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OAK RIDGE NATIONAL LABORATORY

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FOREWORD

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Prior reports and open-literature publications in this series are:

1. W. L. Greenstreet, S. E. Moore, and E. C. Rodabaugh, "Investigations of Piping Components, Valves, and Pumps to Provide Information for Code Writing Bodies," ASME Paper 68-WA/PTC-6, American Society of Mechanical Engineers, New York, Dec. 2, 1968.

2. W. L. Greenstreet, S. E. Moore, and R. C. Gwaltney, *Progress Report on Studies in Applied Solid Mechanics*, ORNL-TM-4576 (August 1970).

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1. INTRODUCTION

Purpose and Scope

The *ASME Boiler and Pressure Vessel Code*[1] gives rules for designing bolted flange connections with ring-type gaskets based on a stress analysis developed by Waters et al.[2] These rules give formulas and graphs for calculating stresses due to a moment applied to the flange ring. The Code rules, however, do not require that stresses due to internal pressure be taken into account, although Ref. 2 briefly discusses such stresses.

The computer program FLANGE was written to calculate not only the stresses due to moment loads on the flange ring but also stresses due to internal pressure; stresses due to a temperature difference between the hub and ring; and stresses due to the variations in bolt load that result from pressure, hub-ring temperature gradient, and/or bolt-ring temperature difference. The program FLANGE is applicable to tapered-hub, straight, and blind flanges. The analysis method is based on the differential equations for thin plates and shells rather than on the strain-energy method used by Waters et al.[2] The stresses due to moment loading calculated by the two methods are essentially identical for identical boundary conditions. The analysis provided herein also includes a different, and perhaps more realistic, set of boundary conditions than those used in Ref. 2.

The nomenclature used in this report is identified in the remainder of this chapter. In Chapter 2 a description of the general model of flanges used in the theoretical development of the computer code is provided. The actual mathematical expressions for calculating stresses and displacements due to moment and pressure loads are derived in Chapters 3, 4, and 5 for tapered-hub, straight hub, and blind flanges, respectively. In Chapters 6 and 7, these expressions are extended to include the effects of thermal gradients and variations in bolt loads. The computer program FLANGE is described in the last chapter of this report. Example calculations, listings, and flowcharts of the program and its subroutines are included as appendices.

Nomenclature

a = outside radius of ring
$A = 2a$ = outside diameter of ring
A_b = cross-sectional bolt area
A_g = gasket area
b = inside radius of ring and mean radius of pipe
$B = 2b$ = inside diameter of ring
b_n = Bessel function of η
c = bolt-circle radius
$C = 2c$ = bolt-circle diameter
C_i = constant of integration
$C_i' = C_i/b$
$D = Et^3/12(1 - \nu^2)$
D_{ij} = constants of integration (blind-flange analysis)
$E = E_f$ = modulus of elasticity of flange material
E_b = modulus of elasticity of bolt material
E_g = modulus of elasticity of gasket material
f = ASME Code design parameter
F = ASME Code design parameter
g_0 = wall thickness of pipe
g_1 = wall thickness of hub at intersection with ring
g = gasket centerline radius
$G = 2g$ = gasket centerline diameter
h = length of tapered-wall hub
$K = a/b = A/B$
ℓ_0 = bolt length
M = total moment applied to ring, in.-lb
M_i or M_{ij} = moment resultants, in.-lb/in.
p = internal pressure
P_i = shear resultants, lb/in.
$p^* = \dfrac{[1 - (\nu/2)]bp}{g_0E}$ = nondimensional pressure parameter
r = radial coordinate, ring

t = ring thickness

t_x = hub thickness

u = radial displacement, hub

u_1 = radial displacement, pipe

u_r = radial displacement, ring

V = ASME Code design parameter

v_0 = undeformed gasket thickness

w = axial displacement, ring

W_1 = initial bolt load, lb

W_2 = residual bolt load, lb

x = axial coordinate, hub

x_1 = axial coordinate, pipe

$\alpha = (g_1 - g_0)/g_0 = \rho - 1$ = nondimensional wall-thickness parameter

$\beta = [3(1 - \nu^2)/b^2g_0^2]^{1/4}$ = dimensional parameter used in the analysis

$\gamma = [12(1 - \nu^2)/b^2g_0^2]^{1/4}(h)$ = dimensional parameter used in the analysis

Δ = temperature difference between hub/pipe and ring

δ_i = axial displacement of ring

ε_f = coefficient of thermal expansion, flange material

ε_b = coefficient of thermal expansion, bolt material

ε_g = coefficient of thermal expansion, gasket material

$\eta = 2\gamma(\psi/\alpha)^{1/2}$ = nondimensional argument of the modified Bessel functions

ν = Poisson's ratio (0.3 used herein)

$\xi = x/h$ = nondimensional distance parameter

$\rho = g_1/g_0$ = nondimensional wall-thickness parameter

σ = stress, with subscripts:

- ℓ = longitudinal (pipe or hub)
- c = circumferential (pipe or hub)
- t = tangential (ring)
- r = radial (ring)
- b = bending
- m = membrane
- o = outside surface of the pipe or hub on the hub side of ring
- i = inside surface of the pipe or hub on the gasket-face side of ring

$\psi = \xi + (1/\alpha)$ = nondimensional parameter

2. GENERAL DESCRIPTION OF THE ANALYSIS

The model used for the analysis of tapered-hub flanges is shown in Fig. 1. The three parts involved are the pipe, hub, and ring, respectively. The analysis presented here is based on the theory of thin plates and shells. The pipe is considered to be a uniform-wall-thickness cylindrical shell with midsurface radius b. The hub is considered to be a linearly variable-wall-thickness cylindrical shell with midsurface radius b. The ring is considered to be a flat annular plate with constant thickness t, inside radius b, and outside radius a. The effects of the bolt holes are neglected.

Three different types of loadings on bolted flanges are considered:

1. Bolt load, represented by W in Fig. 1. In application, the moment M applied to the flange ring is converted into an equivalent bolt load by the relationship $W(a - b) = M$. This is the same approach used in the ASME Code calculation method.[1]

2. Internal pressure, acting radially on the pipe, hub, and ring and axially on an (assumed remote) end closure on the pipe.

3. A temperature difference between the pipe and the ring. The pipe and the hub are assumed to be at the same uniform temperature. The ring is also assumed to be at a uniform temperature, which may be different from that of the pipe or hub.

Upon integration of the shell and plate differential equations, algebraic equations in terms of dimensions, materials properties and loadings, and 12 integration constants are obtained, 4 for each part. These constants are evaluated by the usual discontinuity analysis method of writing continuity equations at the junctures of the parts and at the boundaries. After numerical values are determined for the constants, the algebraic equations provide the means for computing the stresses and deflections. In the development of the equations for stresses, the assumption is made that the bolt load W does not change with pressure or temperature. Later the analysis is modified to include changes in W as a function of these loadings. Because the relations are linear, it is possible to determine the stresses (or stress range) due to combinations

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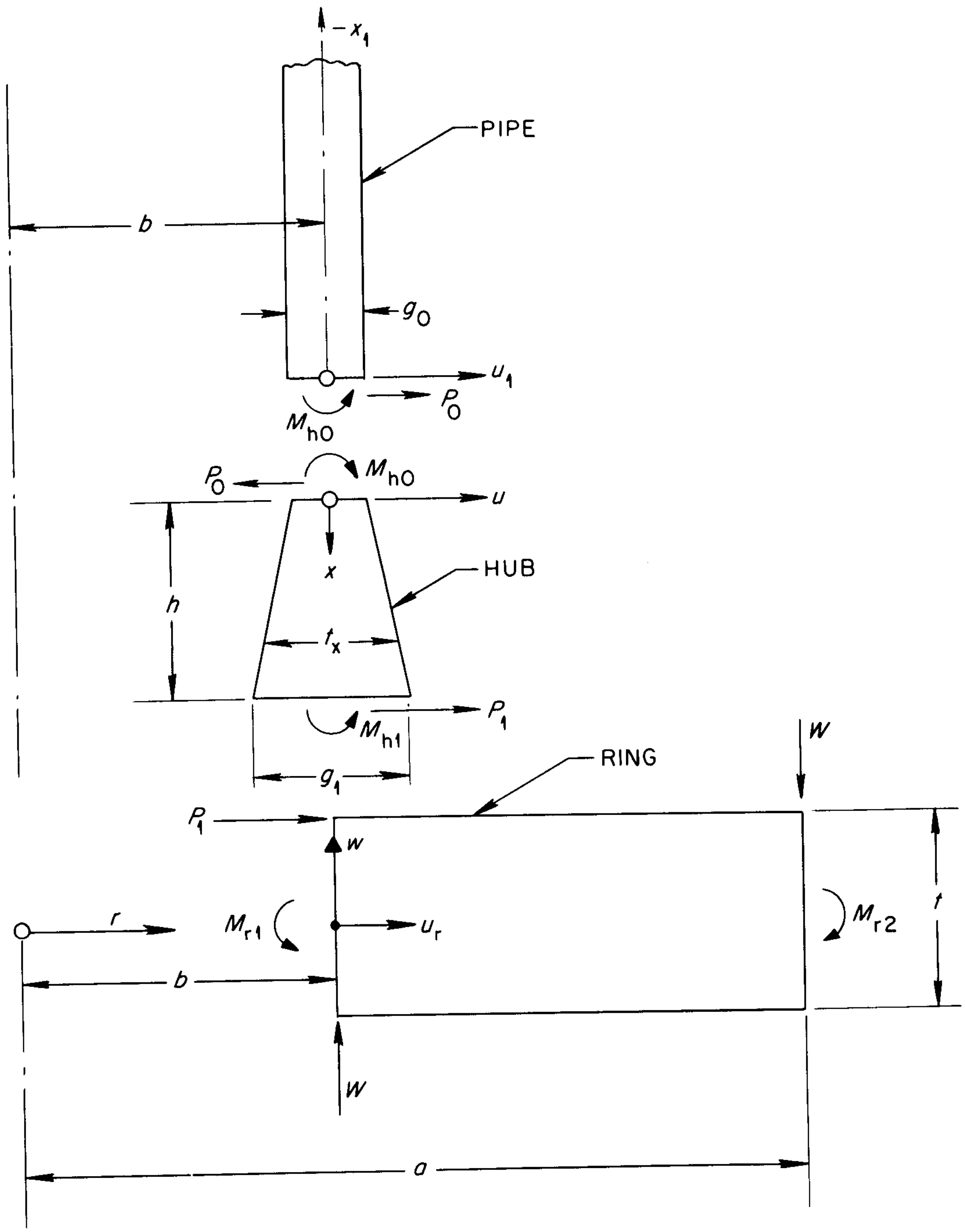

Fig. 1. Analysis model of a tapered-hub flange.

of initial bolt loading, pressure, and temperature change. The model used for straight-hub flanges is a simplification of the tapered-hub case in that only two parts are involved, the pipe and the ring.

