ARTICLE A-3000

METHOD OF $K_I$ DETERMINATION

A-3100 SCOPE

(a) This Article provides methods of calculating crack tip stress intensity factors, $K_I$, for subsurface and surface flaws using the representative stresses at the flaw location and acting normal to the plane of the flaw (Mode I). The solutions for $K_I$ are based on either flat plate or cylindrical geometries, and can be used for subsurface flaws, and internal and external surface flaws in various types of components (e.g., vessels, pumps, valves, etc.), for which the flaw can be defined in terms of crack depth, $a$, for surface flaws (half crack depth for subsurface flaws), wall thickness, $t$, and component curvature, $R/t$ (ratio of inside radius to wall thickness).

(b) The flaw shall be represented by an ellipse or semi-ellipse, as applicable, as shown in Figure A-3100-1. $K_I$ for the appropriate flaw model shall be determined using the stress representation described in A-3200, and the equations provided in A-3300 for subsurface flaws or A-3400 for surface flaws.

A-3200 STRESSES

(a) When defining the stresses acting at the flaw location, applied stresses from all forms of loading, including internal pressure, thermal transients, cladding-induced stresses, and weld residual shall be evaluated. When surface flaws are in contact with the pressure-side of the component, the pressure acting on the crack faces shall be included in the determination of $K_I$.

(b) When stress distributions are determined using a numerical stress analysis method, stress values are obtained at discrete locations. Stress distribution may be represented by a polynomial equation as described in A-3210. Stress distribution may also be represented over discrete intervals as described in A-3220.

A-3210 POLYNOMIAL STRESS REPRESENTATION

The stress distribution may be represented by a polynomial. The selection of the order of the polynomial fit is established based on achieving the best fit to the actual stress variation. For nonlinear stress variations through the wall of the component, higher order regression fits up to 4th order might be required. Two acceptable fitting methods, as described in A-3211 and A-3212, may be used; namely, stress fit over the crack depth, or stress fit over the wall thickness of the component.
where

\[ C_0 = A_0 - A_1 \left( \frac{d}{a} \right) + A_2 \left( \frac{d}{a} \right)^2 - A_3 \left( \frac{d}{a} \right)^3 + A_4 \left( \frac{d}{a} \right)^4 \]

\[ C_j = \left( \frac{t}{a} \right)^2 \left[ A_j - 2A_2 \left( \frac{d}{a} \right) + 3A_3 \left( \frac{d}{a} \right)^2 - 4A_4 \left( \frac{d}{a} \right)^3 \right] \]

\[ C_2 = \left( \frac{t}{a} \right)^3 \left[ A_2 - 3A_3 \left( \frac{d}{a} \right) + 6A_4 \left( \frac{d}{a} \right)^2 \right] \]

\[ C_3 = \left( \frac{t}{a} \right)^4 \left[ A_3 - 4A_4 \left( \frac{d}{a} \right) \right] \]

\[ C_4 = A_4 \left( \frac{t}{a} \right)^4 \]

\[ d = \text{distance from the intersection of the major and minor axes of the flaw to the nearest free boundary surface as shown in Figure A-3210-2} \]

\[ A_0, A_1, A_2, A_3, \]

\[ A_4 = \text{coefficients from eq. (1) that represent the stress distribution over the flaw depth, } -1 \leq x/a \leq 1. \text{ When calculating } K_I \text{ as a function of flaw depth, a new set of coefficients } A_0 \text{ through } A_4 \text{ shall be determined for each new value of flaw depth.} \]

\[ G_0, G_1, G_2, G_3, G_4 = \text{ } K_I \text{ coefficients provided in tabular format in A-3312 or in equational format in A-3313} \]

The flaw shape parameter \( Q \) is calculated using the following equation:

\[ Q = \Phi - q_y \quad (5) \]

Where

\[ \Phi = 1 + 4.593 \left( \frac{a}{\ell} \right)^{0.65} \]

\[ \ell = \text{the length of the major axis of the flaw} \]

\[ a/\ell = \text{the flaw aspect ratio } 0 \leq a/\ell \leq 0.5 \]

\[ q_y = \text{the plastic zone correction factor calculated using the following equation:} \]

\[ q_y = \left[ (C_0G_0 + C_1G_1 + C_2G_2 + C_3G_3 + C_4G_4) / \sigma_{y_0} \right]^2 / 6 \]

\[ \sigma_{y_0} = \text{material yield strength} \]

For stresses represented by eq. (2) where the stress is defined over the component thickness, the stress intensity factor is given by

\[ K_I = \left( B_0G_0 + B_1G_1 + B_2G_2 + B_3G_3 + B_4G_4 \right) \sqrt{\pi a / Q} \quad (6) \]
In eq. (10) and eq. (11), $k_i$ and $b_i$ are defined in eq. (3).

