Annex P
(normative)

Allowable External Loads on Tank Shell Openings

This annex provides a number of design options requiring decisions by the Purchaser; standard requirements; recommendations; and information that supplements the basic standard. This annex becomes a requirement only when the Purchaser specifies an option covered by this annex or specifies the entire annex.

P.1 Introduction

This Annex shall be used (unless specified otherwise by the Purchaser on Line 29 of the Data Sheet) for tanks larger than 36 m (120 ft) in diameter, and only when specified by the Purchaser for tanks 36 m (120 ft) in diameter and smaller. See W.2(5) for additional requirements.

This Annex presents two different procedures to determine external loads on tank shells. Section P.2 establishes limit loads and P.3 is based on allowable stresses. This Annex is based on H. D. Billimoria and J. Hagstrom's "Stiffness Coefficients and Allowable Loads for Nozzles in Flat Bottom Storage Tanks" and H. D. Billimoria and K. K. Tam's "Experimental Investigation of Stiffness Coefficients and Allowable Loads for a Nozzle in a Flat Bottom Storage Tank."

P.2 Limit Loads

• P.2.1 Scope

This Annex establishes requirements for the design of storage-tank openings that conform to Table 5.6a and Table 5.6b and will be subjected to external piping loads. The requirements of this Annex represent accepted practice for the design of shell openings in the lower half of the bottom shell course that have a minimum elevation from the tank bottom and meet the requirements of Table 5.6a and Table 5.6b. It is recognized that the Purchaser may specify other procedures, special factors, and additional requirements. Any deviation from these requirements shall be mutually agreed upon by the Purchaser and the Manufacturer.

• P.2.2 General

The design of an external piping system that will be connected to a thin-walled, large-diameter cylindrical vertical storage tank may pose a problem in the analysis of the interface between the piping system and the tank opening connections. The piping designer must consider the stiffness of the tank shell and the radial deflection and meridional rotation of the shell opening at the opening-shell connection resulting from product head, pressure, and uniform or differential temperature between the shell and the bottom. The work of the piping designer and the tank designer must be coordinated to ensure that the piping loads imposed on the shell opening by the connected piping are within safe limits. Although three primary forces and three primary moments may be applied to the mid-surface of the shell at an opening connection, only one force, F_R, and two moments, M_L and M_C, are normally considered significant causes of shell deformation (see P.2.3 for a description of the nomenclature).

P.2.3 Nomenclature

a is the outside radius of the opening connection, in mm (in.);

E is the modulus of elasticity, in MPa (lbf/in.^{2}) (see Table P.1a and Table P.1b);

F_R is the radial thrust applied at the mid-surface of the tank shell at the opening connection, in N (lbf);

F_P is the pressure end load on the opening for the pressure resulting from the design product head at the elevation of the opening centerline, $\pi a^2 P$, in N (lbf);

G is the design specific gravity of the liquid;

H is the maximum allowable tank filling height, in mm (in.). See F.2.1 for tanks designed with internal pressures greater than 1 kPa (4 in. of water);

K_C is the stiffness coefficient for the circumferential moment, in N-mm/radian (in.-lbf/radian);

K_L is the stiffness coefficient for the longitudinal moment, in N-mm/radian (in.-lbf/radian);

K_R is the stiffness coefficient for the radial thrust load, in N/mm (lbf/in.);

L is the vertical distance from the opening centerline to the tank bottom, in mm (in.);

M_C is the circumferential moment applied to the mid-surface of the tank shell, in N-mm (in.-lbf);

M_L is the longitudinal moment applied to the mid-surface of the tank shell, in N-mm (in.-lbf);

P is the pressure resulting from product head at the elevation of the opening centerline, in MPa (lbf/in.^{2});

R is the nominal tank radius, in mm (in.);

t is the shell thickness at the opening connection, in mm (in.);

ΔT is the normal design temperature minus installation temperature, in °C (°F);

W is the unrestrained radial growth of the shell, in mm (in.);

W_R is the resultant radial deflection at the opening connection, in mm (in.);

X_A is the $L + a$, in mm (in.);

X_B is the $L – a$, in mm (in.);

X_C is the L, in mm (in.);

Y_C is the coefficient determined from Figure P.4b;

Y_F, Y_L are the coefficients determined from Figure P.4a;

α is the thermal expansion coefficient of the shell material, in mm/[mm-°C] (in./[in.-°F]) (see Table P.1a and Table P.1b);

β is the characteristic parameter, $1.285/(Rt)^{0.5}$ (1/mm) (1/in.);

λ equals $a/(Rt)^{0.5}$;

θ is the unrestrained shell rotation resulting from product head, in radians;

θ_C is the shell rotation in the horizontal plane at the opening connection resulting from the circumferential moment, in radians;

θ_L is the shell rotation in the vertical plane at the opening connection resulting from the longitudinal moment, in radians.

Table P.1a—Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature (SI)

Design Temperature °C	Modulus of Elasticity (MPa) *E*	Thermal Expansion Coefficient[a] (mm × 10^{-6}/[mm-°C])
20	203,000	—
93	199,000	12.0
150	195,000	12.4
200	191,000	12.7
260	188,000	13.1

[a] Mean coefficient of thermal expansion, going from 20 °C to the temperature indicated.

NOTE Linear interpolation may be applied for intermediate values.

Table P.1b—Modulus of Elasticity and Thermal Expansion Coefficient at the Design Temperature (USC)

Design Temperature °F	Modulus of Elasticity (lbf/in.^{2}) *E*	Thermal Expansion Coefficient[a] (in. × 10^{-6} per in.-°F)
70	29,500,000	—
200	28,800,000	6.67
300	28,300,000	6.87
400	27,700,000	7.07
500	27,300,000	7.25

[a] Mean coefficient of thermal expansion, going from 70 °F to the temperature indicated.

NOTE Linear interpolation may be applied for intermediate values.

P.2.4 Stiffness Coefficients for Opening Connections

The stiffness coefficients K_R, K_L, and K_C corresponding to the piping loads F_R, M_L, and M_C at an opening connection, as shown in Figure P.1, shall be obtained by the use of Figures P.2A through P.2L. Figures P.2A through P.2L shall be used to interpolate intermediate values of coefficients.

P.2.5 Shell Deflection and Rotation

P.2.5.1 Radial Growth of Shell

The unrestrained outward radial growth of the shell at the center of the opening connection resulting from product head and/or thermal expansion shall be determined as follows:

In SI units:

$$W = \frac{9.8 \times 10^{-6} GHR^2}{Et} \times \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

In USC units:

$$W = \frac{0.036 GHR^2}{Et} \times \left[1 - e^{-\beta L} \cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

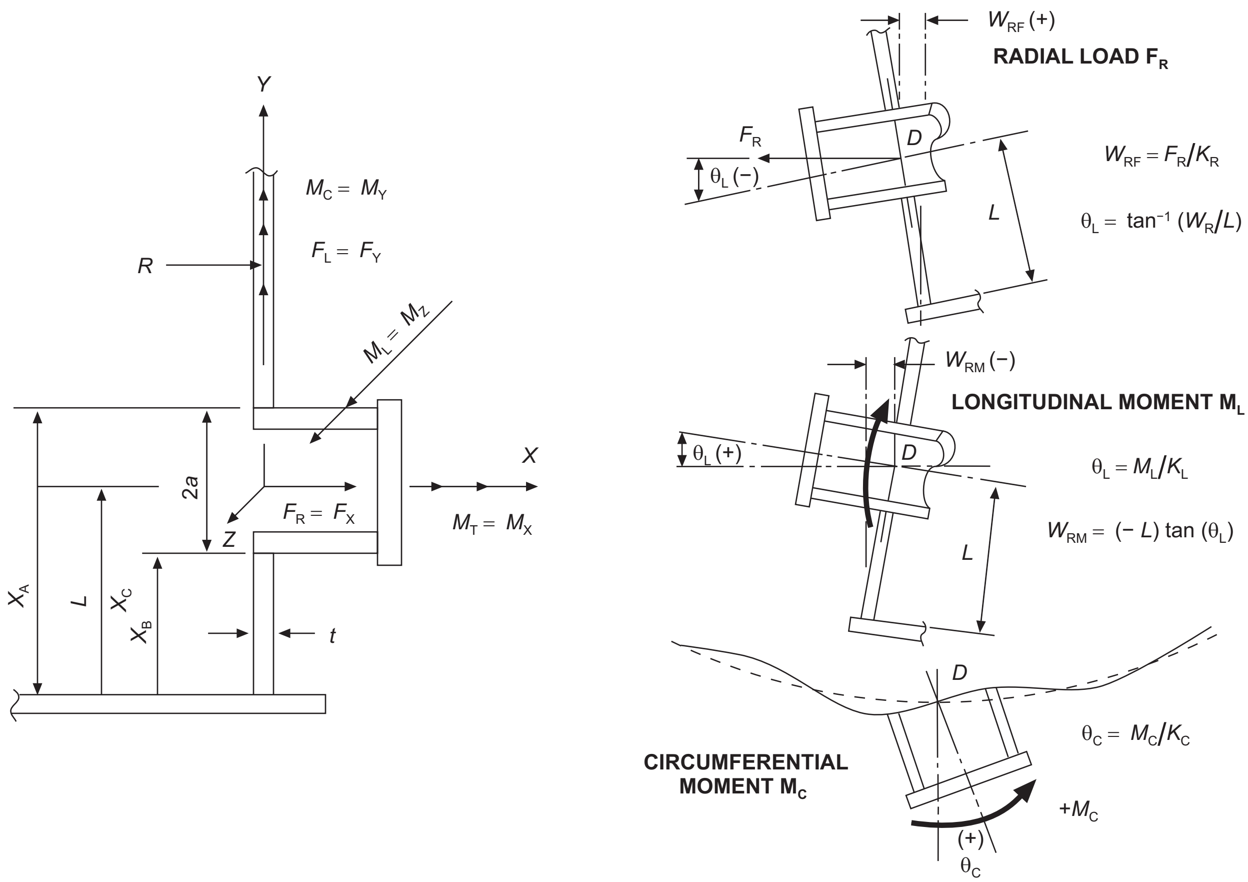

Figure P.1—Nomenclature for Piping Loads and Deformation

P.2.5.2 Rotation of Shell

The unrestrained rotation of the shell at the center of the nozzle-shell connection resulting from product head shall be determined as follows:

