(c) If the unit forces $T_1$ and $T_2$ are both negative and are of equal magnitude for the governing condition of loading at a given level of the tank, the thickness of tank wall required shall be calculated using:

$$t = \frac{T_1}{S_{ca}} + c = \frac{T_2}{S_{ca}} + c$$

(15)

where $S_{ca}$ has the appropriate value for the thickness–radius ratio, as required in NC-3922.3(b).

(d) If the unit forces $T_1$ and $T_2$ are unequal magnitude, for the condition at a given level, the thickness for this condition shall be the larger of the two thicknesses calculated in Step 1, eq. (16) or Step 1, eq. (17), if both such thicknesses are of equal magnitude for the governing condition of loadings at a given level of the tank. Otherwise, proceed with Step 3.

Step 1. Calculate the values of

$$t = \frac{\sqrt{T' + 0.8T''R'}}{1,342} + c$$

and

$$t = \frac{\sqrt{TR''}}{1,000} + c$$

(16)

(17)

using values of $T'$ equal to the larger of the two coexistent unit forces, $T''$ equal to the smaller of the two unit forces, and taking $R'$ and $R''$ as equal to $R_1$ and $R_2$, respectively, if the larger unit force is latitudinal; but, conversely, taking $R'$ and $R''$ as equal to $R_2$ and $R_1$, respectively, if the larger unit force is meridional.

Step 2. Deduct the corrosion allowance from each of the two thicknesses calculated in Step 1 and check the thicknesses against the respective thickness–radius ratio $(t - c)/R$ for each using a value of $R$ equal to $R'$ as defined in Step 1 in connection with the thickness determined from Step 3, eq. (18) and a value of $R$ equal to $R''$ in connection with the thickness determined from Step 3, eq. (19). If both such thickness–radius ratios are greater than 0.0175, the larger of the two thicknesses determined in Step 3 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 5.

Step 3. If one or both of the thickness–radius ratios determined in Step 2 or Step 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Step 1, eq. (16) or Step 3, eq. (18), find a thickness which satisfies the following equation:

$$10(0.150(t - c) + 277.400(t - c)^2) = T' + 0.8T''$$

(20)

or, if the thickness involved was calculated by Step 1, eq. (17) or Step 3, eq. (19), find a thickness which satisfies the following equation:

$$\frac{5,650(t - c) + 154,200(t - c)^2}{R''} = T''$$

(21)

Step 4. Deduct the corrosion allowance from each of the two thicknesses calculated in Step 3 and check the thickness–radius ratio $(t - c)/R$ for each using a value of $R$ equal to $R'$ as defined in Step 1 in connection with the thickness determined from Step 3, eq. (18) and a value of $R$ equal to $R''$ in connection with the thickness determined from Step 3, eq. (19). If both such thickness–radius ratios are greater than 0.0175, the larger of the two thicknesses calculated in Step 3 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 5.

Step 5. If one or more of the thickness–radius ratios determined in Step 2 or Step 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Step 1, eq. (16) or Step 3, eq. (18), find a thickness which satisfies the following equation:

$$10(0.150(t - c) + 277.400(t - c)^2) = T' + 0.8T''$$

(20)

or, if the thickness involved was calculated by Step 1, eq. (17) or Step 3, eq. (19), find a thickness which satisfies the following equation:

$$\frac{5,650(t - c) + 154,200(t - c)^2}{R''} = T''$$

(21)

Step 6. Make a selection of thickness from the values calculated. Calculate the values of $S_{ce}$ for both $T_1$ and $T_2$ and check that the values of $S_{ce}$ satisfy the requirements of NC-3922.3(c). Adjustment in the thickness may be required to make the values of $S_{ce}$ satisfy the requirements of NC-3922.3(c).

NOTE: The procedure described in (d) is predicated on the assumption that the problem is one in which biaxial compression with unit forces of unequal magnitude is the governing condition. In many cases, however, a tentative thickness will have been established previously by other design considerations and only needs to be checked for the external pressure or partial vacuum condition. In such cases, the problem is greatly simplified because the designer has only to calculate the values of $S_{ce}$ for both $T_1$ and $T_2$ and then check to see that these values satisfy the requirements of NC-3922.3(c), as specified in Step 6 [see Section F.3 of Appendix I of API Standard 620. Feb. 1970 Edition, for examples illustrating the application of (a)].

