loss region projected to be less than $t_{\text{min}}$ exceeds $(R_{\text{min}}/t_{\text{min}})^{1/2}$.

(4) Local Metal Loss Region on Outer Portion of Elbow or Bend. The geometry of an elbow or bend is illustrated in Fig. 3. For a local metal loss region on the outer portion of an elbow or bend and farther than $(R_{\text{min}}/t_{\text{min}})^{1/2}$ from an adjacent piping item, the allowable local wall thickness may be calculated in accordance with 6.1.2.4.

(d) If any portion of a local metal loss region is on the inner portion of an elbow or bend, and is farther than $1.5 (R_{\text{p,pipe}})^{1/2}$ from an adjacent piping item, the pressure-based evaluation wall thickness for the inner portion of an elbow or bend, exclusive of tolerances and any allowances for corrosion, shall be calculated using

$$t_{\text{min,eb}} = t_{\text{min}} \left[ 0.5 + \frac{0.5}{\cos \phi} \right]$$

$$\left( 1 + \frac{(R_b)}{(R_o)} \right) \quad (8)$$

where

$R_b =$ bend radius of the elbow or bend to the elbow or bend centerline, in. (mm)

$R_o =$ outside radius of the piping item adjacent to the metal loss region, in. (mm)

$\phi =$ angle from the extrados of the elbow or bend to the boundary of the local metal loss region that is closest to the intrados, as measured in the pipe circumferential cross-section, see Fig. 3, radians

The value of $t_{\text{min,eb}}$ shall be no less than $t_{\text{min}}$ from eq. (3). In the evaluations of 6.1.2.1, 6.1.2.2, and 6.1.2.3, $t_{\text{min,eb}}$ shall be used in place of $t_{\text{min}}$ unless otherwise specified.

6.1.2.1 Local Metal Loss Region With Limited Circumferential Extent. With reference to Fig. 2, if the circumferential extent, $L_{\text{m(t)}}$, of the local metal loss region projected to be less than $t_{\text{min}}$ does not exceed $(R_{\text{min}}/t_{\text{min}})^{1/2}$, the allowable local wall thickness shall be calculated in accordance with 6.1.2.1(a) and 6.1.2.1(b).

(a) With reference to Fig. 4, the wall thickness between adjacent local metal loss regions shall exceed $t_{\text{min}}$ for a length that is the greater of $2.5 (R_{\text{p,pipe}})^{1/2}$ or $2L_{\text{m,avg}}$ of the adjacent local metal loss regions. The parameter $L_{\text{m,avg}}$ is the average of the maximum extents of wall thickness less than $t_{\text{min}}$ for the adjacent local metal loss regions.
FIG. 5 ALLOWABLE WALL THICKNESS AND LENGTH OF LOCAL METAL LOSS REGION

\[ L_{\text{avg}} = \frac{L_{m,i} + L_{m,j}}{2} \]  

(9)

where

- \( L_{m,i} = L_m \) for local metal loss region \( i \), in. (mm)
- \( L_{m,j} = L_m \) for local metal loss region \( j \), in. (mm)

Alternatively, the adjacent local metal loss regions shall be combined and evaluated as one metal loss region. Combination of adjacent local metal loss regions into an equivalent single local metal loss region shall be based on dimensions and extents prior to any combination of adjacent local metal loss regions. These requirements for adjacent local metal loss regions shall apply to any two adjacent local metal loss regions on the inside surface, on the outside surface, or to one local metal loss region on the inside surface and the other local metal loss region on the outside surface.

(b) The pressure-based minimum allowable local wall thickness of the metal loss region, \( t_{\text{loc}} \), shall be determined from the ratio of \( t_{\text{loc}}/t_{\text{min}} \) that is given as a function of \( L_m(a)/(R_{\text{min}}) \) by Curve 1 of Fig. 5, where \( L_m(a) \) is the axial extent of the local metal loss region with wall thickness projected to be less than \( t_{\text{min}} \).