In SI units:

$$\theta = \frac{9.8 \times 10^{-6} GHR^2}{Et} \times \left\{ \frac{1}{H} - \beta e^{-\beta L} [\cos(\beta L) + \sin(\beta L)] \right\}$$

In USC units:

$$\theta = \frac{0.036 GHR^2}{Et} \times \left\{ \frac{1}{H} - \beta e^{-\beta L} [\cos(\beta L) + \sin(\beta L)] \right\}$$

P.2.6 Determination of Loads on the Opening Connection

The relationship between the elastic deformation of the opening connection and the external piping loads is expressed as follows:

$$W_R = \frac{F_R}{K_R} - L\tan\left(\frac{M_L}{K_L}\right) + W$$

$$\theta_L = \frac{M_L}{K_L} - \tan^{-1}\left(\frac{F_R}{LK_R}\right) + \theta$$

$$\theta_C = \frac{M_C}{K_C}$$

K_R, K_L, and K_C are the shell stiffness coefficients determined from Figures P.2a through P.2l. W_R, θ_L, and θ_C are the resultant radial deflection and rotation of the shell at the opening connection resulting from the piping loads F_R, M_L, and M_C and the product head, pressure, and uniform or differential temperature between the shell and the tank bottom. F_R, M_L, and M_C shall be obtained from analyses of piping flexibility based on consideration of the shell stiffness determined from Figures P.2a through P.2l, the shell deflection and rotation determined as described in P.2.5.1 and P.2.5.2, and the rigidity and restraint of the connected piping system.

P.2.7 Determination of Allowable Loads for the Shell Opening

P.2.7.1 Construction of Nomograms

P.2.7.1.1 Determine the nondimensional quantities $X_A/(Rt)^{0.5}$, $X_B/(Rt)^{0.5}$, and $X_C/(Rt)^{0.5}$ for the opening configuration under consideration.

P.2.7.1.2 Lay out two sets of orthogonal axes on graph paper, and label the abscissas and ordinates as shown in Figure P.3a and Figure P.3b, where Y_C, Y_F, and Y_L are coefficients determined from Figure P.4a and Figure P.4b.

P.2.7.1.3 Construct four boundaries for Figure P.3a and two boundaries for Figure P.3b. Boundaries b_1 and b_2 shall be constructed as lines at 45-degree angles between the abscissa and the ordinate. Boundaries c_1, c_2, and c_3 shall be constructed as lines at 45-degree angles passing through the calculated value indicated in Figure P.3a and Figure P.3b plotted on the positive x axis.

P.2.7.2 Determination of Allowable Loads

P.2.7.2.1 Use the values for F_R, M_L, and M_C obtained from the piping analyses to determine the quantities $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda/aY_L)(M_L/F_P)$, and $(\lambda/aY_C)(M_C/F_P)$.

P.2.7.2.2 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda/aY_L)(M_L/F_P)$ on the nomogram constructed as shown in Figure P.5a.

P.2.7.2.3 Plot the point $(\lambda/2Y_F)(F_R/F_P)$, $(\lambda/aY_L)(M_C/F_P)$ on the nomogram constructed as shown in Figure P.5b.

P.2.7.2.4 The external piping loads F_R, M_L, and M_C to be imposed on the shell opening are acceptable if both points determined from P.2.7.2.2 and P.2.7.2.3 lie within the boundaries of the nomograms constructed for the particular opening-tank configuration.

P.2.8 Manufacturer and Purchaser Responsibility

• **P.2.8.1** The Manufacturer is responsible for furnishing to the Purchaser the shell stiffness coefficients (see P.2.4) and the unrestrained shell deflection and rotation (see P.2.5). The Purchaser is responsible for furnishing to the Manufacturer the magnitude of the shell-opening loads (see P.2.6). The Manufacturer shall determine, in accordance with P.2.7, the acceptability of the shell-opening loads furnished by the Purchaser. If the loads are excessive, the piping configuration shall be modified so that the shell-opening loads fall within the boundaries of the nomograms constructed as in P.2.7.1.

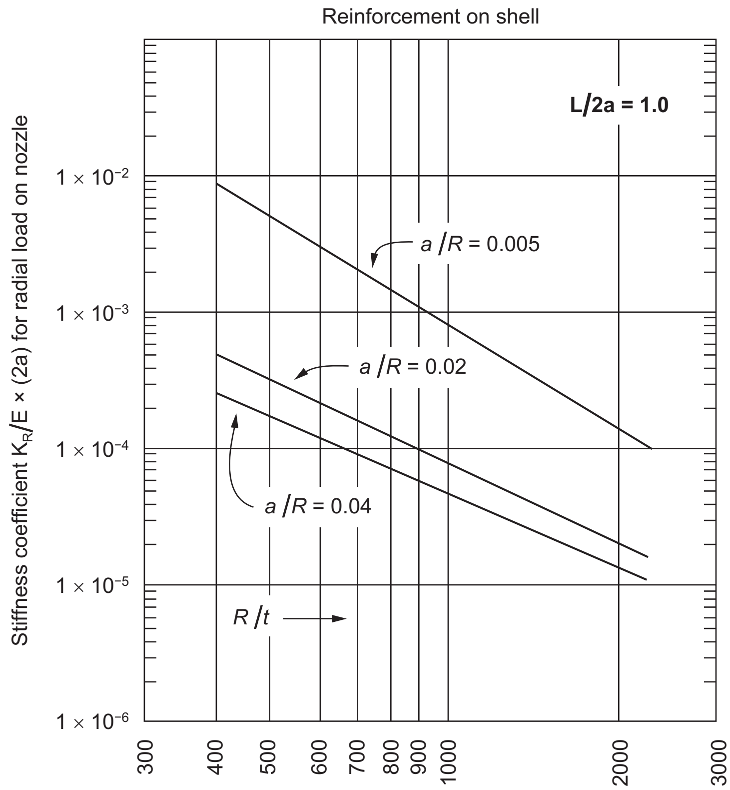

Figure P.2a—Stiffness Coefficient for Radial Load: Reinforcement on Shell (*L*/2*a* = 1.0)

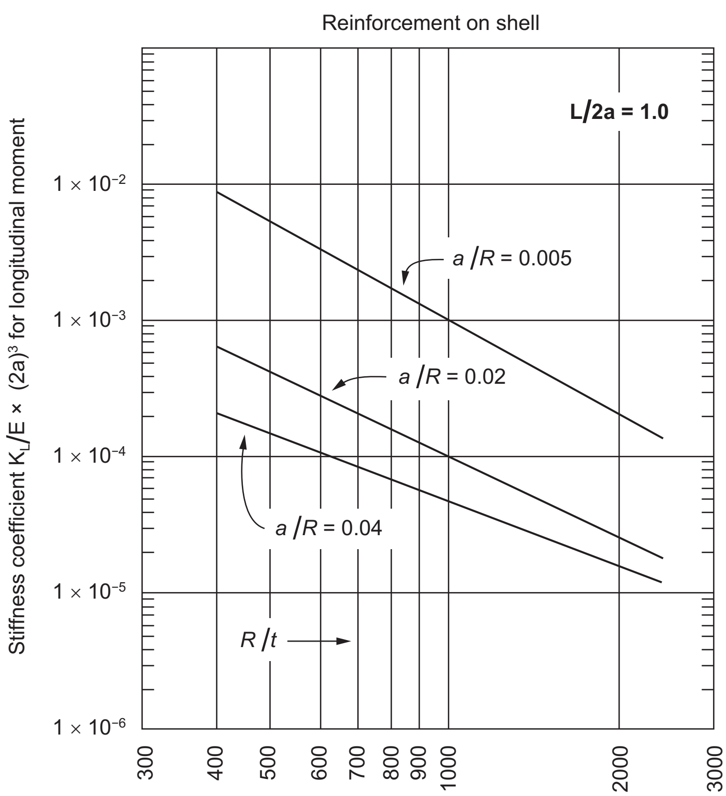

Figure P.2b—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell (*L*/2*a* = 1.0)