(b) For the surface point (Point 2) of a semi-elliptical surface crack as shown in Figure A-3100-1(b), the weight function is given by

$$m(x,a) = \frac{2}{(\pi x)^{1/2}} \left[ I + N_1 \left( \frac{x}{a} \right)^{1/2} + N_2 \left( \frac{x}{a} \right) + N_3 \left( \frac{x}{a} \right)^{3/2} \right]$$

where weight function coefficients $N_j$ are dependent on geometry of the structure and crack dimensions. The stress intensity factor calculated using the weight function method of eq. (9) and the piecewise linear stress of eq. (3) is given by

$$K_I = K_{IN0} + K_{IN1} N_1 + K_{IN2} N_2 + K_{IN3} N_3$$

where

$$K_{IN0} = \frac{4}{3\sqrt{\pi}} \sum_{i=1}^{n} \left[ \sqrt{x_{i+1}/(k_i x_{i+1} + 3b_i)} - \sqrt{x_i/(k_i x_i + 3b_i)} \right]$$

$$K_{IN1} = \frac{1}{\sqrt{\pi a}} \sum_{i=1}^{n} \left[ x_{i+1}/(k_i x_{i+1} + 2b_i) - x_i/(k_i x_i + 2b_i) \right]$$

$$K_{IN2} = \frac{4}{15a\sqrt{\pi}} \sum_{i=1}^{n} \left[ x_{i+1}^{3/2}/(3k_i x_{i+1} + 5b_i) - x_i^{3/2}/(3k_i x_i + 5b_i) \right]$$

$$K_{IN3} = \frac{1}{3a\sqrt{\pi a}} \sum_{i=1}^{n} \left[ x_{i+1}^2/(2k_i x_{i+1} + 3b_i) - x_i^2/(2k_i x_i + 3b_i) \right]$$

In eq. (10) and eq. (11), $k_i$ and $b_i$ are defined in eq. (3).

A-3422 Equations For Weight Function Coefficients $M_j$ and $N_j$

(a) Coefficients $M_j$ for $j = 1, 2,$ and $3,$ to calculate $K_I$ in A-3421(a), where $G_i$ is evaluated at the deepest point (Point 1), are given by

$$M_1 = \frac{2\pi}{\sqrt{2\phi}}(3G_1 - G_0) - \frac{24}{5}$$

$$M_2 = 3$$

$$M_3 = \frac{6\pi}{\sqrt{2\phi}}(G_0 - 2G_1) + \frac{8}{5}$$

Solutions for $G_0$ and $G_1$ are provided in A-3412 and A-3413 for various flaw geometries.

(b) Coefficients $N_j$, for $j = 1, 2,$ and $3,$ to calculate $K_I$ in A-3421(b), where $G_i$ are evaluated at the surface point (Point 2), is given by
\[ N_1 = \frac{3\pi}{\sqrt{Q}} \left( 2G_0 - 5G_1 \right) - 8 \]
\[ N_2 = \frac{15\pi}{\sqrt{Q}} \left( 3G_1 - G_0 \right) + 15 \]
\[ N_3 = \frac{3\pi}{\sqrt{Q}} \left( 3G_0 - 10G_1 \right) - 8 \]

Solutions for \( G_0 \) and \( G_1 \) are provided in A-3412 and A-3413 for various flaw geometries.

**A-3500 FLAW MODEL SOLUTIONS**

**A-3510 SUBSURFACE FLAWS**

In course of preparation. The tabular \( G_i \) coefficients for subsurface flaws in Tables A-3610-1 through A-3610-6 may be used. Interpolation within the listed values is permitted.