In common with all shell-type analyses, the analysis gives anomalous results at points of abrupt thickness change or meridional direction change. In particular, the stresses at the juncture of the hub to the ring represent only the gross loading effect; detailed local stresses are not determined by the theory. Displacements, however, are represented fairly accurately.

3. FLANGE WITH A TAPERED-WALL HUB

The first step in deriving the stress equations is to state the basic shell/plate equations for the ring, the hub, and the pipe. We then inspect the boundary conditions, compute the constants, and calculate the stresses and displacements.

Equations for the Annular Ring

The basic differential equation for the displacement w of a circular plate given by Timoshenko[3] is

$$\frac{1}{r}\frac{d}{dr}\left\{r\frac{d}{dr}\left[\frac{1}{r}\frac{d}{dr}\left(r\frac{dw}{dr}\right)\right]\right\} = \frac{q}{D} , \tag{1}$$

where the coordinate r and displacement w are illustrated in Fig. 1 and q = a uniformly distributed lateral load on the plate, $D = Et^3/12(1 - \nu^2)$ = the flexural rigidity of the plate, E = modulus of elasticity of the flange material, t = plate thickness, and ν = Poisson's ratio. Equation (1) can be integrated to give a relation for the displacement in terms of arbitrary constants:

$$w = C_7 r^2 \ln r + C_8 r^2 + C_9 \ln r + C_{10} + \frac{r^4 q}{64D} , \tag{2}$$

where numerical values for the constants $C_7, \ldots, C_{10}$ are established from boundary conditions. Derivatives of w, required in the subsequent analysis, are:

$$\frac{dw}{dr} = C_7(2r \ln r + r) + 2C_8 r + \frac{C_9}{r} + \frac{r^3 q}{16D} , \tag{3}$$

$$\frac{d^2w}{dr^2} = C_7(2 \ln r + 3) + 2C_8 - \frac{C_9}{r^2} + \frac{3r^2 q}{16D} , \tag{4}$$

and

$$\frac{d^3w}{dr^3} = C_7\left(\frac{2}{r}\right) + \frac{2C_9}{r^3} + \frac{3rq}{8D} . \qquad (5)$$

In the subsequent analysis the distributed load q is taken as zero.

The radial and tangential moments are given[3] by the equations:

$$M_r = -D\left(\frac{d^2w}{dr^2} + \frac{\nu}{r}\frac{dw}{dr}\right) \qquad (6)$$

and

$$M_t = -D\left(\frac{1}{r}\frac{dw}{dr} + \nu\frac{d^2w}{dr^2}\right) . \qquad (7)$$

Using Eqs. (3) and (4), these moments can be expressed as

$$M_r = -D\left\{C_7[2(1 + \nu)\ \ell n\ r + (3 + \nu)] + C_8[2(1 + \nu)] - C_9\left(\frac{1 - \nu}{r^2}\right)\right\} \qquad (8)$$

and

$$M_t = -D\left\{C_7[2(1 + \nu)\ \ell n\ r + (1 + 3\nu)] + C_8[2(1 + \nu)] + C_9\left(\frac{1 - \nu}{r^2}\right)\right\} . \qquad (9)$$

Equations for the Tapered Hub

The basic differential equation for the radial displacement u of a cylindrical shell with a linearly variable wall thickness t_x is given by Timoshenko[3] as

$$\frac{d^2}{dx^2}\left(t_x^3 \frac{d^2u}{dx^2}\right) + \frac{12(1 - \nu^2)t_x u}{b^2} - \frac{12(1 - \nu^2)[1 - (\nu/2)]p}{E} = 0 \ . \tag{10}$$

The solution of Eq. (10) can be shown* to be:

$$u = \frac{b}{\psi^{1/2}} (C_1 b_1 + C_2 b_2 + C_3 b_3 + C_4 b_4) + \frac{bP^*}{1 + \alpha\xi} \ , \tag{11}$$

where $P^* = [1 - (\nu/2)]bp/g_0E$. Derivatives of u, required in the subsequent analysis, are

$$u' = \frac{du}{dx} = \frac{b}{2\psi^{3/2}h} (C_1 b_5 + C_2 b_6 + C_3 b_7 + C_4 b_8) - \frac{b\alpha P^*}{h(1 + \alpha\xi)^2} \ , \tag{12}$$

$$u'' = \frac{d^2u}{dx^2} = \frac{b}{4\psi^{5/2}h^2} (C_1 b_9 + C_2 b_{10} + C_3 b_{11} + C_4 b_{12}) + \frac{2b\alpha^2 P^*}{h^2(1 + \alpha\xi)^3} \ , \tag{13}$$

and

$$u''' = \frac{d^3u}{dx^3} = \frac{b}{8\psi^{7/2}h^3} (C_1 b_{13} + C_2 b_{14} + C_3 b_{15} + C_4 b_{16}) - \frac{6r\alpha^2 P^*}{h^3(1 + \alpha\xi)^4} \ . \tag{14}$$

The b_n's used in Eqs. (11) through (14) are modified Bessel functions of argument $\eta = 2\gamma(\psi/\alpha)^{1/2}$ defined in Table 1, which gives equations for n = 1 through 20; ψ, α, and ξ are defined in the nomenclature.

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*A solution to an equation that is essentially the same as Eq. (10) is given by Timoshenko,[3] who credits the original solution to G. Kirchoff in 1879.

Table 1. Modified Bessel functions of argument η[a]

b_1	$= \text{ber}' \eta$
b_2	$= \text{bei}' \eta$
b_3	$= \text{ker}' \eta$
b_4	$= \text{kei}' \eta$
b_5	$= -\eta \text{ bei } \eta - 2 \text{ ber}' \eta$
b_6	$= \eta \text{ ber } \eta - 2 \text{ bei}' \eta$
b_7	$= -\eta \text{ kei } \eta - 2 \text{ ker}' \eta$
b_8	$= \eta \text{ ker } \eta - 2 \text{ kei}' \eta$
b_9	$= 4\eta \text{ bei } \eta + 8 \text{ ber}' \eta - \eta^2 \text{ bei}' \eta$
b_{10}	$= -4\eta \text{ ber } \eta + 8 \text{ bei}' \eta + \eta^2 \text{ ber}' \eta$
b_{11}	$= 4\eta \text{ kei } \eta + 8 \text{ ker}' \eta - \eta^2 \text{ kei}' \eta$
b_{12}	$= -4\eta \text{ ker } \eta + 8 \text{ kei}' \eta + \eta^2 \text{ ker}' \eta$
b_{13}	$= -\eta^3 \text{ ber } \eta - 24\eta \text{ bei } \eta - 48 \text{ ber}' \eta + 8\eta^2 \text{ bei}' \eta$
b_{14}	$= -\eta^3 \text{ bei } \eta + 24\eta \text{ ber } \eta - 48 \text{ bei}' \eta - 8\eta^2 \text{ ber}' \eta$
b_{15}	$= -\eta^3 \text{ ker } \eta - 24\eta \text{ kei } \eta - 48 \text{ ker}' \eta + 8\eta^2 \text{ kei}' \eta$
b_{16}	$= -\eta^3 \text{ kei } \eta + 24\eta \text{ ker } \eta - 48 \text{ kei}' \eta - 8\eta^2 \text{ ker}' \eta$
b_{17}	$= -\eta \text{ ber } \eta + 2 \text{ bei}' \eta$
b_{18}	$= -\eta \text{ bei } \eta - 2 \text{ ber}' \eta$
b_{19}	$= -\eta \text{ ker } \eta + 2 \text{ kei}' \eta$
b_{20}	$= -\eta \text{ kei } \eta - 2 \text{ ker}' \eta$

[a]The argument $\eta = 2\gamma(\psi/\alpha)^{1/2}$, where $\gamma = [12(1 - \nu^2)/b^2 g_0{}^2]^{1/4}(h)$, $\psi = \xi + (1/\alpha)$, $\xi = x/h$, and $\alpha = (g_1 - g_0)/g_0$.