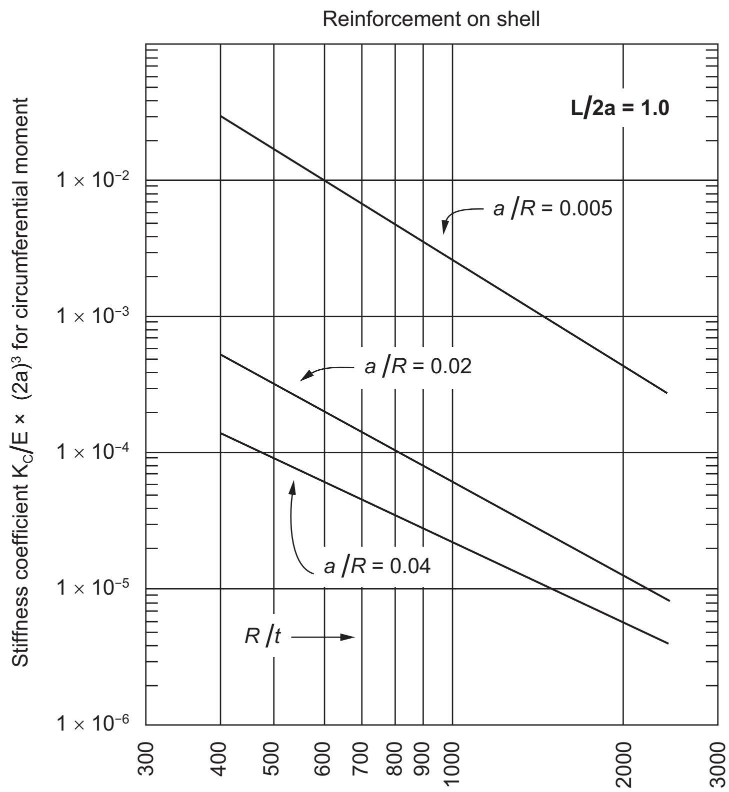

Figure P.2c—Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell (*L*/2*a* = 1.0)

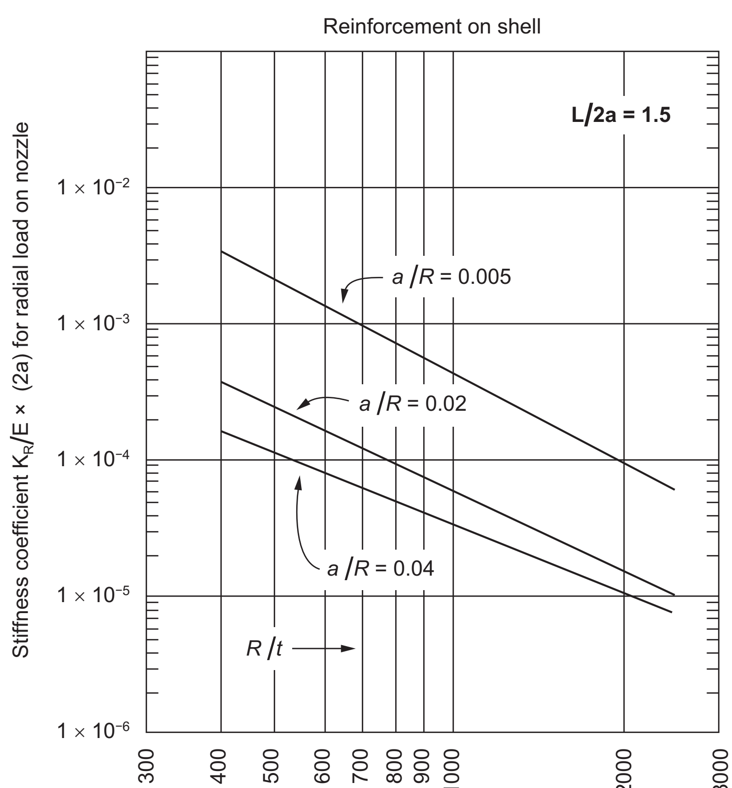

Figure P.2d—Stiffness Coefficient for Radial Load: Reinforcement on Shell (*L*/2*a* = 1.5)

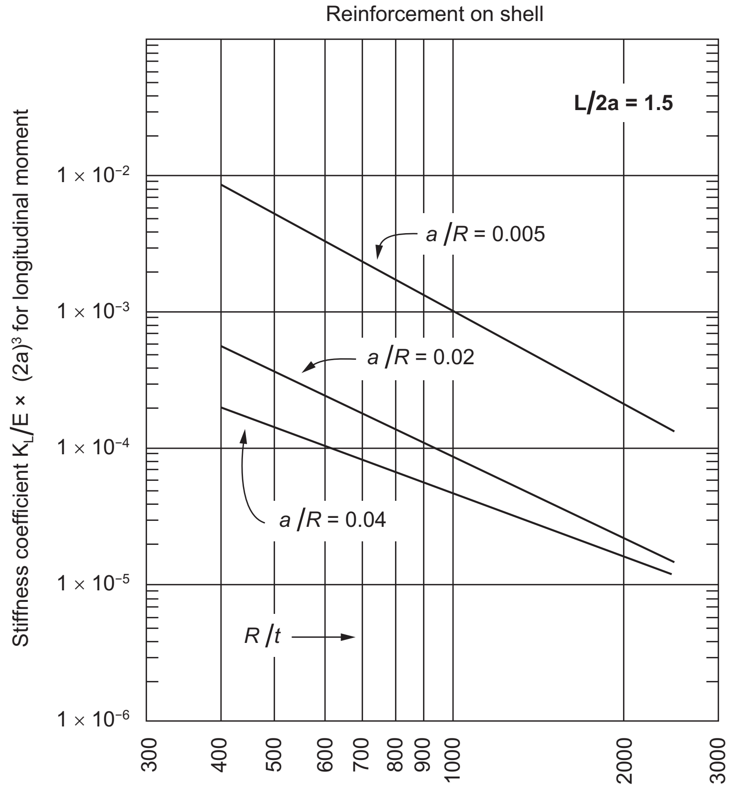

Figure P.2e—Stiffness Coefficient for Longitudinal Moment: Reinforcement on Shell (*L*/2*a* = 1.5)

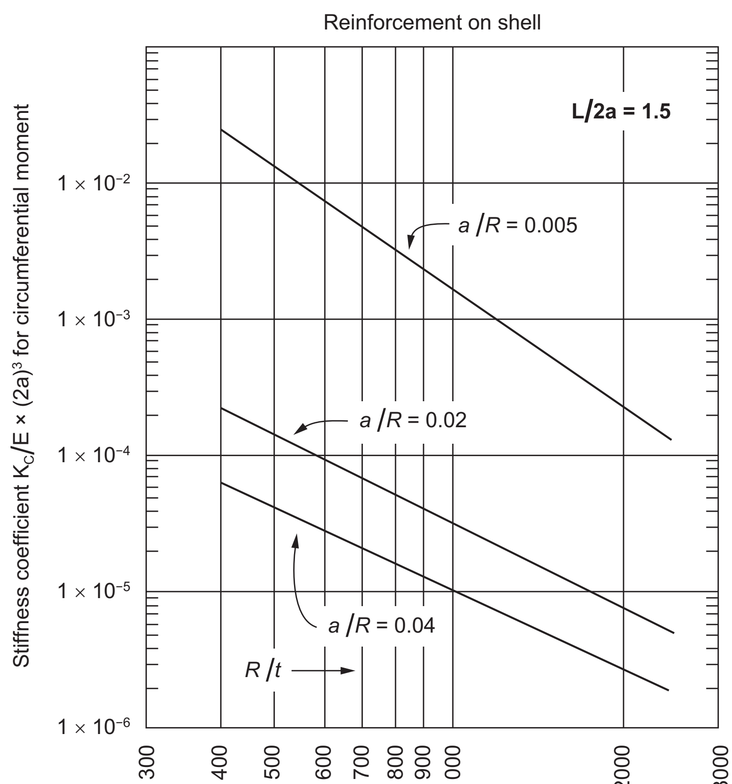

Figure P.2f—Stiffness Coefficient for Circumferential Moment: Reinforcement on Shell (*L*/2*a* = 1.5)