6.1.2.2 Local Metal Loss Region With Limited Axial and Circumferential Extent. With reference to Fig. 2, if the maximum extent, \( L_m \), of local wall thickness projected to be less than \( t_{\text{min}} \) is less than or equal to 2.65\((R_{\text{min}}/t_{\text{min}})^{1/2}\), and \( t_{p,\text{pipe}} \) is greater than 1.13\( t_{\text{min}} \), the allowable local wall thickness shall be calculated in accordance with 6.1.2.2(a) and 6.1.2.2(b).

(a) The proximity requirements for adjacent local metal loss regions for Limited Circumferential Extent in 6.1.2.1(a) shall be applied to Limited Axial and Circumferential Extent of the local metal loss region.

(b) The value of pressure-based minimum allowable local wall thickness of the metal loss region, \( t_{\text{loc}} \), shall be equal to the greater of \( t_{\text{loc1}} \) of 6.1.2.2(b)(1) and \( t_{\text{loc2}} \) of 6.1.2.2(b)(2).

1. The value of \( t_{\text{loc1}} \) is given by eq. (10)

\[ t_{\text{loc1}} = 0.353 L_m \left( \frac{t_{\text{min}}}{R_{\text{min}}} \right)^{1/2} \]  

(10)

For a local metal loss region on any portion of an elbow of bend, \( t_{\text{min}} \) in eq. (10) is given by eq. (3).

2. With reference to Fig. 2, a surrounding reinforcement zone with projected wall thickness of at least \( t_{p,\text{pipe}} \) is required for a distance no less than the larger of \( L/2 \) or 0.75\((R_{\text{min}}/t_{\text{min}})^{1/2}\) in all directions. If these requirements are satisfied, the value of \( t_{\text{loc2}} \) that provides adequate area reinforcement of the local metal loss region is given by

\[ t_{\text{loc2}} = t_{\text{min}} - 1.5 \left( \frac{R_{\text{min}}/t_{\text{min}}}{L} \right)^{1/2} (t_{p,\text{pipe}} - t_{\text{min}}) \]  

(11)

This procedure shall not be applied to adjacent local metal loss regions where the reinforcement zones for each local metal loss region overlap. As an alternative, area reinforcement may be evaluated in accordance with the Construction Code.

6.1.2.3 Local Metal Loss Region With Unlimited Circumferential Extent. With reference to Fig. 2, if the circumferential extent, \( L_m(t) \), of the local metal loss region projected to be less than \( t_{\text{min}} \) exceeds \( R_{\text{min}}/t_{\text{min}} \), the allowable local wall thickness shall be calculated in accordance with 6.1.2.3(a) and 6.1.2.3(b).

(a) With reference to Fig. 6, the wall thickness between adjacent local metal loss regions shall exceed \( t_{\text{min}} \) for an axial distance that is the greater of 2.5\((R_{p,\text{pipe}})^{1/2}\) or
(c) **Buoyancy and Flotation** Procedures for evaluation of the metal loss region for soil and surcharge loads are provided in Nonmandatory Appendix B of this Case.

6.3 Evaluation of Longitudinal Stresses

(a) The longitudinal stresses in the piping item at the location of the metal loss region shall be evaluated in accordance with the equations of the Construction Code used in the evaluation, and shall meet the requirements of the Construction Code. Stresses due to axial forces shall be added to the stresses due to internal pressure and bending moments in the equations of the Construction Code.

(b) The potential for shell buckling of the metal loss region due to compressive longitudinal stresses shall be evaluated.

(c) Changes in the piping item metal area, piping item inside area, section modulus, and stress intensification factors, shall be evaluated in accordance with 6.3.1 and 6.3.2.

(d) The piping stress evaluation shall be based on the projected wall thickness at each cross-section of the piping item that contains a metal loss region or is affected by a change in stress index or stress intensity factor. Alternatively, the evaluation may be based on the limiting cross-section.

6.3.1 Properties of Circumferential Cross-Section of Piping Item

(a) The piping item may be assumed to have uniform metal loss with a wall thickness of $t_{p,\text{min}}$, with the section properties of the cross-section of the piping item based on a uniformly thinned cross-section with wall thickness $t_{p,\text{min}}$.