Equations for the Pipe

The basic differential equation for the radial displacement u_1 of a cylindrical shell with uniform wall thickness is:

$$g_0^3 \frac{d^4 u_1}{dx_1^4} + \frac{12(1 - \nu^2)g_0}{b^2} u_1 - \frac{12(1 - \nu^2)[1 - (\nu/2)]p}{E} = 0 . \qquad (15)$$

The solution of Eq. (15) is:

$$u_1 = e^{-\beta x_1} (C_{11} \sin \beta x_1 + C_{12} \cos \beta x_1)$$

$$+ e^{\beta x_1} (C_5 \sin \beta x_1 + C_6 \cos \beta x_1) + bP^* . \qquad (16)$$

For large negative values of x_1, $u_1 = bP^*$. Hence, $C_{11} = C_{12} = 0$. Derivatives of u_1 needed in the subsequent analysis are

$$u_1' = \frac{du_1}{dx_1} = \beta e^{\beta x_1} [C_5 (\sin \beta x_1 + \cos \beta x_1)$$

$$+ C_6 (\cos \beta x_1 - \sin \beta x_1)] , \qquad (17)$$

$$u_1'' = \frac{d^2 u_1}{dx_1^2} = 2\beta^2 e^{\beta x_1} [C_5 \cos \beta x_1 - C_6 \sin \beta x_1] , \qquad (18)$$

and

$$u_1''' = \frac{d^3 u_1}{dx_1^3} = -2\beta^3 e^{\beta x_1} [C_5 (\sin \beta x_1 - \cos \beta x_1)$$

$$+ C_6 (\sin \beta x_1 + \cos \beta x_1)] . \qquad (19)$$

Boundary Conditions

The equations listed above involve ten unknown constants: C_1, C_2, ..., C_{10}. These can be determined from the ten boundary-condition equations shown in Table 2 [Eq. (20)]. The ASME Code stress-calculation method[1] is based on the assumption that the radial displacement at the hub-to-ring juncture is zero. A more realistic assumption (particularly for internal pressure loading) is that the displacement of the hub equals the displacement of the surface of the ring where it joins the hub. Boundary-condition equations for both of these alternatives are provided in Table 2. [See Eqs. (20-5).] In Eq. (20-5b) a positive dw/dr gives a negative radial displacement at the surface of the ring adjacent to the hub. Also in Eq. (20-5b), u_r is the radial expansion of the ring due to internal pressure as given by Lame's equation:

$$u_r = \frac{b}{E}\left[\frac{(1+\nu)k^2 + (1-\nu)}{k^2 - 1}\right]\left(p - \frac{P_1}{t}\right) , \tag{21}$$

where $k = a/b$. In this expression, it is assumed that in addition to internal pressure p, the shear resultant P_1 is uniformly distributed around the inner edge of the ring.

Boundary Equations

When the equations in Table 2 are satisfied simultaneously, they establish the values of the ten constants (C_1, C_2, ..., C_{10}) in terms of the dimensions, Poisson's ratio, and the loads (total bolt load W and internal pressure p). After algebraic manipulation, the equations are reduced to the forms shown in Table 3. This table provides the elements for the matrix equation $[A]|C| + |B| = 0$, where the terms in the coefficient matrix [A] are given under the headings of the corresponding constants in the column matrix $|C|$. The loading parameters constitute the column matrix $|B|$.

To derive numerical values for the constants, three items should be noted.

1. It is convenient to define two new constants, $C_5' = C_5/b$ and $C_6' = C_6/b$.
2. The radial expansion of the ring u_r is defined in Eq. (21).

Table 2. Equations for the boundary conditions for a tapered-hub flange

	Hub-to-pipe juncture		Hub-to-ring juncture		Ring	
	Equation	Eq. No.	Equation	Eq. No.	Equation	Eq. No.
Displacements[a]	$(u)_{x=0} = (u_1)_{x_1=0}$	(20-1)	$\begin{cases} (u)_{x=h} = 0 \\ (u)_{x=h} = \left(u_r - \frac{t}{2}\frac{dw}{dr}\right)_{r=b} \end{cases}$	(20-5a) (20-5b)	$(w)_{r=b} = 0$ (Footnote *b*)	(20-8)
Rotations	$(u')_{x=0} = (u_1')_{x_1=0}$	(20-2)	$(u')_{x=h} = \left(\frac{dw}{dr}\right)_{r=b}$	(20-6)		
Moments[c]	$(u'')_{x=0} = (u_1'')_{x_1=0}$	(20-3)	$M_{h1} = -M_{r1} + \frac{1}{2} P_1 t$ (Footnote *d*)	(20-7)	$M_{r2} = 0$	(20-9)
Shears	$\left(\frac{3\alpha}{h} u'' + u'''\right)_{x=0} = (u_1''')_{x_1=0}$	(20-4)			$Q = -\frac{dM_r}{dr} + \frac{M_t - M_r}{r} = \frac{W}{2\pi r}$	(20-10)

[a] Radial for hub-to-pipe and hub-to-ring junctures and axial for the ring.
[b] Setting $(w)_{r=b}$ equal to zero provides a reference point for all other axial displacements.
[c] Radial for ring.
[d] The assumption is that the shear P_1 of the hub on the ring produces an additional moment on the ring.

Table 3. Matrix coefficients of the discontinuity equations[a] for a flange with a tapered-wall hub

Eq. No.	C_1	C_2	C_3	C_4	C'_5	C'_6	C_7	C_8	C_9	C_{10}	Loading parameters
(20-1)[b]	b_1^0	b_2^0	b_3^0	b_4^0	0	$-\psi_0^{1/2}$	0	0	0	0	0
(20-2)	b_5^0	b_6^0	b_7^0	b_8^0	$-\frac{\eta_0\psi_0^{1/2}}{\sqrt{2}}$	$-\frac{\eta_0\psi_0^{1/2}}{\sqrt{2}}$	0	0	0	0	$-2\psi_0^{1/2}p^*$
(20-3)	b_9^0	b_{10}^0	b_{11}^0	b_{12}^0	$-\eta_0^2\psi_0^{1/2}$	0	0	0	0	0	$8\psi_0^{1/2}p^*$
(20-4)	b_{17}^0	b_{18}^0	b_{19}^0	b_{20}^0	$-\frac{\eta_0\psi_0^{1/2}}{\sqrt{2}}$	$\frac{\eta_0\psi_0^{1/2}}{\sqrt{2}}$	0	0	0	0	0
(20-5a)[c]	b'_1	b'_2	b'_3	b'_4	0	0	0	0	0	0	$(\psi_1^{1/2}/b)(bP^*/\rho)$
(20-5b)[d]	$b'_1 + U_1b'_5 - U_2U_3b'_{17}$	$b'_2 + U_1b'_6 - U_2U_3b'_{18}$	$b'_3 + U_1b'_7 - U_2U_3b'_{19}$	$b'_4 + U_1b'_8 - U_2U_3b'_{20}$	0	0	0	0	0	0	$(\psi_1^{1/2}/b)(bP^*/\rho - U_3p + U_4)$
(20-6)	b'_5	b'_6	b'_7	b'_8	0	0	$-2\psi_1^{3/2}h \times (2 \ln b + 1)$	$-4\psi_1^{3/2}h$	$-2\psi_1^{3/2}h/b^2$	0	$-2\psi_1^{1/2}p^*/\rho$
(20-7)[d]	$b'_9 + U_5b'_{17}$	$b'_{10} + U_5b'_{18}$	$b'_{11} + U_5b'_{19}$	$b'_{12} + U_5b'_{20}$	0	0	$U_6[2(1 + \nu) \ln b + (3 + \nu)$	$U_6[2(1 + \nu)]$	$-U_6 \frac{(1 - \nu^2)}{b^2}$	0	$8\psi_1^{1/2}p^*/\rho$
(20-8)	0	0	0	0	0	0	$b^2 \ln b$	b^2	$\ln b$	1.0	0
(20-9)	0	0	0	0	0	0	$2(1 - \nu) \ln a + (3 + \nu)$	$2(1 + \nu)$	$-(1 - \nu)/a^2$	0	0
(20-10)	0	0	0	0	0	0	1.0	0	0	0	$-\frac{3(1 - \nu^2)M}{2\pi Et^3(a - b)}$

[a]These equations are in the form $[A]|C| + |B| = 0$, where $[A]$ is the coefficient matrix, $|C|$ is the column matrix of unknown constants, and $|B|$ is the column matrix of loading parameters.

[b]A superscript "0" on the b's indicates that the Bessel function is to be evaluated at $x = 0$, $\eta = 2\gamma/\alpha$.

[c]A prime (') on the b's indicates that the Bessel function is to be evaluated at $x = h$, $\eta = 2\gamma\rho^{1/2}/\alpha$.

[d]$U_1 = t/4\psi_1h$; $U_2 = \eta_1^2Eg_1^3/96t\psi_1^3h^3\ (1 - \nu^2)$; $U_3 = (b/E)\left[\frac{(1 + \nu)K^2 + (1 - \nu)}{K^2 - 1}\right]$, where $K = a/b$; $U_4 = tb\alpha P^*/2h(1 + \alpha)^2$; $U_5 = \gamma^2t/h\alpha$; $U_6 = -4\psi_1^{5/2}h^2t^3/bg_1^3$.

3. The ASME Code stress-calculation method uses a moment M, applied to the flange ring, rather than a bolt load W, where the correlation between M and W is $M = W(a - b)$. In the present analysis, however, Eq. (20-10) from Table 2 is used with the loading parameter M, rather than W.

Stresses

After having solved the set of equations in Table 3 for the constants C_1, ..., C_{10}, the stresses can be obtained anywhere in the structure. The equations for these stresses, used in other reports[4,5] in this series, are given in Table 4 [Eqs. (22)–(45)] for the same locations as those given by the ASME Code stress-calculation method; these are (1) at the hub-to-pipe juncture, (2) in the hub at the hub-to-ring juncture, and (3) at the inside edge of the ring ($r = b$).

Displacements

In Chapter 7 the displacements w of the flange ring are used. The equations for these displacements (with w arbitrarily set to zero at $r = b$) are:

$$w_g = C_7 g^2 \ln g + C_8 g^2 + C_9 \ln g + C_{10} \tag{46}$$

at the gasket centerline radius, $g = G/2$; and

$$w_c = C_7 c^2 \ln c + C_8 c^2 + C_9 \ln c + C_{10} \tag{47}$$

at the bolt-circle radius, $c = C/2$.