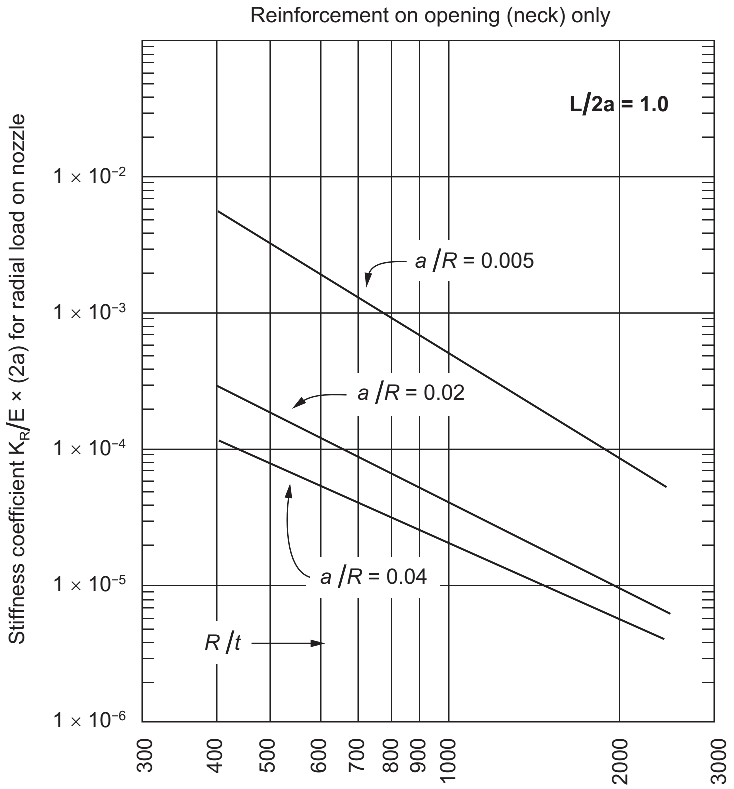

Figure P.2g—Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only (*L*/2*a* = 1.0)

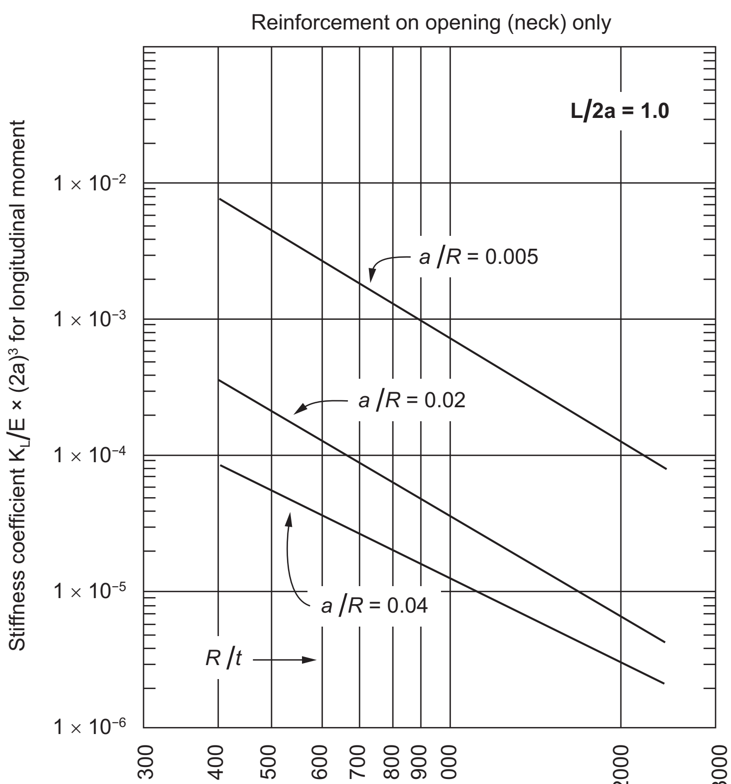

Figure P.2h—Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only (*L*/2*a* = 1.0)

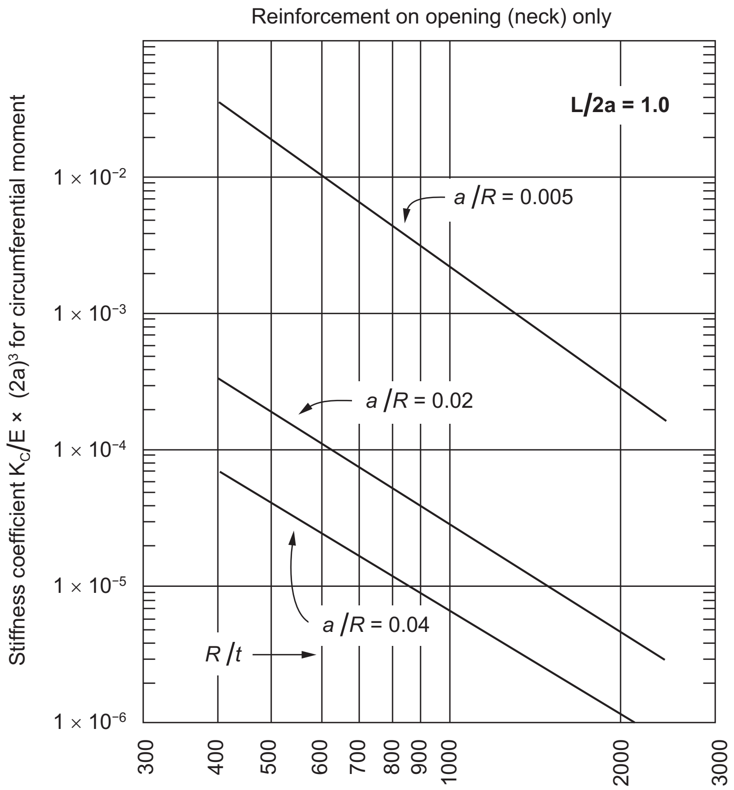

Figure P.2i—Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only (*L*/2*a* = 1.0)

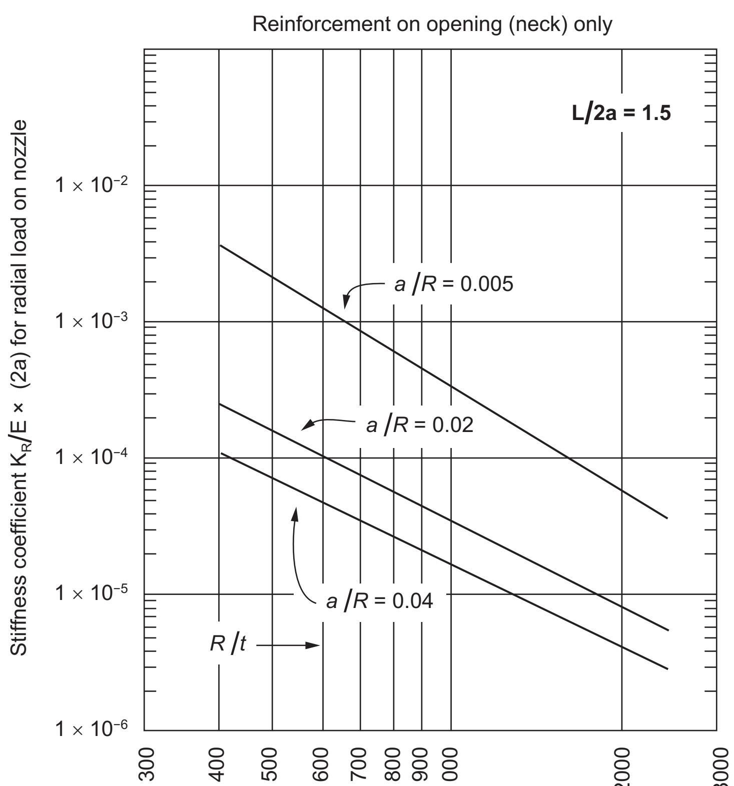

Figure P.2j—Stiffness Coefficient for Radial Load: Reinforcement in Nozzle Neck Only (*L*/2*a* = 1.5)

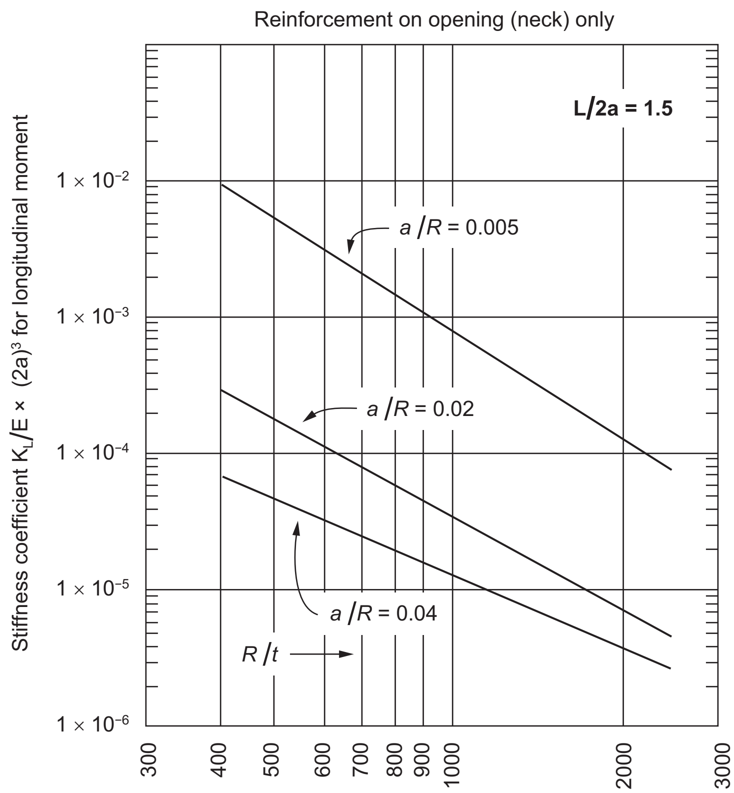

Figure P.2k—Stiffness Coefficient for Longitudinal Moment: Reinforcement in Nozzle Neck Only (*L*/2*a* = 1.5)