**A-3520 SURFACE FLAWS IN FLAT PLATE**

For surface flaws in a flat plate of finite thickness, the following expressions define the solution functions for determining the \( G_i \) coefficients in A-3413. For the deepest point (Point 1),

\[ Y_0 = f_0 \]
\[ Y_1 = f_0 - f_1 \]

where

\[ f_0 = a_0 + a_1\left( \frac{a}{t} \right)^2 + a_2\left( \frac{a}{t} \right)^4 \]

\[ a_0 = 1.10190 - 0.019863\left( \frac{a}{c} \right) - 0.043588\left( \frac{a}{c} \right)^2 \]
\[ a_1 = 4.32489 - 14.9372\left( \frac{a}{c} \right) + 19.4389\left( \frac{a}{c} \right)^2 - 8.52318\left( \frac{a}{c} \right)^3 \]
\[ a_2 = -3.03329 + 9.96083\left( \frac{a}{c} \right) - 12.582\left( \frac{a}{c} \right)^2 + 5.3462\left( \frac{a}{c} \right)^3 \]

and

\[ f_1 = b_0 + b_1\left( \frac{a}{t} \right)^2 + b_2\left( \frac{a}{t} \right)^4 \]

\[ b_0 = 0.456128 - 0.114206\left( \frac{a}{c} \right) - 0.046523\left( \frac{a}{c} \right)^2 \]
\[ b_1 = 3.022 - 10.8679\left( \frac{a}{c} \right) + 14.94\left( \frac{a}{c} \right)^2 - 6.8537\left( \frac{a}{c} \right)^3 \]
\[ b_2 = -2.28655 + 7.88771\left( \frac{a}{c} \right) - 11.0675\left( \frac{a}{c} \right)^2 + 5.16354\left( \frac{a}{c} \right)^3 \]

over the ranges \( 0 < a/t \leq 0.8 \) and \( 0.2 \leq a/c \leq 1.0 \), where \( c = \ell/2 \).

For the surface point (Point 2),
NONMANDATORY APPENDIX E
EVALUATION OF UNANTICIPATED OPERATING EVENTS

ARTICLE E-1000
INTRODUCTION

(13) E-1100 SCOPE

This Nonmandatory Appendix provides acceptance criteria and guidance for performing an engineering evaluation of the effects of an out-of-limit condition on the structural integrity of the reactor vessel beltlime region. Showing compliance with the criteria in either E-1200 or E-1300 assures that the beltlime region has adequate structural integrity for the unit to return to service. Evaluations performed using this Nonmandatory Appendix shall meet all the requirements of the Appendix.

(13) E-1200 ACCEPTANCE CRITERIA

Adequate structural integrity of the reactor vessel beltlime region is assured if the following applicable criterion is satisfied throughout the event:

(a) For isothermal pressure transients [i.e., $\Delta T_c/\Delta t < 10^8F/hr$ (5.5$^\circ$C/hr)], the maximum pressure does not exceed the allowable values of Table E-1 at any value of $T_c - RT_{NDT}$.

(b) For pressurized thermal transients [i.e., $\Delta T_c/\Delta t \geq 10^8F/hr$ (5.5$^\circ$C/hr)], the maximum pressure does not exceed the design pressure and $T_c - RT_{NDT}$ is not less than 55$^\circ$F (31$^\circ$C).

If compliance with the above applicable criterion is not shown, adequate structural integrity can be assured by satisfying the guidelines and criteria specified in E-1300.

E-1300 EVALUATION BY ANALYSIS

(a) Adequate structural integrity of the reactor vessel beltlime region is assured if it can be shown by analysis using the input of Table E-2 that the following criterion is met throughout the event:

$$1A(K_{Im} + K_{Ir}) + K_{Ir} \leq K_{Ic}$$

where

$K_{Im}$ = stress intensity factor due to membrane stress

$K_{Ir}$ = stress intensity factor due to residual stress

$K_{Ic}$ = fracture toughness per Article A-0000

(b) If compliance with the above criterion cannot be shown, additional analyses or other actions shall be taken to ensure that acceptable margins of safety will be maintained during subsequent operation.