**NC-3932.4 Least Permissible Thickness.** In no event shall the net thickness after fabrication of any plate subjected to pressure imposed membrane stresses be less than $\frac{3}{16}$ in. (5 mm), exclusive of corrosion allowance. For tanks having cylindrical sidewalls with diameters from 60 ft (18 m) up to but not including 120 ft (37 m), such thickness for sidewall plates shall not be less than $\frac{1}{4}$ in. (6 mm) exclusive of corrosion allowance.
Step 5. If one or more of the thickness–radius ratios determined in Step 2 or Step 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Step 1, eq. (16) or Step 3, eq. (18), find a thickness which satisfies the following equation:

\[
\frac{10,150(t - c) + 277,400(t - c)^2}{R'} = T' + 0.8T''
\]  

or, if the thickness involved was calculated by Step 1, eq. (17) or Step 3, eq. (19), find a thickness which satisfies the following equation:

\[
\frac{5,650(t - c) + 154,200(t - c)^2}{R''} = T''
\]  

Step 6. Make a selection of thickness from the values calculated. Calculate the values of \( S_{cc} \) for both \( T_1 \) and \( T_2 \) and check that the values of \( S_{cc} \) satisfy the requirements of NC-3922.3(c). Adjustment in the thickness may be required to make the values of \( S_{cc} \) satisfy the requirements of NC-3922.3(c).

NOTE: The procedure described in (d) is predicated on the assumption that the problem is one in which biaxial compression with unit forces of unequal magnitude is the governing condition. In many cases, however, a tentative thickness will have been established previously by other design considerations and only needs to be checked for the external pressure or partial vacuum condition. In such cases, the problem is greatly simplified because the designer has only to calculate the values of \( S_{cc} \) for both \( T_1 \) and \( T_2 \) and then check to see that these values satisfy the requirements of NC-3922.3(c), as specified in Step 6 [see Section F.3 of Appendix I of API Standard 620, Feb. 1970 Edition, for examples illustrating the application of (a)].

**NC-3932.4 Least Permissible Thickness.** In no event shall the net thickness after fabrication of any plate subject to pressure imposed membrane stresses be less than \( \frac{3}{16} \) in. (5 mm), exclusive of corrosion allowance. For tanks having cylindrical sidewalls with diameters from 60 ft (18 m) up to but not including 120 ft (37 m), such thickness for sidewall plates shall not be less than \( \frac{1}{4} \) in. (6 mm) exclusive of corrosion allowance.

**NC-3932.5 External Pressure Limitations.** The thickness computed by the equations and procedures specified in NC-3932, using a negative value of \( P_c \) equal to the partial vacuum for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius \( R_1 \) is equal to or less than \( R_2 \) or does not exceed \( R_2 \) by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking and it is not intended that the equations and procedures be used for evaluating the stability of such surfaces or of cylindrical surfaces against external pressure. However, cylindrical sidewalks of vertical tanks designed in accordance with these rules for storage of liquids,48 with the thickness of upper courses not less than specified in NC-3932.4 for the size of tank involved and with increasing thicknesses from top to bottom as required for the combined gas and liquid loadings, may safely be subjected to a partial vacuum in the gas or vapor space not exceeding 1 oz/in.\(^2\) (0.43 kPa) with the operating liquid level in the tank at any stage from full to empty.

**NC-3932.6 Special Considerations Applicable to Bottoms Resting Directly on Foundations.**

(a) **Uplift Considerations.** In the case of tanks with cylindrical sidewalls and flat bottoms, the uplift50 from the pressure acting on the underside of the roof must not exceed the weight of the sidewalls plus the weight of that portion of the roof which is carried by the sidewalls when no uplift exists, unless such excess is counteracted by increasing the magnitude of the downward acting forces. This shall be a matter of agreement between the Certificate Holder and Owner. Similar precautions shall be taken with flat bottomed tanks of other shapes. All weights used in such calculations shall be based on net thicknesses of the materials, exclusive of corrosion allowance.

(b) **Foundation Considerations.** The type of foundation used for supporting the tank shall be taken into account in the design of bottom plates and welds. For recommended practice for construction of foundations, see API Standard 620, Feb. 1970 Edition, Appendix C.

**NC-3933 Design of Roof and Bottom Knuckle Regions and Compression Rings**

**NC-3933.1 Nomenclature.** The symbols used are defined as follows:

- \( A_c = \) net area, in.\(^2\) (mm\(^2\)), of the vertical cross section of metal required in the compression ring region, exclusive of all corrosion allowances
- \( Q = \) total circumferential force, lb (N), acting on a vertical cross section through the compression ring region
- \( R_2 = \) length, in. (mm), of the normal to the roof or bottom at the juncture between the roof or bottom and the sidewalls, measured from the roof or bottom to the tank’s vertical axis of revolution
- \( R_c = \) horizontal radius, in. (mm), of the cylindrical sidewall at its juncture with the roof or bottom
- \( S_{ts} = \) maximum allowable stress value for simple tension, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)
- \( T_1 = \) meridional unit force in the roof or bottom of the tank at its juncture with the sidewall, lb/in. (kN/m) of circumferential arc
- \( T_2 = \) corresponding latitudinal unit force in the roof or bottom, lb/in. (N/mm) of meridian arc
- \( T_{2x} = \) circumferential unit force in the cylindrical sidewall of the tank at its juncture with the roof or bottom, lb/in. (N/mm), measured along an element of the cylinder
- \( t_c = \) corresponding thickness, in. (mm), of the cylindrical sidewalls at and near such juncture