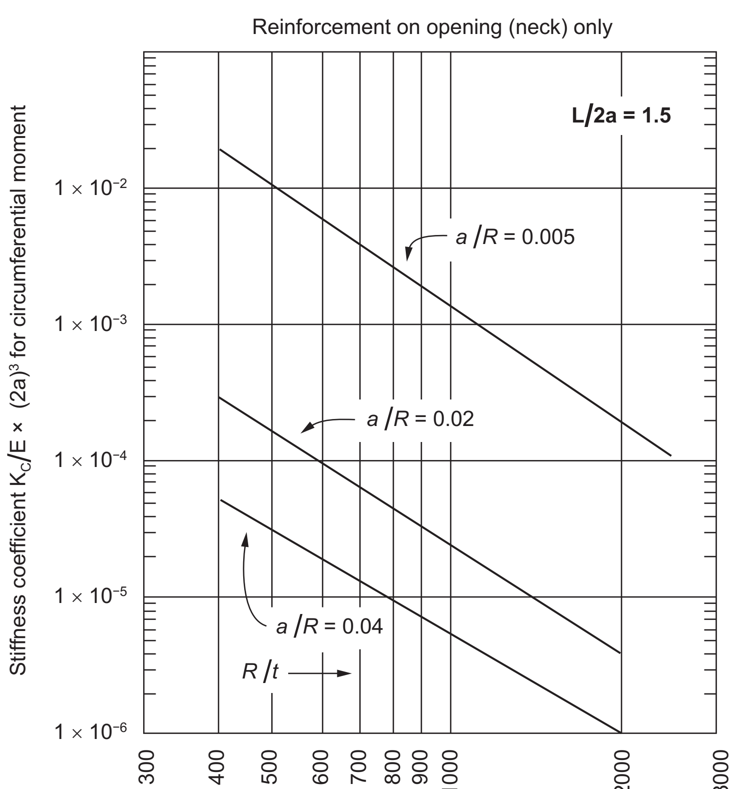

Figure P.2l—Stiffness Coefficient for Circumferential Moment: Reinforcement in Nozzle Neck Only (*L*/2*a* = 1.5)

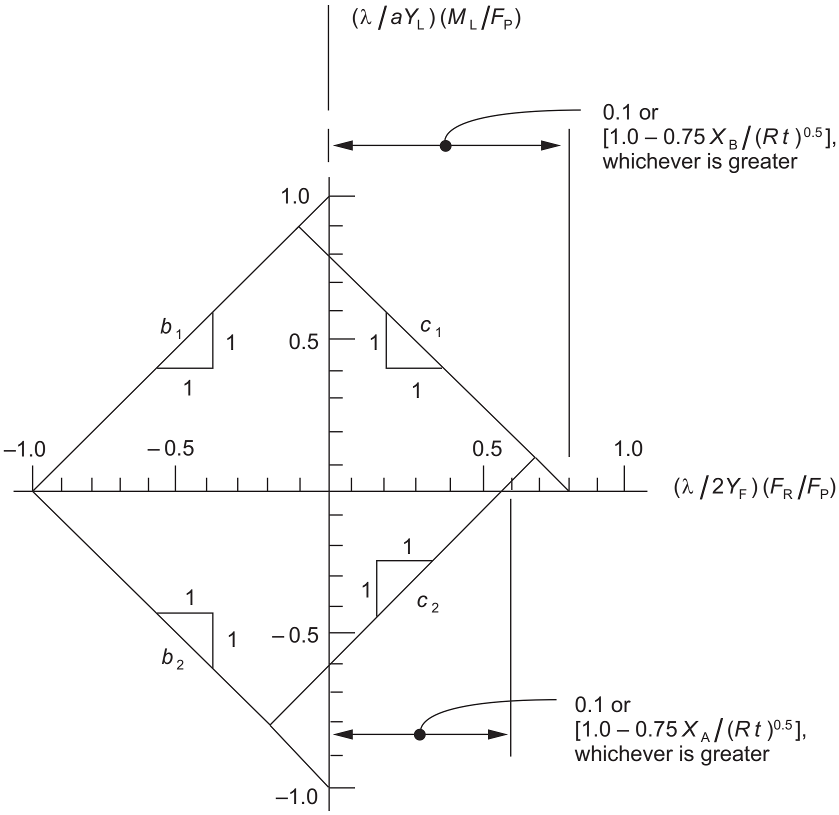

Figure P.3a—Construction of Nomogram for b_1, b_2, c_1, c_2 Boundary

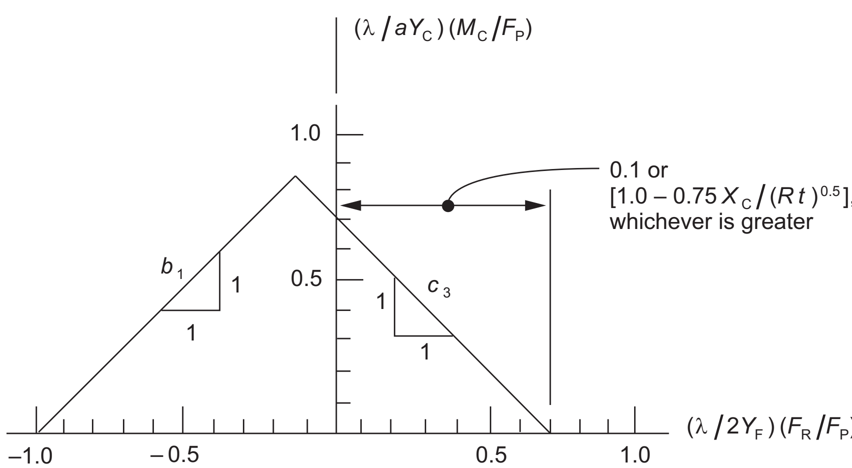

Figure P.3b—Construction of Nomogram for b_1, c_3 Boundary

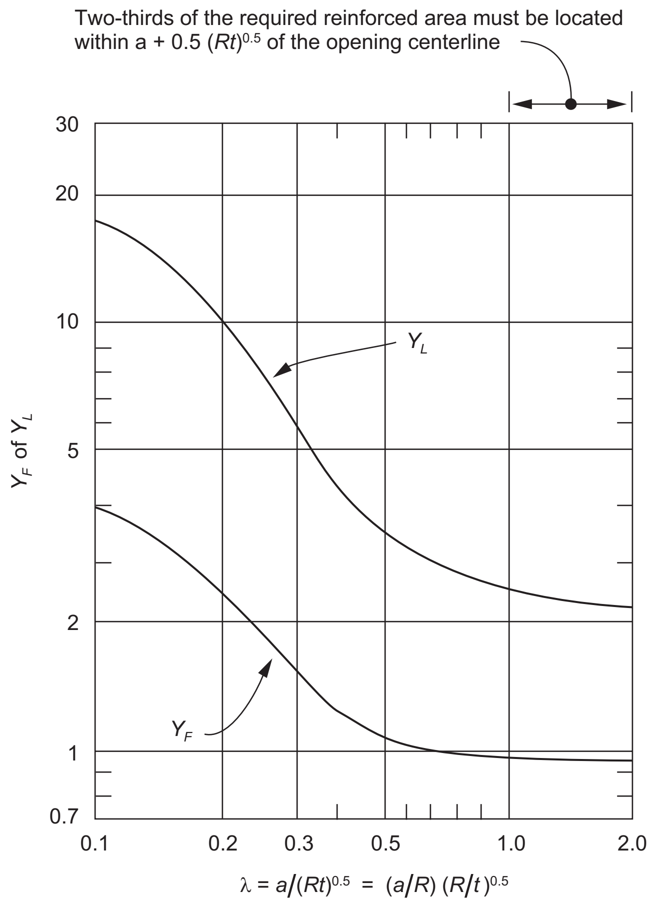

Figure P.4a—Obtaining Coefficients Y_F and Y_L

- **P.2.8.2** Changing the elevation of the opening and changing the thickness of the shell are alternative means of reducing stresses, but because these measures can affect fabrication, they may be considered only if mutually agreed upon by the Purchaser and the Manufacturer.

P.2.9 Sample Problem

P.2.9.1 Problem

A tank is 80 m (260 ft) in diameter and 19.2 m (64 ft) high, and its bottom shell course is 34 mm (1.33 in.) thick. The tank has a low-type nozzle with an outside diameter of 610 mm (24 in.) in accordance with API Standard 650, and the nozzle centerline is 630 mm (24.75 in.) up from the bottom plate, with reinforcement on the shell (see Figure P.6). Assume a specific gravity of 1.0 and a design temperature of 90 °C (200 °F). What are the end conditions (W, θ, K_R, K_L, and K_C) for an analysis of piping flexibility? What are the limit loads for the nozzle?

a = 305 mm (12 in.)

L = 630 mm (24.75 in.)

H = 19,200 mm (64 × 12 = 768 in.)