Table E-1
Maximum Allowable Pressure as a Function of $T_c - RT_{NDT}$ for Isothermal Pressure Transients [$\Delta T_c/\Delta t < 10^8F/hr$ (5.5$^\circ$C/hr)]
For design pressures greater than 2,400 psig (16.5 MPa)

<table>
<thead>
<tr>
<th>$T_c - RT_{NDT}$ $^\circ$F (°C)</th>
<th>Maximum Allowable Pressure, psig (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ 25 (14) and greater</td>
<td>1.1 x Design</td>
</tr>
<tr>
<td>+ 15 (8)</td>
<td>2400 (16.5)</td>
</tr>
<tr>
<td>+ 10 (5.5)</td>
<td>2250 (15.5)</td>
</tr>
<tr>
<td>0 (0)</td>
<td>2000 (13.8)</td>
</tr>
<tr>
<td>-10 (-5.5)</td>
<td>1750 (12.1)</td>
</tr>
<tr>
<td>-25 (-14)</td>
<td>1500 (10.3)</td>
</tr>
<tr>
<td>-50 (-28)</td>
<td>1200 (8.3)</td>
</tr>
<tr>
<td>-75 (-42)</td>
<td>1000 (6.9)</td>
</tr>
<tr>
<td>-105 (-58)</td>
<td>850 (5.9)</td>
</tr>
<tr>
<td>-130 (-72)</td>
<td>800 (5.5)</td>
</tr>
<tr>
<td>-200 (-111)</td>
<td>750 (5.2)</td>
</tr>
</tbody>
</table>

GENERAL NOTE: Linear interpolation is permitted.
### Table E-2
Evaluation Input for Plant and Event Specific Linear Elastic Fracture Mechanics Analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>Event pressure time history</td>
</tr>
<tr>
<td>Temperature</td>
<td>Event temperature time history</td>
</tr>
<tr>
<td>Heat transfer</td>
<td>Event/plant specific flow/mixing conditions</td>
</tr>
<tr>
<td>Crack type</td>
<td>Semi-elliptical surface flaw</td>
</tr>
<tr>
<td>Minimum initiation crack</td>
<td>$0.0 &lt; a \leq 1.0$ in. (25 mm) [Note [1]]</td>
</tr>
<tr>
<td>Crack orientation</td>
<td>Longitudinal</td>
</tr>
<tr>
<td>$K_{IC}$/$K_I$ location</td>
<td>Surface and maximum depth</td>
</tr>
<tr>
<td>Clad effects</td>
<td>Clad to be considered in the thermal, stress, and fracture mechanics analyses [Note [2]]</td>
</tr>
<tr>
<td>Transition toughness</td>
<td>$K_{IC}$ per Article A-9000</td>
</tr>
<tr>
<td>Upper shelf toughness</td>
<td>(In course of preparation)</td>
</tr>
<tr>
<td>Fluence</td>
<td>Fluence at the time of the transient</td>
</tr>
<tr>
<td>Shift curve</td>
<td>Regulatory Guide 1.99 Rev. 2</td>
</tr>
<tr>
<td>Residual stress</td>
<td>Appropriate distribution for the fabrication process, or linear distribution with $+10$ ksi ($+69$ MPa) at the inside surface and $-10$ ksi ($-69$ MPa) at the outside surface</td>
</tr>
</tbody>
</table>

**NOTES:**

1. $a$ = the maximum crack depth in the base metal.
2. The stresses due to the difference between the base metal and cladding thermal expansion coefficients need not be considered in the isothermal pressure transient evaluation [i.e., $\Delta T_c/\Delta t < 10^5$°F/hr (5.5°C/hr)].
The hoop stress, \( \sigma_h \), and axial membrane pressure stress, \( \sigma_m \), for reducer or expander evaluation shall be as follows:

\[
\sigma_h = \frac{pD_b}{2t} \quad (13)
\]

\[
\sigma_m = \frac{pD_t}{2t} \quad (14)
\]

where

\( D_b = \) small-end O.D. for flaws in the small-end and the large-end O.D. for all other flaws.