(b) As an alternative to 6.3.1(a), stress analysis may be performed for a piping item cross-section with a uniform wall thickness outside of the local metal loss region, as illustrated in Fig. 7 for a local metal loss region on the inside surface. A conservative value for the wall thickness outside of the local metal loss region at the end of the evaluation period, $t_{p,\text{pipe}}$ shall be used. Section properties for this idealization of the cross-section of the piping item are provided in Nonmandatory Appendix C of this Case.

(c) When either 6.3.1(a) or 6.3.1(b) is applied, the minimum section modulus of the cross-section of the piping item containing the metal loss region, including consideration of the shift of the neutral axis of the cross-section containing the metal loss region, shall be calculated using

$$Z_{\text{min}} = \frac{I_{\text{min}}}{K_a}$$

where

$I_{\text{min}}$ = projected minimum moment of inertia of the cross-section of the piping item containing the metal loss region about the neutral axis, considering all orientations of the cross-section of the neutral axis, in.\(^4\) (mm\(^4\))

(d) As an alternative to 6.3.1(a) and 6.3.1(b), detailed analysis may be performed based on the variation of wall thickness around the cross-section of the piping item containing the metal loss region.

6.3.2 Stress Intensification Factors and Stress Indices

(a) Except as permitted in 6.3.2(b) or 6.3.2(c), stress intensification factors or stress indices for a piping item shall be based on the assumption of uniform metal loss using a wall thickness of $t_{p,\text{min}}$ and an associated pipe mean radius in the equations for the stress intensification factors or stress indices.

(b) As an alternative 6.3.2(a), the stress intensification factors or stress indices may be based on the average value of the projected wall thickness of the metal loss region at the end of the evaluation period, $t_p$, excluding branch reinforcement zones, except that projected wall thickness at locations within a distance of twice the pipe wall thickness, $t_{p,\text{pipe}}$, from butt welds to adjacent components need not be considered.

(c) As an alternative to 6.3.2(a) and 6.3.2(b), detailed stress analysis of the piping item containing the metal loss region may be performed to evaluate the effects of metal loss on the stress distributions in the affected piping item.

6.4 Evaluation of Shear Stresses

(a) Shear loads and shear stresses in the piping item containing a metal loss region shall be calculated using a pipe-soil interaction model to represent the confining effect of the soil, and the interaction between buried pipe and its extension above the ground, if applicable. The modeling method of the 2010 Edition of B31.1, Appendix VII, "Procedures for the Design of Restrained Underground Piping," may be used.

(b) Shear loads shall be included in the evaluation. Shear loads that might be applicable to an evaluation include the following:

1. differential seismic anchor motion
2. frost heave
3. non-seismic natural ground settlement and building settlement
4. buoyancy and flotation

(c) The following equations shall be satisfied for the maximum shear loads for each service level:

$$\frac{V}{A_p} \leq 0.6S_n$$ for Service Levels A, B, and C  \hspace{1cm} (14)$$\frac{V}{A_p} \leq 0.42S_n$$ for Service Level D  \hspace{1cm} (15)

where

$A_p =$ projected metal cross-sectional area of the piping item at the end of the evaluation period, in.\(^2\) (mm\(^2\))
where

\[ W_{CL} = \text{linear weight of coating and lining of the piping item per unit length, lb/in. (N/mm)} \]

\[ W_{pipe} = \text{linear weight of the piping item per unit length excluding the linear weight of fluid inside the piping item, lb/in. (N/mm)} \]

\[ W_{w} = \text{linear weight of water displaced by the piping item, lb/in (N/mm)} \text{ and } P_{soil} \text{ is given by eq. (B-6) or (B-9)} \]
FIG. C-1 CROSS-SECTION OF PIPING ITEM WITH LOCAL METAL LOSS REGION ON THE INSIDE SURFACE

FIG. C-2 CROSS-SECTION OF PIPING ITEM WITH LOCAL METAL LOSS REGION ON THE OUTSIDE SURFACE