ΔT = 90 ° – 20 ° = 70 °C (200 ° – 70 ° = 130 °F)

R = 80,000/2 = 40,000 mm ((260 × 12)/2 = 1560 in.)

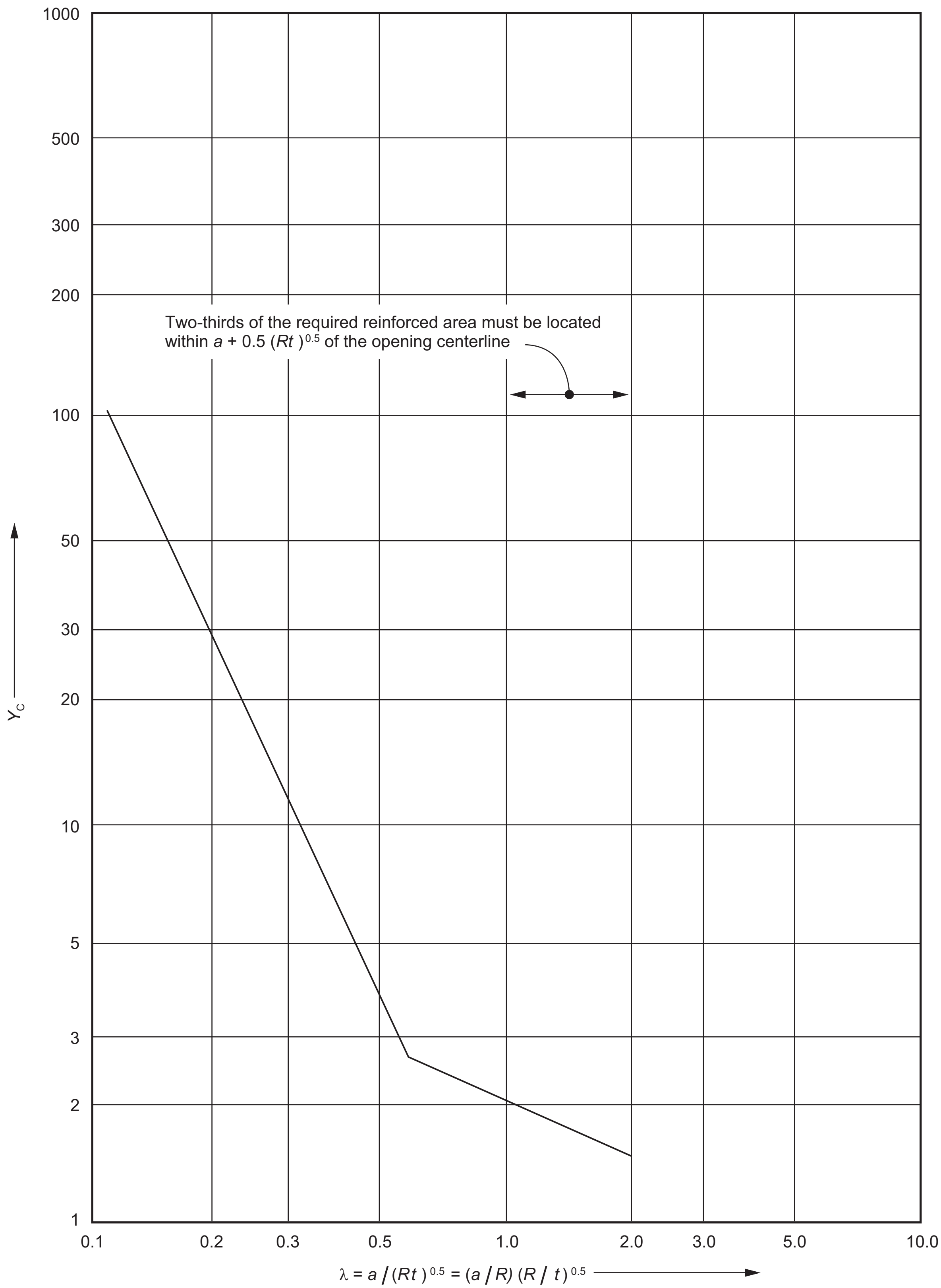

Figure P.4b—Obtaining Coefficient Y_C

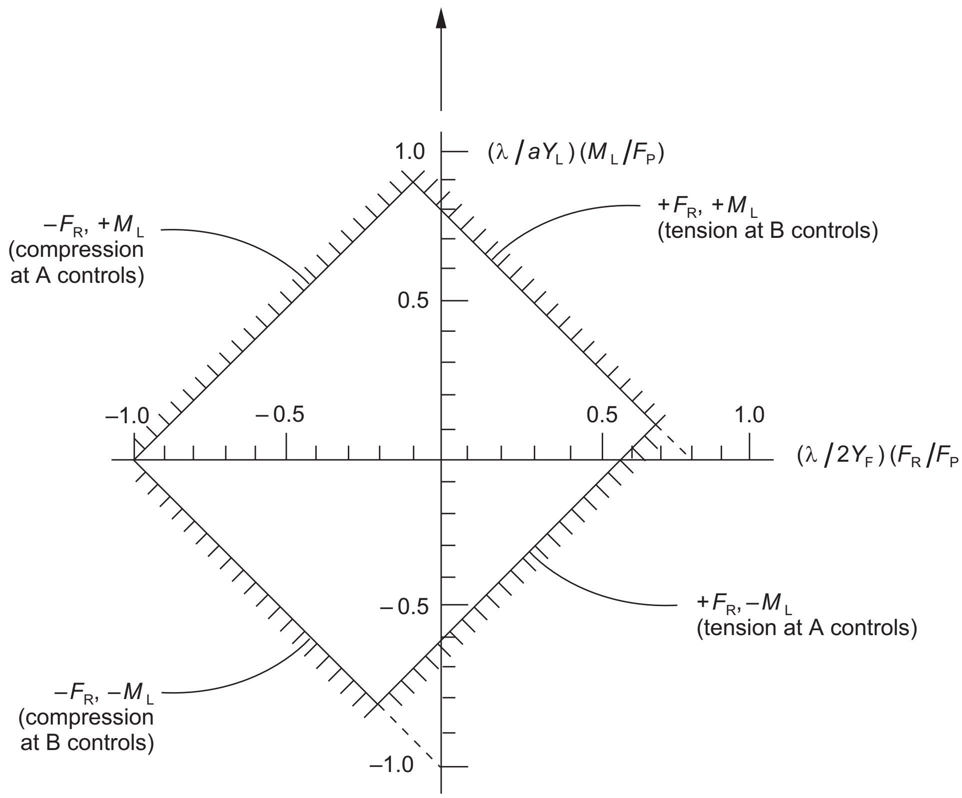

Figure P.5a—Determination of Allowable Loads from Nomogram: F_R and M_L

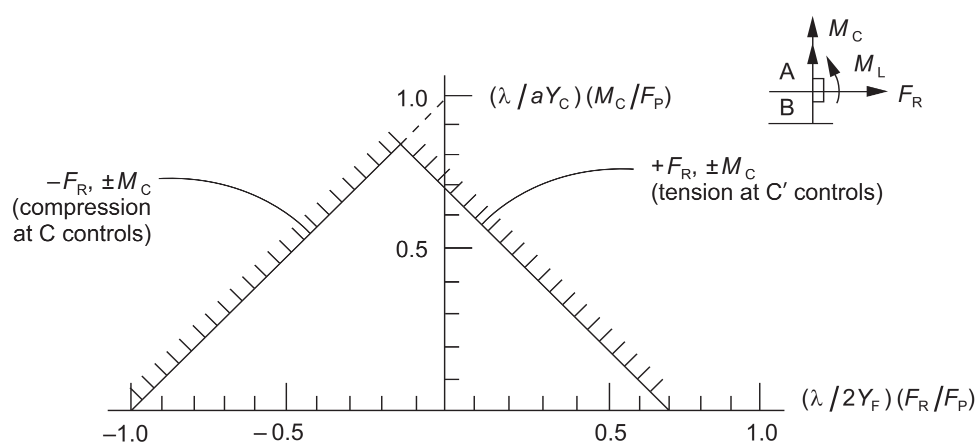

Figure P.5b—Determination of Allowable Loads from Nomogram: F_R and M_C

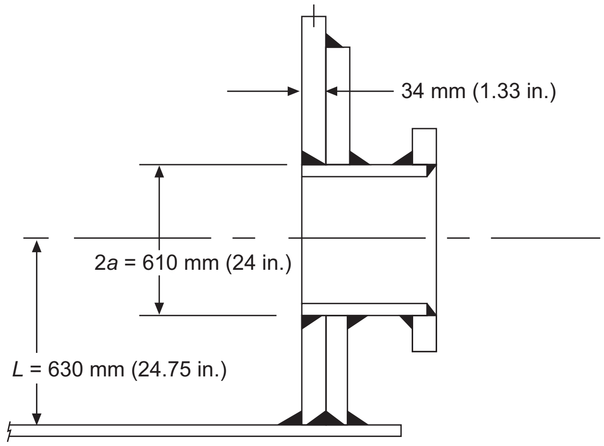

Figure P.6—Low-type Nozzle with Reinforcement on Shell

G = 1.0

t = 34 mm (1.33 in.)