Table 4. Equations for the stresses in a tapered-hub flange

Type	Hub-to-pipe-juncture, longitudinal and circumferential: Equation	Eq. No.	Hub-to-ring juncture, longitudinal and circumferential: Equation	Eq. No.	Inside edges of ring, tangential and radial: Equation	Eq. No.
Longitudinal or tangential						
Bending	$(\sigma_\ell)_b = \pm \dfrac{Eg_0}{2(1-\nu^2)}(2\beta^2)C_5'b$	(22)	$(\sigma_\ell)_b = \pm \dfrac{Eg_1}{2(1-\nu^2)}\left[\dfrac{b}{4\psi_1^{5/2}h^2}(C_1b_9' + C_2b_{10}' + C_3b_{11}' + C_4b_{12}') + \dfrac{2b\alpha^2P^*}{h^2(1+\alpha)^3}\right]$	(30)	$(\sigma_t)_b = \pm(6/t^2)(M_t)_{r=b} = \pm[Et/2(1-\nu^2)] \times [C_7(2.6 \ln b + 1.9) + 2.6C_8 + 0.7C_9/b^2]$	(38)
Membrane	$(\sigma_\ell)_m = pb/2g_0$	(23)	$(\sigma_\ell)_m = pb/2g_1$	(31)	$(\sigma_t)_m = \dfrac{K^2+1}{K^2-1}\left(p - \dfrac{P_1}{t}\right)$	(39)[a]
Outside	$(\sigma_\ell)_o = pb/2g_0 - 1.816C_5'$	(24)	$(\sigma_\ell)_o = pb/2g_1 - (\sigma_\ell)_b$	(32)	$(\sigma_t)_o = (\sigma_t)_m + (\sigma_t)_b$	(40)[b]
Inside	$(\sigma_\ell)_i = pb/2g_0 + 1.816C_5'$	(25)	$(\sigma_\ell)_i = pb/2g_1 + (\sigma_\ell)_b$	(33)	$(\sigma_t)_i = (\sigma_t)_m - (\sigma_t)_b$	(41)[c]
Circumferential or radial						
Bending	$\pm(\sigma_c)_b = \pm\nu(\sigma_\ell)_b$	(26)	$\pm(\sigma_c)_b = \pm(\sigma_\ell)_b$	(34)	$(\sigma_r)_b = \pm \dfrac{6M_{r\ell}}{t^2} = \pm \dfrac{Et}{2(1-\nu^2)} \times [C_7(2.6 \ln b + 3.3) + 2.6C_8 - 0.7C_9/b^2]$	(42)
Membrane	$(\sigma_c)_m = (Eu_0/b) + \nu(pb/2g_0)$	(27)[d]	$(\sigma_c)_m = (Eu_h/b) + \nu(pb/2g_1)$	(35)[e]	$(\sigma_r)_m = -p + P_1/t$	(43)
Outside	$(\sigma_c)_o = (Eu_0/b) + \nu(\sigma_\ell)_o$	(28)	$(\sigma_c)_o = (Eu_h/b) + \nu(\sigma_\ell)_o$	(36)	$(\sigma_r)_o = (\sigma_r)_m + (\sigma_t)_b$	(44)[b]
Inside	$(\sigma_c)_i = (Eu_0/b) + \nu(\sigma_\ell)_i$	(29)	$(\sigma_c)_i = (Eu_h/b) + \nu(\sigma_\ell)_i$	(37)	$(\sigma_r)_i = (\sigma_r)_m - (\sigma_t)_b$	(45)[c]

[a] Here, $K = a/b$, and $\dfrac{P_1}{t} = -\dfrac{Eg_1^3}{(1-\nu^2)}\dfrac{b\eta_1^2}{8h^3\psi_1^{7/2}}(C_1b_{17}' + C_2b_{18}' + C_3b_{19}' + C_4b_{20}')$.

[b] Hub-side surface of ring.

[c] Gasket-side surface of ring.

[d] $u_o = b(C_6' + P^*)$.

[e] $u_h = \dfrac{b}{\psi^{1/2}}(C_1b_1' + C_2b_2' + C_3b_3' + C_4b_4') + bP^*/(1+\alpha)$.

4. FLANGE WITH A STRAIGHT HUB

Although the mathematical expressions for the straight hub can be obtained by letting $g_0 = g_1$, this would result in indeterminate quantities in the computer program. Therefore, the direct solution to the ring with a straight hub was obtained by using the previously given basic equations for only the pipe and the ring. There are six constants of integration to be established; the boundary-condition equations are displayed in Table 5 [Eq. (48)].

After algebraic manipulation, the equations displayed in Table 5 are reduced to the matrix-equation form $[A]|C| + |B| = 0$, where the terms in the coefficient matrix $[A]$ are given in Table 6 under the headings of the corresponding constants in the column matrix $|C|$. Solving this set of equations for the six constants (C_5', C_6', C_7, C_8, C_9, and C_{10}) allows calculation of the stresses in the structure. The equations for the stresses in the pipe at the pipe-to-ring juncture and in the ring at the inner edge ($r = b$) are analogous to those previously derived for the flange with a tapered hub (see Table 4).

One can calculate the displacements w_g and w_c for a straight-hub flange from Eqs. (46) and (47), respectively, using the constants C_7, ..., C_{10}, identified in Table 6.

Table 5. Equations for the boundary conditions for a straight-hub flange

	Hub-to-ring juncture		Ring	
	Equation	Eq. No.	Equation	Eq. No.
Displacements	$(u_1)_{x_1=0} = 0$	(48-1a)[a,b]	$(w)_{r=b} = 0$	(48-4)[c]
	$(u_1)_{x_1=0} = \left(u_r - \frac{t}{2}\frac{dw}{dr}\right)_{r=b}$	(48-1b)[a,b]		
Rotations	$(u_1')_{x_1=0} = \left(\frac{dw}{dr}\right)_{r=b}$	(48-2)		
Moments	$M_{r1} = -M_{ho} + \frac{1}{2} P_0 t$	(48-3)	$M_{r2} = 0$	(48-5)[d]
Shear along radius r			$Q = -\frac{dM_r}{dr} + \frac{M_t - M_r}{r} = \frac{W}{2\pi r}$	(48-6)

[a]Radial displacements.

[b]For an ASME-type calculation, Eq. (48-1a) is used.

[c]Axial displacements; $(w)_{r=b} = 0$ is the reference point for all other axial displacements.

[d]Radial moment at outside edge of ring (r = a).

Table 6. Matrix coefficients of the discontinuity equations[a] for a flange with a straight hub

Eq. No.	Coefficients of C_n						Loading parameters
	C_5'	C_6'	C_7	C_8	C_9	C_{10}	
(48-1a)	0	1.0	0	0	0	0	$bP^* + b\varepsilon_f\Delta - U_3P$
(48-1b)[b]	$U_{34} - U_{33}$	$1 + U_{34} + U_{33}$	0	0	0	0	0
(48-2)	β	β	$-(2b\ \ell n\ b + b)$	$-2b$		0	0
(48-3)	$2\beta^2 + 2\beta^3 t/2$	$-2\beta_1^3 t/2$	$-(2.6\ \ell n\ b + 3.3) \times (t/g_0)^3$	$-2.6(t/g_0)^3$	$(0.7/b^2)(t/g_0)^3$	0	0
(48-4)	0	0	$b^2\ \ell n\ b$	b^2	$\ell n\ b$	1.0	0
(48-5)	0	0	$2.6\ \ell n\ a + 3.3$	2.6	$-0.7/a^2$	0	0
(48-6)	0	0	1.0	0	0	0	$\dfrac{-3(1 - \nu^2)M}{2\pi\ Et^3(a - b)}$

[a]These equations are in the form $[a]|C| + |B| = 0$, where $[A]$ is the coefficient matrix, $|C|$ is the column matrix of unknown constants, $|B|$ is the column matrix of loading parameters.

[b]$U_3 = (b/E)\left[\dfrac{(1 + \nu)K^2 + (1 - \nu)}{K^2 - 1}\right]$, where $K = a/b$; $U_{33} = \dfrac{2U_3Eg_0^3\beta^3}{12(1 - \nu^2)t}$; $U_{34} = t\beta/2$.

5. BLIND FLANGES

Analysis Method

Blind flanges (or flat heads) are modeled as shown in Fig. 2. The general equations for a circular flat plate are:[3]

$$w = D_1 r^2 \ln r + D_2 r^2 + D_3 \ln r + D_4 + r^4 p/64D \ , \tag{49}$$

$$\frac{dw}{dr} = D_1(2r \ln r + r) + D_2(2r) + D_3/r + r^3 p/16D \ , \tag{50}$$

$$\frac{d^2w}{dr^2} = D_1(2 \ln r + 3) + D_2(2) - D_3/r^2 + 3r^2 p/16D \ , \tag{51}$$

and

$$\frac{d^3w}{dr^3} = D_1(2/r) + D_3(2/r^3) + 3rp/8D \ . \tag{52}$$

The radial and tangential moments M_r and M_t (see Fig. 2) are given by

$$M_r = -D\left(\frac{d^2w}{dr^2} + \frac{\nu}{r}\frac{dw}{dr}\right) \tag{53}$$

and

$$M_t = -D\left(\frac{1}{r}\frac{dw}{dr} + \nu\frac{d^2w}{dr^2}\right) \ ; \tag{54}$$

