln \left( S_u \right)^2 - 203.37 \ln \left( S_u \right) + 175.13
\]

103 ksi ≤ $S_u$ < 129 ksi

\[
N = \left( 56.735 \ln \left( S_u \right) \right)^3 + 347.76 \ln \left( S_u \right)^2 + 707.66 \ln \left( S_u \right) - 475.12
\]

71 ksi ≤ $S_u$ < 103 ksi

\[
N = \left( 29.577 \ln \left( S_u \right) \right)^3 - 180.59 \ln \left( S_u \right)^2 + 370.62 \ln \left( S_u \right) + 259.15
\]

71 ksi > $S_u$ ≥ 35.7 ksi

\[
N = \left( 41.740 \ln \left( S_u \right) \right)^3 - 201.51 \ln \left( S_u \right)^2 + 311.25 \ln \left( S_u \right) - 146.68
\]

(7) Figure KD-320.5, HSLA steel bolting

81 ksi < $S_u$ ≤ 450 ksi

\[
N = -73.187 + \frac{10.789.34}{\left( S_u \right)^{0.5}} - \frac{95.157.4 \ln \left( S_u \right)}{S_u} + \frac{407.873.1}{S_u}
\]

22.5 ksi < $S_u$ ≤ 81 ksi

\[
N = 19.878 + \frac{1.711.995}{\left( S_u \right)} + \frac{992.406 \ln \left( S_u \right)}{S_u^{0.5}} + \frac{1.916.134}{S_u^2}
\]

8.4 ksi < $S_u$ ≤ 22.5 ksi

\[
N = \exp \left[ 23.9644 + 1.1253 \ln \left( S_u \right)^2 - 8.2444 \ln \left( S_u \right) \right]
\]

5.3 ksi ≤ $S_u$ ≤ 8.4 ksi

\[
N = \left[ 7.6208 E - 06 - \frac{3.9025 E - 06 \left( S_u \right)}{S_u} + \left( 4.97327 E - 07 \right) S_u^{0.5} \right]^{-1}
\]

(e) Equations shall not be used outside of the cycle range given in the Table.