P.2.9.2 Solution

P.2.9.2.1 Calculate the stiffness coefficients for the nozzle-tank connection:

R/t = 40,000/34 = 1176 (1560/1.33 = 1173)

a/R = 305/40,000 = 0.008 (12/1560 = 0.008)

$L/2a$ = 630/610 ≈ 1.0 (24.75/24 ≈ 1.0)

For the radial load (from Figure P.2a),

In SI units:

$$\frac{K_R}{E(2a)} = 3.1 \times 10^{-4}$$

$$K_R = (3.1 \times 10^{-4})(199{,}000 \text{ N/mm}^2)(610 \text{ mm})$$
$$= 3.76 \times 10^4 \text{ N/mm}$$

In USC units:

$$\frac{K_R}{E(2a)} = 3.1 \times 10^{-4}$$

$$K_R = (3.1 \times 10^{-4})(28.8 \times 10^6 \text{ lb/in.}^2)(24 \text{ in.})$$

$$= 2.14 \times 10^5 \text{ lbf/in.}$$

For the longitudinal moment (from Figure P.2b),

In SI units:

$$\frac{K_L}{E(2a)^3} = 4.4 \times 10^{-4}$$

$$K_L = (4.4 \times 10^{-4})(199{,}000\ \text{N/mm}^2)(610\ \text{mm})^3$$

$$= 2.0 \times 10^{10}\ \text{N-mm/rad}$$

In USC units:

$$\frac{K_L}{E(2a)^3} = 4.4 \times 10^{-4}$$

$$K_L = (4.4 \times 10^{-4})(28.8 \times 10^6)(24)^3$$

$$= 1.8 \times 10^8\ \text{in.-lb/rad}$$

For the circumferential moment (from Figure P.2C),

In SI units:

$$\frac{K_C}{E(2a)^3} = 9.4 \times 10^{-4}$$

$$K_C = (9.4 \times 10^{-4})(199{,}000\ \text{N/mm}^2)(610\ \text{mm})^3$$

$$= 4.2 \times 10^{10}\ \text{N-mm/rad}$$

In USC units:

$$\frac{K_C}{E(2a)^3} = 9.4 \times 10^{-4}$$

$$K_C = (9.4 \times 10^{-4})(28.8 \times 10^6)(24)^3$$

$$= 3.7 \times 10^8\ \text{in.-lb/rad}$$

P.2.9.2.2 Calculate the unrestrained shell deflection and rotation at the nozzle centerline resulting from the hydrostatic head of the full tank:

In SI units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(40{,}000 \times 34)^{0.5}} = 0.0011\ \text{mm}$$

$$\beta L = (0.00110)(630) = 0.7\ \text{rad}$$

$$W = \frac{9.8 \times 10^{-6} GHR^2}{Et}\left[1 - e^{-\beta L}\cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

$$= \frac{(9.8 \times 10^{-6})(1)(19{,}200)(40{,}000)^2}{(199{,}000)(34)}$$

$$\left[1-e^{-0.7}\cos(0.7)-\frac{630}{19{,}200}\right] + (12.0 \times 10^{-6})(40{,}000)(70)$$

$$= 59.77 \text{ mm}$$

$$\theta = \frac{9.8 \times 10^{-6} GHR^2}{Et}\left\{\frac{1}{H} - \beta e^{-\beta L}[\cos(\beta L) + \sin(\beta L)]\right\}$$

$$= \frac{(9.8 \times 10^{-6})(1)(19{,}200)(40{,}000)^2}{(199{,}000)(34)}$$

$$\left\{\frac{1}{19{,}200} - 0.0011 e^{-0.7}[\cos(0.7)+\sin(0.7)]\right\}$$

$$= -0.032 \text{ rad}$$

In USC units:

$$\beta = \frac{1.285}{(Rt)^{0.5}} = \frac{1.285}{(1560 \times 1.33)^{0.5}} = 0.0282 \text{ in.}$$

$$\beta L = (0.0282)(24.75) = 0.7 \text{ rad}$$

$$W = \frac{0.036 GHR^2}{Et}\left[1 - e^{-\beta L}\cos(\beta L) - \frac{L}{H}\right] + \alpha R \Delta T$$

$$= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)}\left[1 - e^{-0.7}\cos(0.7) - \frac{24.75}{768}\right]$$

$$+ (6.67 \times 10–6)(1560)(130)$$

$$= 2.39 \text{ in.}$$

$$\theta = \frac{0.036 GHR^2}{Et}\left\{\frac{1}{H} - \beta e^{-\beta L}[\cos(\beta L) + \sin(\beta L)]\right\}$$

$$= \frac{0.036(1)(768)(1560)^2}{(28.8 \times 10^6)(1.33)}\left\{\frac{1}{768} - 0.0282 e^{-0.7}[\cos(0.7)+\sin(0.7)]\right\}$$

$$= -0.032 \text{ rad}$$

Perform the analysis of piping flexibility using W, θ, K_R, K_L, and K_C as the end conditions at the nozzle-to-piping connection.

$$X_A = \text{L} + \text{a} = 935 \text{ mm } (36.75 \text{ in.})$$

X_B = L – a = 325 mm (12.75 in.)

X_C = L = 630 mm (24.75 in.)

Determine the allowable loads for the shell opening, as shown in P.9.2.3.

P.2.9.2.3 Determine the nondimensional quantity λ :

In SI units:

$$\frac{X_A}{(Rt)^{0.5}} = \frac{935}{[(40{,}000)(34)]^{0.5}} = 0.80$$

$$\frac{X_B}{(Rt)^{0.5}} = \frac{325}{[(40{,}000)(34)]^{0.5}} = 0.28$$

$$\frac{X_C}{(Rt)^{0.5}} = \frac{630}{[(40{,}000)(34)]^{0.5}} = 0.54$$

$$\lambda = \frac{a}{(Rt)^{0.5}} = \frac{305}{[(40{,}000)(34)]^{0.5}} = 0.26$$

In USC units:

$$\frac{X_A}{(Rt)^{0.5}} = \frac{36.75}{[(1560)(1.33)]^{0.5}} = 0.81$$

$$\frac{X_B}{(Rt)^{0.5}} = \frac{12.75}{[(1560)(1.33)]^{0.5}} = 0.28$$

$$\frac{X_C}{(Rt)^{0.5}} = \frac{24.75}{[(1560)(1.33)]^{0.5}} = 0.54$$

$$\lambda = \frac{a}{(Rt)^{0.5}} = \frac{12}{[(1560)(1.33)]^{0.5}} = 0.26$$

From Figure P.4a and Figure P.4b,

Y_F = 1.9/N (1.9/lbf)

Y_L = 7.8/N-mm (7.8/in.-lbf)

Y_C = 17.3/N-mm (17.3/in.-lbf)

P.2.9.2.4 Construct the load nomograms (see Figure P.7):

In SI units:

$$1.0 - 0.75\frac{X_B}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{325}{1166}\right) = 0.79$$

$$1.0 - 0.75\frac{X_A}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{935}{1166}\right) = 0.40$$

$$1.0 - 0.75\frac{X_C}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{630}{1166}\right) = 0.59$$

$$F_P = P\pi a^2 = (9800)(1.0)(19.2 - 0.630)\pi(0.305)^2$$

= 53,200 N

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = \frac{0.26}{(2)(1.9)}\left(\frac{F_R}{53{,}200}\right) = 1.29 \times 10^{-6}F_R$$

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = \frac{0.26}{(305)(7.8)}\left(\frac{M_L}{53{,}200}\right) = 2.05 \times 10^{-9}M_L$$

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = \frac{0.26}{(305)(17.3)}\left(\frac{M_C}{53{,}200}\right) = 9.26 \times 10^{-10}M_C$$