and the shear is given by

$$Q = -\frac{dM_r}{dr} + \frac{M_t - M_r}{r} \ . \tag{55}$$

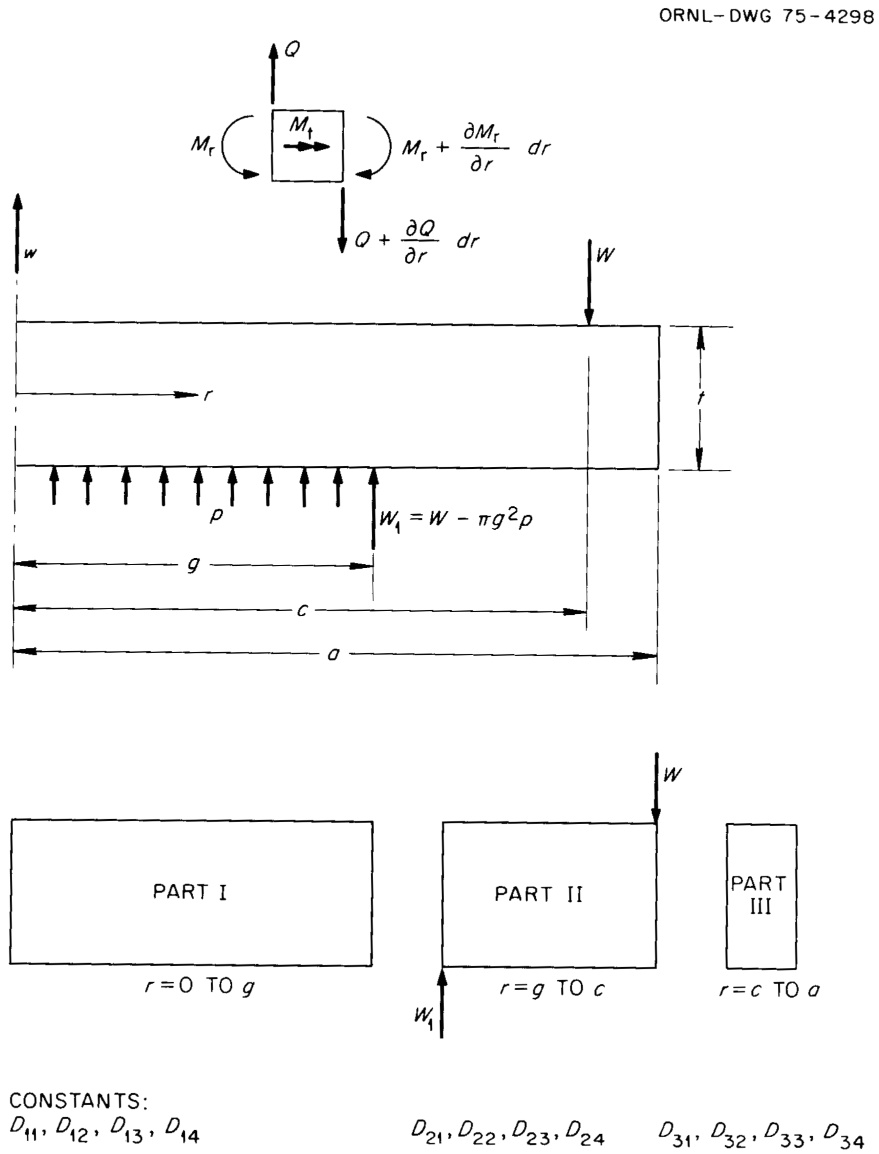

Fig. 2. Flat-plate analysis model of a blind flange or cover plate.

The moments and shears, in terms of the integration constants D_1 through D_4, are:

$$M_r = -D\{D_1[2(1 + \nu)\ \ell n\ r + (3 + \nu)] + D_2[2(1 + \nu)] - D_3[(1 - \nu)/r^2]\} - r^2p/16(3 + \nu) \ , \qquad (56)$$

$$M_t = -D\{D_1[2(1 + \nu)\ \ln r + (1 + 3\nu)] + D_2[2(1 + \nu)] + D_3[(1 - \nu)/r^2]\} - r^2p/16(1 + 3\nu)\ , \quad (57)$$

and

$$Q = D\left(\frac{4D_1}{r}\right) + \frac{rp}{2}\ . \quad (58)$$

For analysis, the plate is divided into three parts as shown in Fig. 2. There are four integration constants for each segment. The boundary-condition equations used to evaluate these constants are shown in Table 7. These boundary conditions show that 3 of the 12 constants are zero. The set of simultaneous equations to be solved to establish the remaining 9 constants is shown in Table 8. Again, this table presents the elements of the matrix equation $[A]|C| + |B| = 0$.

Table 7. Boundary condition equations used for blind-flange analysis

Equation No.	Boundary condition
1	$2\pi rQ = \pi r^2p$ for all of Part I. This gives $D_{11} = 0$.
2	$(dw/dr)_I = 0$ at $r = 0$. This gives $D_{13} = 0$.
3	$(w)_I = 0$ at $r = g$
4	$(dw/dr)_I = (dw/dr)_{II}$ at $r = g$
5	$(Q)_{II} = (W/2\pi r) - (\pi g^2p/2\pi g)$ at $r = g$. This gives $D_{21} = W/8\pi D - g^2p/8D$. (For pressure loading, $W = \pi g^2p$; hence $D_{21} = 0$.)
6	$(w)_{II} = 0$ at $r = g$
7	$(M_r)_I = (M_r)_{II}$ at $r = g$
8	$(dw/dr)_I = (dw/dr)_{II}$ at $r = g$
9	$(Q)_{III} = 0$. This gives $D_{31} = 0$.
10	$(M_r)_{II} = (M_r)_{III}$ at $r = c$
11	$(M_r)_{III} = 0$ at $r = a$
12	$(w)_{II} = (w)_{III}$ at $r = c$

Table 8. Boundary equations[a] for a blind flange

No.[b]	Coefficients of D_{ij}									Loading parameter
	D_{12}	D_{14}	D_{21}	D_{22}	D_{23}	D_{24}	D_{32}	D_{33}	D_{34}	
3	g^2	1.0	0	0	0	0	0	0	0	$g^4p/64D$
4	$-2g$	0	$2g \ln g + g$	$2g$	$1/g$	0	0	0	0	$-g^3p/16D$
5	0	0	1.0	0	0	0	0	0	0	$-W/8\pi D$
6	0	0	$g^2 \ln g$	g^2	$\ln g$	1.0	0	0	0	0
7	-2.6	0	$2.6 \ln g + 3.3$	2.6	$-0.7/g^2$	0	0	0	0	$-3.3g^2p/16D$
8	0	0	$2c \ln c + c$	$2c$	$1/c$	0	$-2c$	$-1/c$	0	0
10	0	0	$2.6 \ln c + 3.3$	2.6	$-0.7/c^2$	0	-2.6	$0.7/c^2$	0	0
11	0	0	0	0	0	0	2.6	$-0.7/a^2$	0	0
12	0	0	$c^2 \ln c$	c^2	$\ln c$	1.0	$-c^2$	$-\ln c$	-1.0	0

[a]These equations are in the form $[A]|C| + |B| = 0$, where $[A]$ is the coefficient matrix, $|C|$ is the column matrix of unknown constants, and $|B|$ is the column matrix of loading parameters.

[b]Boundary condition number from Table 4.

Stresses

After having established values for the integration constants, the stresses at any point in the blind flange can be readily obtained. Equations for stresses at the center of the flange and at $r = g$ and $r = c$ are given by

$$\sigma_t = \pm 6M_t/t^2 = \pm EtM_t/[2(1 - \nu^2)]D \tag{59a}$$

and

$$\sigma_r = \pm 6M_r/t^2 = \pm EtM_r/[2(1 - \nu^2)]D \ . \tag{59b}$$

At the center of the flange $(r = 0)$,

$$M_t = M_r = -D\{D_{12}[2(1 + \nu)]\} \ . \tag{60}$$

At the gasket $(r = g)$,

$$M_r = -D\{D_{12}[2(1 + \nu)] + g^2 p(3 + \nu)/16D\} \ , \tag{61}$$

and

$$M_t = -D\{D_{12}[2(1 + \nu)] + g^2 p(1 + 3\nu)/16D\} \ . \tag{62}$$

At the bolt circle $(r = c)$,

$$M_r = -D\{D_{32}[2(1 + \nu)] - D_{33}(1 - \nu)/c^2\} \ , \tag{63}$$

and

$$M_t = -D\{D_{32}[2(1 + \nu)] + D_{33}(1 - \nu)/c^2\} \ . \tag{64}$$

In all of the above, a positive moment produces a tensile stress on the back of the flange (positive w side of Fig. 2).

Displacements

In the third and sixth boundary conditions listed in Table 7, the axial displacement at the gasket has been arbitrarily set equal to zero. The relative displacement of the bolt circle to the gasket is therefore

$$w_c = D_{32}c^2 + D_{33}\ \ell n\ c + D_{34}\ . \tag{65}$$

6. THERMAL GRADIENTS

Two kinds of thermal gradients are included in the analysis: (1) a constant temperature in the pipe and hub that may be different from the assumed constant temperature in the ring and (2) a constant temperature in the bolts that may be different from the assumed constant temperature in the ring.

The significance of the bolt-to-ring thermal gradients is dependent upon the dimensional and material characteristics of the flanged joint and is covered later in Chapter 7.

The pipe/hub-to-ring temperature gradient is included in the analysis by an appropriate change in the "loading parameters" shown in Table 3. We define Δ as the difference in temperature between the pipe/hub and the ring; Δ is positive if the pipe/hub is hotter than the ring. The radial expansion of the tapered hub at its juncture with the ring is then:

$$u = \frac{b}{\sqrt{\psi_1}} (C_1 b_1' + C_2 b_2' + C_3 b_3' + C_4 b_4') + b\varepsilon_f \Delta \ , \tag{66}$$

where b is the pipe radius; b_i' terms are the Bessel functions defined in Table 1 evaluated at $x = h$, $\eta = 2\gamma\rho^{1/2}/\alpha$, as indicated in footnote *c* of Table 3; and ε_f is the coefficient of thermal expansion of the flange material.

The effects of such a thermal gradient are taken into account by adding $(\sqrt{\psi_1}/b)(b\varepsilon_f\Delta)$ to the existing terms in the loading-parameter column in Table 3 [Eqs. (20-5a) and (20-5b)]. The analogous term is already included in Table 6.

7. CHANGE IN BOLT LOAD WITH PRESSURE, TEMPERATURE, AND EXTERNAL MOMENTS

A flanged joint is a statically indeterminate structure. Thus, in order to determine the residual bolt load in the joint, it is necessary to calculate the relative displacements of the parts when the joint is subjected to (1) initial bolt loading, (2) moment loading, (3) internal pressure, and (4) thermal gradients.

The object of the analysis is to determine the residual bolt load W_2 in terms of (1) the loadings W_1, p, Δ, and Δ'; (2) the component temperatures T_b, T_g, T_f, and T_f'; (3) the flanged-joint dimensions; and (4) the material properties.

The basic analysis is given by Wesstrom and Bergh,[6] and we follow their nomenclature, with additions as necessary. Reference 6 covers only the effect of initial bolt loading and part of the influence of internal pressure; the remaining influence from the internal pressure is discussed by Rodabaugh.[7] The extension of the analysis to cover thermal gradients is relatively simple and is covered below.