The axial bending stress, \( \sigma_b \), and thermal expansion stress, \( \sigma_x \), for reducer or expander evaluation shall be as follows:

\[
\sigma_b = B_z \left( \frac{D_bM_b}{2t} \right) \quad (15)
\]

\[
\sigma_x = i \left( \frac{D_bM_b}{2t} \right) \quad (16)
\]

where

\( i = \) based on the degraded section

### 3.5 Through-Wall Flaws in Branch Tees

Branch reinforcement requirements shall be met in accordance with the design Code. If the design Code did not require reinforcement, for evaluation purposes, a reinforcement region is defined as a region of radius \( D_r \) of the branch pipe from the center of the branch connection. Through-wall flaws in branch tees outside of the reinforcement region may be evaluated using the straight pipe procedures given in 3.1 or 3.2(d), provided the stresses used in the evaluation are adjusted, to account for the geometry differences, as described below. Alternative methods may be used to calculate the stresses used in evaluation. Evaluation of flaws in the region of branch reinforcement is outside the scope of this Case.

The hoop stress, \( \sigma_h \), and axial membrane pressure stress, \( \sigma_m \), for branch tee evaluation shall be determined from eq. 3.4(13) and eq. 3.4(14), respectively. The outside diameter for each of these equations shall be for the branch or run pipe, depending on the flaw location. The axial bending stress, \( \sigma_b \), and thermal expansion stress, \( \sigma_x \), for branch tee evaluation shall be determined from eq. 3.4(15) and eq. 3.4(16) respectively.

### 3.6 Flaw Growth Evaluation

If a flaw growth analysis is performed, the growth analysis shall consider both corrosion and crack-growth mechanisms as relevant to the application.

In performing a flaw growth analysis, the procedures in Article C-3000 may be used as guidance. Relevant growth rate mechanisms shall be considered. When stress corrosion cracking (SCC) is active, the following growth rate equation shall be used:

\[
du/dt = S_T e^{\beta \sigma} \quad (17)
\]
Case N-597-3
Evaluation of Pipe Wall Thinning
Section XI

Inquiry: What methods may be used for evaluation of Class 2 and 3 piping items subjected to internal or external wall thinning?

Reply: It is the opinion of the Committee that the following methods may be used for evaluation of Class 2 and 3 piping items subjected to internal or external wall thinning.

-1000 SCOPE
(a) This Case provides requirements for evaluation of Class 2 and 3 piping items (e.g., pipe and fittings) with internal or external wall thinning.
(b) This Case is applicable to wall thinning due to flow-accelerated corrosion and other corrosion mechanisms.
(c) The provisions of this Case apply to Class 2 and 3 butt-welded pipe, pipe bend, elbow, tee, branch connection, or reducer piping items.
(d) This Case shall not be applied to planar flaws.
(e) This Case shall not be applied to wall thinning locations in piping items that are not accessible for either volumetric examination or direct physical measurement.

-3000 ACCEPTANCE STANDARDS
-3100 PRESERVICE EXAMINATION
Piping items examined prior to commercial service are acceptable for service when the measured wall thickness meets the requirements of the Construction Code.

-3200 INSERVICE EXAMINATION
-3210 General
(a) The current wall thickness of the metal loss region, \( t_c \), shall be determined in accordance with -3220.
(b) The predicted wall thickness in the metal loss region, \( t_p \), shall be determined at the end of the evaluation period in accordance with -3220.

\[ t_p = t_c - R \times \tau \]

where
\[ R = \text{predicted rate of metal loss during the evaluation period, and which includes a factor for uncertainty in metal loss rate, in/yr (mm/yr)} \]
\[ t_c = \text{current local wall thickness at the position along the profile of the metal loss region corresponding to } t_p, \text{ in. (mm)} \]
\[ \tau = \text{length of the evaluation period, yr} \]
bends, and
Figure 3621-1
Flow Chart for Analytical Evaluation of Pipe Bends, Elbows, Branch Connections, and Reducers

Analytical Evaluation (3620)

NO

Are hoop stress acceptance criteria in 3622 satisfied? (See Figure 3622-1)

YES

NO

Are longitudinal stress acceptance criteria in 3623 satisfied?

YES

NO

Are criteria for branch reinforcement (3624) satisfied, if applicable?

YES, or Not Applicable

NO

Are criteria for cyclic loading in 3625 satisfied?

YES

NO

Is a buckling analytical evaluation per 3621(g) acceptable, if required?