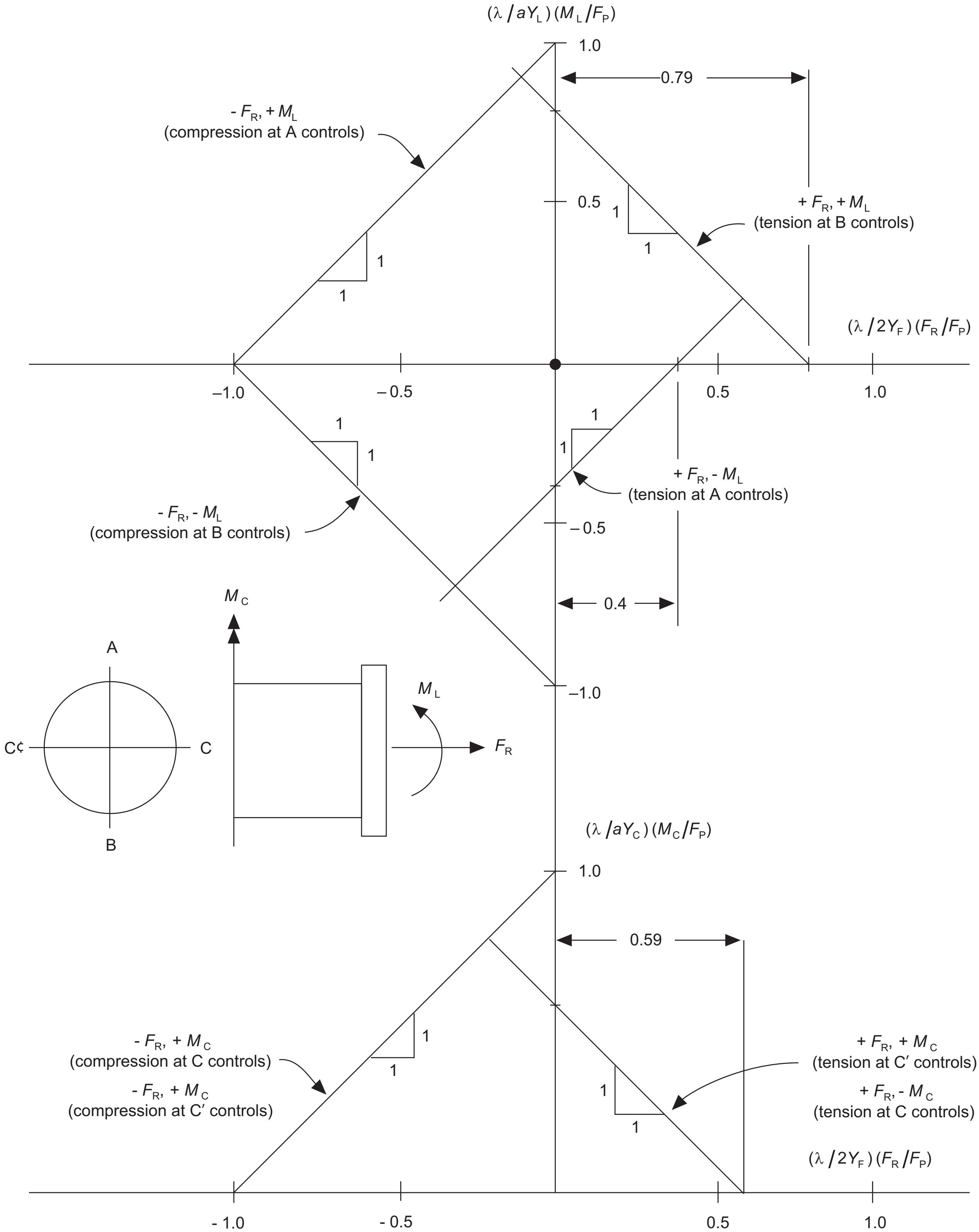

Figure P.7—Allowable-load Nomograms for Sample Problem

In USC units:

$$1.0 - 0.75\frac{X_B}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{12.75}{45.6}\right) = 0.79$$

$$1.0 - 0.75\frac{X_A}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{36.75}{45.6}\right) = 0.40$$

$$1.0 - 0.75\frac{X_C}{(Rt)^{0.5}} = 1.0 - 0.75\left(\frac{24.75}{45.6}\right) = 0.59$$

$$F_P = P\pi a^2 = \left[\frac{(62.4)(1.0)}{1728}\right][(64)(12) - 24.75]\pi 12^2$$

= 12,142 pounds

$$\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = \frac{0.26}{(2)(1.9)}\left(\frac{F_R}{12{,}142}\right) = 5.64 \times 10^{-6} F_R$$

$$\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = \frac{0.26}{(12)(7.8)}\left(\frac{M_L}{12{,}142}\right) = 2.29 \times 10^{-7} M_L$$

$$\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = \frac{0.26}{(12)(17.3)}\left(\frac{M_C}{12{,}142}\right) = 1.03 \times 10^{-7} M_C$$

P.2.9.2.5 Determine the limiting piping loads.

In SI units:

For M_L = 0 and M_C = 0,

For F_R, $\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = 1.29 \times 10^{-6} F_R \le 0.4$

Therefore,

$$F_{R\max} = \frac{0.4}{1.29 \times 10^{-6}}$$ = 310,000 N (tension at A controls)

For M_L = 0 and F_R = 0,

For M_C, $\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = 9.26 \times 10^{-10} M_C \le 0.59$

Therefore,

$$M_{C\max} = \frac{0.59}{9.26 \times 10^{-10}} = 6.37 \times 10^8 \text{ N-mm (tension at C′ controls)}$$

For F_R = 0 and M_C = 0,

For M_L, $\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = 2.05 \times 10^{-9} M_L \le 0.4$

Therefore,

$$FR_{MAX} = \frac{0.4}{2.05 \times 10^{-9}} = 1.95 \times 10^8 \text{ N-mm (tension at A controls)}$$

In USC units:

For M_L = 0 and M_C = 0,

For F_R, $\frac{\lambda}{2Y_F}\left(\frac{F_R}{F_P}\right) = 5.64 \times 10^{-6} F_R \le 0.4$

Therefore,

$$F_{RMAX} = \frac{0.4}{5.64 \times 10^{-6}} = 70{,}900 \text{ lbf (tension at A controls)}$$

For M_L = 0 and F_R = 0,

For M_C, $\frac{\lambda}{aY_C}\left(\frac{M_C}{F_P}\right) = 1.03 \times 10^{-7} M_C \le 0.59$

Therefore,

$$M_{C\max} = \frac{0.59}{1.03 \times 10^{-7}} = 5.73 \times 10^6 \text{ in.-lbf (tension at C′ controls)}$$

For F_R = 0 and M_C = 0,

For M_L, $\frac{\lambda}{aY_L}\left(\frac{M_L}{F_P}\right) = 2.29 \times 10^{-7} M_L \le 0.4$

Therefore,

$$M_{L\max} = \frac{0.4}{2.29 \times 10^{-7}} = 1.75 \times 10^6 \text{ in.-lbf (tension at A controls)}$$

P.2.9.3 Summary

The limiting piping loads are as follows:

In SI units:

$F_{R\max}$ = 310,000 N (tension at A controls)

$M_{C\max}$ = 6.37×10^8 N-mm (tension at C′ controls)

$M_{L\max}$ = 1.95×10^8 N-mm (tension at A controls)

In USC units:

$F_{R\max}$ = 70,900 lbf (tension at A controls)

$M_{C\max}$ = 5.73×10^6 in.-lbf (tension at C′ controls)

$M_{L\max}$ = 1.75×10^6 in.-lbf (tension at A controls)

P.3 Alternative Procedure for the Evaluation of External Loads on Tank Shell Openings

P.3.1 Scope

P.3.1.1 This section provides guidelines for the use of alternative methods in determining local stresses in nozzles and cylindrical shells from external loads. Localized stresses at nozzle locations in shells shall be evaluated using one of the methods listed below. For each method, the acceptance criteria shall be in accordance with P.3.3.

a) Stress calculations shall be in accordance with WRC 297 or ASME Section VIII Division 2, or

b) Stress calculations shall be performed using a numerical analysis such as the finite element analysis (FEA).

P.3.1.2 The guidelines of this section regarding FEA, only apply to analysis utilizing shell elements. The use of solid continuum elements requires different analysis procedures including stress linearization of the results and is beyond the scope of this section.

P.3.1.3 The guidelines of this section do not address all details of good FEA modeling practice. In addition to the subjects addressed, selection of element type, element size, aspect ratio, and application of boundary conditions and loadings, for example, can have a significant effect on the results. Skill and experience on the part of the engineer are necessary.

P.3.2 Parameters

For comparative analysis, modeling shall utilize the following parameters.

P.3.2.1 Any reinforcing plate shape that meets the requirements of this Standard is acceptable. Using a thickened insert plate is considered equivalent to using two separate plates, shell plus reinforcing plate.

P.3.2.2 Welds do not need to be modeled.

P.3.2.3 Loads are applied at end of the nozzle. Evaluate the perimeter surface and membrane stresses at a distance that is 1.50 times the thickness being considered away from the junction. In addition, local primary membrane stress shall be evaluated at a distance $1.0(RT)^{0.5}$ from the discontinuity.

P.3.2.4 Load cases shall include product and hydrostatic conditions at design liquid level (H). Loads on nozzles resulting from thermal movement of the tank shall be considered.

P.3.2.5 Use Figure P.1 sign convention ("right-hand rule"). Loads are mechanical and all loads shall be taken simultaneously. Minimum load combinations are:

a) $+F_R+M_C+M_L$

b) $-F_R+M_C+M_L$

P.3.2.6 FEA will frequently show the neck is overstressed due to product loading alone, however, the stress is self-limiting and neck strains can be shown to be low. Neck stresses need not be analyzed.

P.3.2.7 Bottom of shell plate shall be considered radially fixed and shall be free to rotate.

P.3.2.8 Thermal stress in the shell need not be included in this analysis.

P.3.2.9 Tank size is a non-essential variable. Therefore the entire tank does not need to be modeled.

P.3.3 Allowable Stress Limits

P.3.3.1 For membrane stress, limit stress to 1.5(S_d). Local primary membrane stress, including primary bending, shall be limited to 1.1(S_d).

P.3.3.2 For surface stress, limit stress to the greater of 2(F_y) and 3(S_d), but shall not exceed the tensile (ultimate) strength.