The nomenclature used in this development is:

A = cross-sectional area of bolts or gasket
B = inside diameter of ring
C = bolt-circle diameter
E = modulus of elasticity
g_0 = wall thickness of pipe
G = gasket centerline diameter
ℓ = bolt length
p = internal pressure
p* = equivalent pressure for external moment loading
q = elastic deformation coefficients
t = ring thickness
T = final-state temperature (initial-state temperature is defined as zero)
v = gasket thickness
W = bolt load

δ = relative axial displacement between the gasket centerline and the bolt circle

ε = coefficient of thermal expansion

Δ = temperature between hub/pipe and ring

The subscripts 0, 1, and 2 refer to the undeformed, initial deformed, and final deformed states, respectively; subscripts b, g, and f refer to the bolts, gasket, and flange, respectively. Quantities with a prime (') are for one of the flanges in a pair (e.g., T_f' refers to the temperature of the right-hand flange in Fig. 3); quantities without a prime are for the other flange.

Analysis

Figure 3 shows a schematic illustration of the general case of two dissimilar flanges and their mode of deformation. When the bolts are initially tightened to make up the joint, the resulting initial deformed bolt length is

$$\ell_1 = v_1 + t_1 + t_1' - \delta_1 - \delta_1' \ . \tag{67}$$

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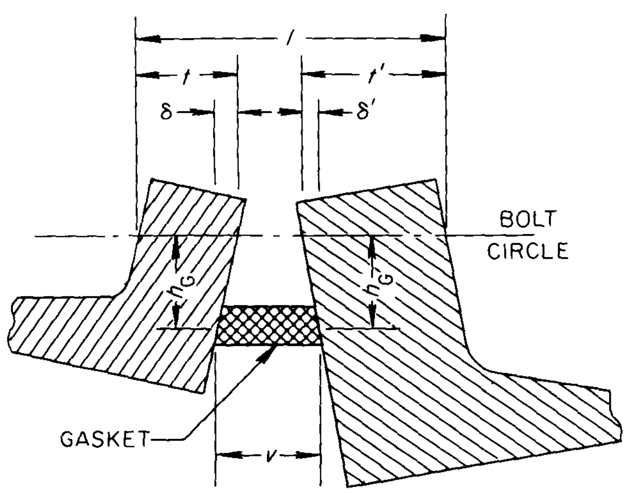

Fig. 3. General case of two dissimilar flanges and their mode of deformation.

After application of loadings, the bolt length becomes

$$\ell_2 = v_2 + t_2 + t_2' - \delta_2 - \delta_2' \; . \tag{68}$$

The basic displacement relationship is thus

$$\ell_2 - \ell_1 = (v_2 - v_1) + (t_2 - t_1) + (t_2' - t_1') - (\delta_2 - \delta_1) - (\delta_2' - \delta_1') \; . \tag{69}$$

We also use the following relationships:

$$
\begin{aligned}
\ell_2 &= \ell_0 + T_b \varepsilon_b \ell_0 + q_{b2} W_2 \; , && \text{(a)} \\
v_2 &= v_0 + T_g \varepsilon_g v_0 - q_{g2}(W_2 - H_{D2} - H_{T2}) \; , && \text{(b)} \\
t_2 &= t_0 + T_f \varepsilon_f t_0 \; , && \text{(c)} \\
t_2' &= t_0' + T_f' \varepsilon_f' t_0' \; , && \text{(d)} \\
\delta_2 &= q_{f2} M_2 h_G + q_p p h_G + q_t \Delta h_g \; , && \text{(e)} \\
\delta_2' &= q_{f2}' M_2' h_G + q_p' p h_G + q_t' \Delta' h_G \; , && \text{(f)} \\
\ell_1 &= \ell_0 + q_{b1} W_1 \; , && \text{(g)} \\
v_1 &= v_0 - q_{g1} W_1 \; , && \text{(h)} \\
t_1 &= t_0 \; , && \text{(i)} \\
t_1' &= t_0' \; , && \text{(j)} \\
\delta_1 &= q_{f1} M_1 h_G \; , && \text{(k)} \\
\delta_1' &= q_{f1}' M_1 h_G \; . && (\ell)
\end{aligned}
\tag{70}
$$

The elastic deformation coefficients q_{b1}, q_{g1}, q_{b2}, and q_{g2} in Eqs. (70a–ℓ) are further defined as

$$q_{b1} = \frac{\ell_0}{A_b E_{b1}} , \tag{71a}$$

$$q_{g1} = \frac{v_0}{A_g E_{g1}} , \tag{71b}$$

$$q_{b2} = \frac{\ell_0}{A_b E_{b2}} , \tag{71c}$$

$$q_{g2} = \frac{v_0}{A_g E_{g2}} . \tag{71d}$$

In Eqs. (70a–ℓ), the term q_{f1} is a rotation of the flange due to a unit moment load, q_p is a rotation of the flange due to a unit internal pressure, and q_t is a rotation of the flange due to a unit temperature gradient between the hub and the ring. The quantities q_{f1}, q_p, and q_t are obtained from the functional expression

$$q(L) = \frac{-w_c(L) + w_g(L)}{h_G} , \tag{72}$$

where $h_G = (C - G)/2$, C is the bolt-circle diameter, and G is the gasket-centerline diameter. Values for the displacements $w_c(L)$ and $w_g(L)$ are obtained from Eqs. (46) and (47) with the appropriate unit values for the loads Δ, P, and M.

For q_{f1} the modulus of elasticity used is that for the initial condition. For q_p and q_t, the moduli used are those for the final condition. The term q_{f2} is obtained from q_{f1} and the ratio of the initial and final elastic moduli; thus:

$$q_{f2} = q_{f1} \frac{E_1}{E_2} .$$

The moments and loads are defined by Eqs. (73a–n). The nomenclature used in these equations is analogous to that used in the ASME Code.[1] The symbol H represents a load, h represents a lever arm, and M represents a moment. The term H_D is the hydrostatic end force (in pounds) on the area inside the flange, H_G is the gasket load in pounds, H_T is the difference between the total hydrostatic end force and the hydrostatic end force on the area inside the flange, h_D is the radial distance in inches from the bolt circle to the circle on which H_D acts (as prescribed in Table UA-50 of the Code), h_G is the radial distance in inches from the gasket-load reaction to the bolt circle, and h_T is the radial distance in inches from the bolt circle to the circle on which H_T acts (as prescribed in Table UA-50). Symbols, C, B, G, g_0, and p are defined earlier in this chapter. Again, a subscript 1 refers to the initial deformed state, a subscript 2 refers to the final deformed state, and primed quantities refer to the mating flange.

$$h_D = (C - B - g_0)/2 \ , \qquad \text{(a)}$$

$$h_D' = (C - B' - g_0')/2 \ , \qquad \text{(b)}$$

$$h_T = [C - (G + B)/2]/2 \ , \qquad \text{(c)}$$

$$h_T' = [C - (G + B')/2]/2 \ , \qquad \text{(d)}$$

$$h_G = (C - G)/2 \ , \qquad \text{(e)}$$

$$H_{D2} = \frac{\pi}{4} B^2 p \ , \qquad \text{(f)}$$

$$H_{D2}' = \frac{\pi}{4} (B')^2 p \ , \qquad \text{(g)} \qquad (73)$$

$$H_{T2} = \frac{\pi}{4} (G^2 - B^2) p \ , \qquad \text{(h)}$$

$$H_{T2}' = \frac{\pi}{4} [G^2 - (B')^2] p \ , \qquad \text{(i)}$$

$$H_{G2} = W_2 - H_{D2} - H_{T2} \ , \qquad \text{(j)}$$

$$H_{G2}' = W_2 - H_{D2}' - H_{T2}' \ , \qquad \text{(k)}$$

$$M_1 = W_1 h_G = H_{G1} h_G \ , \qquad (\ell)$$

$$M_2 = H_{D2} h_D + H_{T2} h_T + H_{G2} h_G \ , \qquad (m)$$

and

$$M_2' = H_{D2}' h_D' + H_{T2}' h_T' + H_{G2} h_G \ . \qquad (n)$$

Substituting Eqs. (70a–ℓ) into Eq. (69) gives

$$T_b \varepsilon_b \ell_0 + q_{b2} W_2 - q_{b1} W_1 = T_g \varepsilon_g v_0 - q_{g2}(W_2 - H_{D2} - H_{T2})$$
$$+ q_{g1} W_1 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - h_G(q_{f2} M_2 + q_p p + q_t \Delta - q_{f1} M_1)$$
$$- h_G(q_{f2}' M_2' + q_p' p + q_t' \Delta' - q_{f1}' M_1) \ . \qquad (74)$$

In order to eliminate M_1 and M_2 from Eq. (74), Eqs. (73ℓ and m) are used; the sixth term on the right-hand side of Eq. (74) then becomes

$$-h_G\{q_{f2}[H_{D2} h_D + H_{T2} h_T + (W_2 - H_{D2} - H_{T2}) h_G] + q_p p + q_t \Delta - q_{f1} W_1 h_G\} \ .$$

The last term in Eq. (74) is treated similarly. Collecting terms containing W_2 on the left gives:

$$(q_{b2} + q_{g2} + h_G^2 q_{f2} + h_G^2 q_{f2}') W_2 = (q_{b1} + q_{g1} + h_G^2 q_{f1} + h_G^2 q_{f1}') W_1$$
$$+ T_g \varepsilon_g v_0 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - T_b \varepsilon_b \ell_0 + q_{g2}(H_{D2} + H_{T2})$$
$$- h_G q_{f2}[H_{D2}(h_D - h_G) + H_{T2}(h_T - h_G)]$$
$$- h_G q_{f2}'[H_{D2}'(h_D' - h_G) + H_{T2}'(h_T' - h_G)]$$
$$- h_G(q_p + q_p') p - h_G(q_t \Delta + q_T' \Delta') \ . \qquad (75)$$