YES, or Not Applicable

Decrease evaluation period, r, or repair/replace

Requirements of analytical evaluation are satisfied
CASE (continued)
N-597-3
CASES OF ASME BOILER AND PRESSURE VESSEL CODE

defined in the Construction Code used in the analytical evaluation, exclusive of any additional corrosion allowance.

(1) For straight pipe, bends, and elbows, $t_{min}$ shall be determined by the following equation:

$$t_{min} = \frac{P_{nom}}{2(E + yP)}$$

(2) For concentric and eccentric reducers, $t_{min}$ at each end shall be equal to $t_{min}$ of straight pipe of the same nominal size as the reducer end. For the conical portion of the reducer and the transition at the large diameter end, $t_{min}$ shall be that of the large diameter end. A gradual transition in $t_{min}$ shall be assumed for the transition at the small end (see Figure 3622-2).

Table 3622-1
Minimum Allowable Local Thickness (Based on Hoop Stress)

<table>
<thead>
<tr>
<th>$l_{th}(\alpha)$</th>
<th>$t_{min} / t_{nom}$</th>
<th>-3622.2, Limited</th>
<th>-3622.4, Unlimited</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Circumferential</td>
<td>Circumferential</td>
</tr>
<tr>
<td>0</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.20</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.23</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.26</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.28</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.30</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.45</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.50</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.60</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.70</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.83</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.85</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>0.90</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>1.00</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>1.20</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>1.40</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>1.60</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>1.80</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
<tr>
<td>2.00</td>
<td>0.100</td>
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<tr>
<td>2.40</td>
<td>0.100</td>
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</tr>
<tr>
<td>2.80</td>
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</tr>
<tr>
<td>3.00</td>
<td>0.100</td>
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</tr>
<tr>
<td>4.00</td>
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</tr>
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<td>5.00</td>
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</tr>
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<td>6.00</td>
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<td>7.00</td>
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<td>8.00</td>
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<tr>
<td>9.00</td>
<td>0.100</td>
<td>0.100</td>
<td>0.100</td>
</tr>
</tbody>
</table>

**GENERAL NOTE:** Interpolation may be used for intermediate values.

Figure 3622-3. The allowable local thickness shall be determined in accordance with the applicable methods of 3622.2, 3622.4, 3622.5, or 3622.6 depending on the extent of the locally thinned area and the piping component. The value of $t_{min}$ shall be not less than $t_{loc}$.

(c) For a region at a distance greater than $1.5 \sqrt{R_{nom} / R_{nom}}$ from the bolt or at the inner portion of elbows or pipe bends (Figure 3622-4), the $t_{min}$ in the analytical evaluation of 3622.2, 3622.4, or 3622.6 shall be replaced by $t_{min}$, defined by the following:

$$t_{min} = \frac{0.5 + \frac{0.5 \cos \theta}{1 + \frac{R_{nom}}{R_{nom}}} t_{min, pipe}}{1}$$

(d) Local thinning analytical shall not be allowed for the following:

(1) Any thinned area in the run piping with a location at which the wall thickness is less than $t_{min}$ and is closer to the center of the branch connection than $D_{b} + 0.5 L_{m}$. The dimension $D_{b}$ is the nominal inside diameter of the branch connection and $L_{m}$ is the maximum extent of the thinned region that is less than $t_{min}$.

(2) At the small end transition of a reducer.

-3622.2 Minimum Allowable Local Thickness of Thinned Area of Limited Circumferential Extent

(a) The analytical evaluation procedure shall consider the depth and extent of the affected area and require that the wall thickness exceed $t_{min}$ for a distance that is greater than $E = 2.5 \sqrt{R_{nom} / R_{nom}}$ or $L_{m} \_ {av}$ between adjacent thinned regions, where $R_{nom}$ is the mean radius of the piping item based on nominal wall thickness and $L_{m} \_ {av}$ is the average of the extent of $L_{m}$ below $t_{min}$ for the adjacent areas (see Figure 3622-5). Alternatively, the adjacent thinned regions shall be considered a single thinned region in the analytical evaluation. Combination of adjacent areas into an equivalent single area shall be based on dimensions and extents prior to combination.