Defining

$$Q_1 = q_{b1} + q_{g1} + h_G^2 q_{f1} + h_G^2 q'_{f1}$$

and

$$Q_2 = q_{b2} + q_{g2} + h_G^2 q_{f2} + h_G^2 q'_{f2}$$

and using the given definitions of H_D, H'_D, H_T, and H'_T, Eq. (75) becomes

$$W_2 = \frac{Q_1}{Q_2} W_1 + \frac{1}{Q_2} (T_g \varepsilon_g v_0 + T_f \varepsilon_f t_0 + T'_f \varepsilon'_f t'_0 - T_b \varepsilon_b \ell_0)$$

$$+ \frac{\pi h_G}{4Q_2} \left\{ \left[\frac{q_{g2}}{h_G} - q_{f2}(h_T - h_G) - q'_{f2}(h_T - h_G) - q'_{f2}(h'_T - h_G) \right] G^2 \right.$$

$$\left. - [q_{f2} B^2 (h_D - h_T) + q'_{f2} (B')^2 (h'_D - h'_T)] \right\} p$$

$$- \frac{h_G}{Q_2} (q_p + q'_p) p - \frac{h_G}{Q_2} (q_t \Delta + q'_t \Delta') \ . \qquad (76)$$

In order to compute the flange stresses under the various loading conditions, it is necessary to compute the flange moment M_2 or M'_2. From Eq. (73m) and the definitions in Eqs. (73a–k),

$$M_2 = \frac{\pi}{4} p[B^2 h_D + (G^2 - B^2) h_T - G^2 h_G] + W_2 h_G \ . \qquad (77a)$$

And similarly for the mating flange,

$$M'_2 = \frac{\pi}{4} p \left\{ (B')^2 h'_D + [G^2 - (B')^2] h'_T - G^2 h_G \right\} + W_2 h_G \ . \qquad (77b)$$

The computer program was written to separately evaluate the various effects involved in bolt-load changes. The residual bolt load due to temperature differences that produce differential axial strain is

$$W_{2a} = W_1 + \frac{1}{Q_1} (T_g \varepsilon_g v_0 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - T_b \varepsilon_b \ell_0) \ . \tag{78}$$

The residual bolt load, after internal pressure (acting in an axial direction) has transferred the bolt load on the gasket to a tensile load on the attached pipes due to a shift in lever arms, is given by:

$$W_{2b} = W_1 + \frac{\pi}{4} \frac{h_G}{Q_1} \left\{ \left[\frac{q_{g1}}{h_G} - q_{f1}(h_T - h_G) - q_{f1}'(h_T' - h_G) \right] G^2 - [q_{f1} B^2 (h_D - h_T) + q_{f1}' (B')^2 (h_D' - h_T')] \right\} p \ . \tag{79}$$

The total effect of internal pressure due to both the shift in the lever arms and the radial effect of pressure acting on the integral flange(s) and/or on the inside surface of a blind flange is given by:

$$W_{2c} = W_{2b} - \frac{h_G}{Q_1} (q_p + q_p')p \ . \tag{80}$$

The residual bolt load due to a temperature difference between the hub and the ring is given by:

$$W_{2d} = W_1 - \frac{h_G}{Q_1} (q_t \Delta + q_t' \Delta') \ . \tag{81}$$

A slight modification of the above is required for the case of a blind flange. If we designate the blind flange as that with the "primed" nomenclature, then all* of Eqs. (70a–ℓ) are valid except Eqs. (70f and ℓ) for δ_1' and δ_2'.

---

*For v_2 it should be noted that $H_{D2} - H_{T2} = \pi G^2 p/4$; hence, this equation is valid for blind flanges.

For blind flanges, W is used rather than M as the loading parameter because the relationship $M = W(a - b)$ is not valid for the blind-flange analysis. For blind-flange analysis, Eq. (65) gives a value of w_c; here $-w_c$ is the equivalent of $-w_c + w_g$ in Eq. (72) because $w_g \equiv 0$ in the blind-flange analysis. For blind flanges we define

$$q_f' = \frac{(-w_c)_W}{h_G^2} , \tag{82}$$

where $(-w_c)_W$ is the axial displacement per unit total bolt load W. The equation for W_2 for a blind flanged joint is then:

$$W_2 = \frac{Q_1}{Q_2} W_1 + \frac{1}{Q_2} (T_g \varepsilon_g v_0 + T_f \varepsilon_f t_0 + T_f' \varepsilon_f' t_0' - T_b \varepsilon_b \ell_0)$$
$$+ \frac{\pi}{4} \frac{h_G}{Q_2} \left\{ \left[\frac{q_{g2}}{h_G} - q_{f2}(h_T - h_G) \right] G^2 - q_{f2} B^2 (h_D - h_T) \right\} p$$
$$- \frac{h_G}{Q_2} (q_p + q_p') p - \frac{h_G}{Q_2} q_t \Delta . \tag{83}$$

In Eq. (83) the primed values refer to properties of the blind flange.

After the internal pressure has transferred the bolt load on the gasket to a tensile load on the attached pipe due to a shift in the lever arms, the residual bolt load for the case where a blind flange is used is

$$W_{2b} = W_1 + \frac{\pi}{4} \frac{h_G}{Q_1} \left\{ \left[\frac{q_{g1}}{h_G} - q_{f1}(h_T - h_G) \right] G^2 - q_{f1} B^2 (h_D - h_T) \right\} p . \tag{84}$$

It should be noted that $q_t' \Delta'$ does not exist for an integral flange mated to a blind flange.

The combined effect of all of the above is also obtained from the computer program by calculating W_2 from Eqs. (76) and (83).

External Moment Loading

Up to this point, all loads considered have been axisymmetric. For flanged joints in pipe lines, there is one other significant loading; that is, the bending moment imposed on the flanged joint by the attached pipe. To distinguish this from the local moments applied to the flange ring, the bending moment will be designated as an "external" moment. The external moment can be represented by a distributed axial edge force acting on the attached pipe:

$$F_M(\theta) = F_m \cos\theta \ , \tag{85}$$

where θ = angle around the circumference ($\theta = 0$ at the point of maximum tensile stress in the pipe due to the external moment). Since this report deals only with cases in which all contact occurs within the bolt-hole circle, a reasonably good first approximation for the effects of the external moment loading can be obtained by replacing the distributed axial force $F_M(\theta)$ with the axisymmetric tensile force $F_m = F_M(\max)$. Then, since F_m is axisymmetric, there is some pressure p* that will produce the same axial force in the pipe; or alternately, there is an equivalent pressure p* that will produce an axial stress in the pipe which is equal to the maximum tensile stress S_b produced by an external moment. The relation between p* and S_b is given by

$$p^* = 4S_b g_0/D_o \ , \tag{86}$$

where S_b is the bending stress in the attached pipe due to the external moment. The change in bolt load W_{2b} is then obtained by replacing p with p + p* in Eqs. (79) and (84). It should be noted that this equivalent pressure is included only in Eqs. (79) and (84) and not in Eq. (80).

8. COMPUTER PROGRAM

A Fortran computer program named FLANGE has been written to carry out the calculations according to the analyses described in this report. The program calculates appropriate loads, stresses, and displacements for the flanges, bolts, and gaskets when the flanged joint is subjected to internal pressure, moment, and/or thermal gradient loadings; thus, the program is much more general than that needed only to determine compliance with the ASME Boiler and Pressure Vessel Code. The program also has the advantage of internally computing the values of the Code variables F, V, and f that must otherwise be extracted manually from the curves given in Code Figs. UA-51.2, UA-51.3, and UA-51.6. Loose hubbed flanges, which are covered by the Code, however, are not covered by the computer program.

The main function of this chapter is to describe the input and output for the various computational options available to the user. For more detailed information, the reader is urged to carefully study the examples given in Appendix A where a flanged joint, selected from API Standard 605 (Ref. 8), is analyzed. Several sample problems are worked, and the data input and program output are given for the various program options along with a discussion of the results. Flowcharts and listings of the program and its subroutines are given in Appendix B. In the following sections, the input data for option control and the input data and program output for Code compliance calculations and for more general calculations are discussed.

Option Control Data Card

The first card of each data set, herein called the option control card, contains control information for execution of the various program options. It contains information specifying the type of flange being analyzed, the boundary condition placed on the displacement $(u_r)_{x=h}$, the stresses and other variables to be calculated, and the joint configuration and which flange (of the pair) is to be analyzed. These specifications are under control of the four variables ITYPE, IBØND, ICØDE, and MATE. The admissible values and their significance are as follows.

ITYPE (indicates the type of flange being analyzed)

1 for a tapered-hub flange

2 for a straight-hub flange

3 for a blind hub

IBØND (specifies the displacement u_r at $x = h$)

0 for $(u_r)_{x=h} = 0$ to conform with the ASME Code basis

1 (see footnote)*

2 for $(u_r)_{x=h} \neq 0$ [see Eq. (20-6) of this report]

ICØDE (controls the amount of output data)

0 for a wide variety of stresses, moments, and loads for specified moment, pressure, and ΔT

1 (see footnote)*

2 for a select list for checking Code compliance in accordance with Section VIII, Div. 1 of the ASME Code

MATE (specifies the joint configuration and the flange to be analyzed)

1 for only one flange to be analyzed (This is the situation for ASME-Code related calculations.)

2 for two <u>identical</u> flanges mated together

3 for the <u>first</u> of two flanges that are <u>not</u> <u>identical</u>, neither of which is a blind flange

4 for the <u>second</u> of two flanges that are <u>not</u> <u>identical</u>, neither of which is a blind flange

5 for a blind flange

6 for a flange that is mated with a blind flange.

The data card with the above information is followed by other data cards containing physical-property data, etc., for the particular flange being analyzed. Since the program can be used to analyze any number of flanges

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*In the original conception of the program, IBØND and ICØDE were envisioned as controlling additional calculations that were not implemented in the present version. As it is now written, the program does not distinghish between values of 0 or 1 nor between 2 and numbers greater than 2 for either IBØND or ICØDE.

or flanged joints sequentially (as done in the examples of Appendix A), the data card set for each flange must start with an option-control data card.

Different types of flanges and different types of calculations have different input data requirements. These data and their formats are discussed in the following sections.

Input for Code-Compliance Calculations

Since the ASME Code calculation procedures consider only one flange at a time, the input data requirements for the computer program are quite simple and straightforward. Input data are completely prescribed by the three data cards illustrated in Table 9. The nomenclature is the same as that used in the Code.