(b) Determine the allowable local thickness $t_{loc}$ from Table 3622-2, provided that the circumferential extent of wall thinning predicted to be less than $t_{min}$ $t_{loc}$ is less than or equal to $E = 2.5 \sqrt{R_{nom} / R_{nom}}$ $t_{loc}$ is the mean radius of the piping item based on nominal wall thickness $t_{min}$. For straight pipe, Table 3622-1 may be used when
Figure -3622-2
Zones of Reducer or Expander

GENERAL NOTE:
Transition zones extend from the point on the ends where the diameter begins to change to the point on the central zone where the cone angle is constant.

(b) below and (c) or (d)

$\frac{L_m(c)}{t_{\text{min}}} \geq \sqrt{R_{\text{min}}/t_{\text{min}}}$, except that an additional thickness $t_{\text{b}}$ (the Construction Code required thickness to withstand the piping sustained and occasional primary moment loads) shall be added to the value determined from Table -3622-1.

(c) This approach shall not be used to evaluate a

(2) Thinned areas for which any portion of the reinforcement zone would lie on the conical or small diameter transition zone of a reducer.

(3) Adjacent thinned areas qualified by this approach when the reinforcement zones associated with each area would overlap.

(b) The thickness of the remaining pipe wall at the thinned section is adequate if the following equation is satisfied.

$$\frac{t_{\text{loc}}}{t_{\text{min}}} \geq \frac{0.35L_m}{\sqrt{R_{\text{min}}/t_{\text{min}}}}$$

(c) If there is a surrounding reinforcement zone with predicted thickness of at least $t_{\text{nom}}$ for a minimum dimension of $L/2$ in all directions, reinforcement for the thinned area shall satisfy the following equation.

$$\frac{t_{\text{loc}}}{t_{\text{min}}} \geq 1 - \left(1.5\sqrt{R_{\text{min}}/t_{\text{min}}}\right)\left(\frac{t_{\text{nom}}}{t_{\text{min}}} - 1\right)$$

(d) As an alternative to (c) above, the reinforcement adjacent to the thinned area shall satisfy the following equation.

$$\frac{t_{\text{loc}}}{t_{\text{min}}} \geq 1 - \left(0.93S_{\text{min}}\right)$$

-3622.3 Minimum Allowable Local Thickness of Thinned Areas of Limited Axial and Circumferential Extent

(a) The value of $t_{\text{loc}}$ shall be determined by satisfying (b), (c) or (d) below when the maximum extent of wall thinning, $L_m$, for which thickness is predicted to be less than $t_{\text{min}}$ is less than or equal to 2.65 $\sqrt{R_{\text{min}}/t_{\text{min}}}$, and $t_{\text{nom}}$ is greater than 1.13 $t_{\text{min}}$. This approach requires that adequate reinforcement be available surrounding the thinned area in accordance with (c) or (d) below. This analytical evaluation approach is not applicable for the following conditions:

(1) Thinned areas adjacent to branch connections, when the reinforcement zone for the thinned area would overlap the required reinforcement of the branch connection.
-3622.4 Minimum Allowable Local Thickness of Thinned Areas of Unlimited Circumferential Extent

(a) A thinned region with unlimited circumferential extent is defined as one that may extend up to the entire circumference of the piping item.

(b) The analytical evaluation shall include consideration of the depth and extent of the affected area less than \( t_{\text{min}} \).

-3622.5 Minimum Allowable Thickness for Elbows and Pipe Bends

(a) For locations at a distance greater than \( \sqrt[1/2]{R_{\text{nom}}/t_{\text{min}}} \) from welds to adjacent piping items, the predicted thickness on the outer portion of an elbow or bend may be less than \( t_{\text{min}} \) for straight pipe. The local allowable thickness at each location shall be determined by...
Figure -3622-4
Elbow or Pipe Bend

Figure -3622-5
Separation Requirements for Adjacent Thinned Areas With Limited Circumferential Extent (Hoop Stress Check)

Legend:
- \( X_{i,j} \) = minimum distance between areas \( i \) and \( j \)
- \( L_{m,i} \times X_{i,j} \times x_{EG} = 0.5 (L_{m,i} + L_{m,j}) \)

GENERAL NOTE: Combination of adjacent areas into an equivalent single area shall be based on dimensions and extents prior to combination.

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