The first card is the option control card discussed in the previous sections. The first variable ITYPE may be equal to 1, 2, or 3, depending on the type of flange being analyzed. The next variable IBØND will always be 0, in which case the displacement u_r will be equal to zero at $x = h$, as specified by the Code. The third variable ICØDE will always be 2 and will therefore cause the program to compute the stresses in accordance with Code paragraph UA-50 for straight or tapered-hub flanges or paragraph UG-34(c)(2) for blind flanges. The last variable MATE will always be 1 for Code-compliance calculations. This variable essentially controls the bolt-load-change calculations made by the program. Since the ASME Code does not consider bolt-load changes in determining compliance, when MATE = 1 these calculations are not performed.

The second card in the data set enters the physical dimensions of the flange being analyzed, as shown in Table 9. These dimensions are the outside and inside diameters of the flange ring A and B, the ring thickness t, the pipe-wall thickness g_0, the hub thickness at the hub-to-ring juncture g_1, the hub length h, the bolt-circle diameter C, and the internal pressure. All dimensions are expressed in inches; the pressure is in pounds per square inch.

Table 9. Input data for ASME bolt and flange stress calculation, using symbols defined in ASME Code, Section VIII, Division 1, Appendix II

Option-Control Card (Read-in in FLANGE)

Column number	5	10	15	20
Variable	ITYPE[a]	IBØND	ICØDE	MATE
Value	1, 2, or 3	0	2	1

Second Card (Read-in in TAPHUB, STHUB, or BLIND)[b,c]

Column number	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
Quantity	Flange outer diameter A	Flange inner diameter B	Ring thickness t	Pipe-wall thickness g_0	Hub thickness g_1	Hub length h	Bolt-circle diameter c	Pressure p
Variable	XA	XB	TH	GO	G1	HL	C	PRESS

Third Card (Read-in in ASMEIN)[d]

Column number	0-10	11-20	21-30	31-40[d]	41-50	51-60	61-70[e]	72[d]	73-80[d]
Quantity	Gasket factor m	Minimum design seating stress y	Gasket outer diameter G_o	Gasket inner diameter G_i	Allowable bolt stress at design temperature S_b	Allowable bolt stress at atmospheric temperature S_a	Bolt cross-sectional area A_b	Option I	Basic gasket seat width b_o
Variable	XM	Y	GOUT	GIN	SB	SA	AB	INBO	BO

[a]When ITYPE = 2 for a ring flange, g_0, on the second card, should be a suitably small value, but not zero (e.g., 0.01).

[b]Subroutines TAPHUB and STHUB call both ASMEIN and FLGDW; BLIND calls ASMEIN.

[c]For ITYPE = 2, g_0 must be entered; g_1 and h are not used. For ITYPE = 3, B, g_0, g_1, and h are not used.

[d]If I (Column 72) is 0, the program computes b, b_o, and G for the particular case of $b_o = N/2 = 1/2(G_o - G_i)/2$ as defined in Table UA-49.2 sketches (1a) and (1b) of the Code. Columns 73–80 may then be left blank. For other values of b_o, enter I = 2. In this case, the value of G_i is not used and thus columns 31-40 may be left blank.

[e]Column 71 is blank.

The third card inputs other physical data, including the gasket factor m, the minimum-design seating stress y, the outside diameter of the gasket G_o, the inside diameter of the gasket G_i, the allowable bolt stress at design temperature S_b, the allowable bolt stress at ambient temperature S_a, the total cross-sectional area of the bolts A_b, an option-selecting variable I, and the basic gasket-seating width b_o. The option variable I controls the calculation of b and G.

Output for Code-Compliance Calculations

For Code-compliance calculations, all of the output for each flange being analyzed is printed on a single page (e.g., see examples 1 and 2 of Appendix A). The program prints the input data followed by the effective gasket seating width b_o and the loads, bolt stresses, and moments identified under the headings shown in Table 10. For compliance with Code criteria, the value of SB1 must not exceed the allowable bolt stress at design temperature, and the value of SB2 must not exceed the allowable bolt stress at atmospheric* temperature.

Immediately below, the program prints the flange stresses needed for comparison with the ASME Code criteria. For tapered-hub and straight-hub flanges (ITYPE = 1 or 2), the program prints five stresses under the two headings "ASME FLANGE STRESSES AT OPERATING MOMENT, MOP" and "ASME FLANGE STRESSES AT GASKET SEATING MOMENT." The stresses are identified as follows:

2/3(SH) = two-thirds of the longitudinal stress on the outside surface at the small end of the hub,

ST = the tangential stress on the hub side of the ring,

SR = the radial stress on the hub side of the ring,

(SH + ST)/2 = the average of SH and ST, and

(SR + ST)/2 = the average of SR and ST.

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*Although "ambient" would probably be a better term here, the word "atmospheric" is used as it is used in the Code.

Table 10. Output data identification, ICØDE = 2, (ASME Code stresses)

ASME Code symbol[a]	Program symbol	Description[a]	
b_o	BO	See ASME Code, Table UA-49.2. (This will be input data for I = 2.)[b]	
H	WM11	$\pi G^2 p/4$	
	WM12	$2\pi bGmp$	
W_{m1}	WM1	$\pi G^2 p/4 + 2\pi bGmp$	
	SB1	Bolt stress, W_{m1}/A_b	
W_{m2}	WM2	πbGy	
	SB2	Bolt stress, W_{m2}/A_b	
(*c*)	MOP	$H_G h_G + H_T h_T + H_D h_D$	
(*d*)	MGS	$[(A_m + A_b)S_a/2] \times [(C - G)/2]$	Except for ITYPE = 3 (Blind flanges)
	MGS1	$W_{m2} \times [(C - G)/2]$	

[a] All symbols are defined in the ASME Boiler Code, Section VIII, Div. 1 (1971), Appendix II.

[b] See Footnote *d* of Table 9.

[c] MOP is the operating moment as defined by the ASME Code.

[d] MGS is the gasket seating moment as defined by the ASME Code.

For compliance with the Code Criteria, each of the above values printed under the first heading must not exceed the allowable stress for the flange material at the design temperature. The values printed under the second heading must not exceed the allowable stress for the flange material at atmospheric temperature.

For blind flanges (ITYPE = 3), the program prints the following five quantities under the heading "ASME CODE STRESSES FOR BLIND FLANGE":

SP = the stress due to pressure loading only,

SW1 = the stress due to the bolt load W_{m1} only, where $W_{m1} = \pi G^2 p/4 + 2\pi bGmp$,

SOP = the stress at operating conditions,

SW2 = the stress due to the bolt load W_{m2}, where $W_{m2} = \pi bGy$, and

SGS = the stress at gasket-seating conditions.

For Code compliance, SOP must not exceed the allowable stress for the flange material at design temperature, and SGS must not exceed the allowable stress at atmospheric temperature.

Input for General Purpose Calculations

When the computer program is used for general purpose calculations, (i.e., when it is used for calculating displacements and stresses other than those needed specifically for checking Code compliance), the user may select almost any combination of admissible values for the four variables ITYPE, IBØND, ICØDE, and MATE coded in the option control data card. The only specific requirement is that the variable ICØDE must be less than two for other than Code-compliance calculations. In this case the input data are structured somewhat differently than those described in the previous section.

When ICØDE = 0 and MATE = 1, (i.e., only one flange is to be analyzed and the user does not wish to obtain bolt load changes), three data cards are needed as shown in Table 11. These are the option-control card (for which ITYPE may be 1, 2, or 3 and IBØND may be 0 or 2) and two physical-property data cards.

When ICØDE = 0 and MATE = 2, 3, ... 6, the program will analyze a pair of flanges mated together and give bolt load changes. If MATE = 2, the program performs the calculations for a pair of identical flanges mated together. The input data requirements include the data cards shown in Table 11 plus the three cards shown in Table 12. These last three cards contain data on the physical properties of the bolts and gasket, supplemental data on the initial and final state of the flange, and other conditions. For this case, the six cards listed below complete the input data set when MATE = 2.

Table 11. Input data for the general purpose analysis of a single flange and partial data for paired flanges

Option-Control Card: [FØRMAT (4I5) read-in in FLANGE]

Column number	5	10	15	20
Variable	ITYPE[a,b]	IBØND	ICØDE	MATE[c]
Value	1, 2, or 3	0 to 2	0	1 or (2)

Second Card: [FØRMAT (8E10.5); read-in in TAPHUB, STHUB, or BLIND]

Column number	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
Quantity	Flange outer diameter A	Flange inner diameter B	Ring thickness t	Pipe-wall thickness g_0	Hub thickness g_1	Hub length h	Bolt-circle diameter C	Pressure p
Variable	XA	XB[b]	TH	G0[a,b]	G1[a,b]	HL[a,b]	C	PRESS

Third Card: [FØRMAT (5E10.5); read-in in TAPHUB, STHUB, or BLIND]

Column number	0-10	11-20	21-30	31-40	41-50
Quantity	Moment applied to flange ring M	Coefficient of thermal expansion ε_f	Thermal gradient pipe or hub to ring Δ	Modulus of elasticity flange E	Gasket centerline diameter 2g
Variable	XMOA[b]	EF[b]	DELTA[b]	YM	G

[a]When ITYPE = 2, G0 must be entered; G1 and HL are not used.

[b]When ITYPE = 3, XB, G0, G1, HL, EF, and DELTA are not used; the value for XMOA is the total bolt load W.

[c]When MATE = 2, additional data as described in Table 12 are also required.

Table 12. Last three input data cards for the general purpose analysis of paired flanges

Card No. 4 or 7:[a] [FØRMAT (7E10.5); read-in in FLGDW]

Column number	0-10	11-20	21-30	31-40	41-50	51-60	61-70
Quantity	Nominal bolt diameter	Initial state; bolt modulus of elasticity E_b	Bolt coefficient of thermal expansion ε_b	Final state; bolt temperature T_b	Outside diameter of gasket	Inside diameter of gasket	Cross-sectional root area of all bolts
Variable	BSIZE[b]	YB	EB	TB	XGO[c]	XGI[c]	AB

Card No. 5 or 8:[a] [FØRMAT (6E10.5); read-in in FLGDW]

Column number	0-10	11-20	21-30	31-40	41-50	51-60
Quantity	Gasket thickness v_o	Initial state; gasket modulus of elasticity E_g	Gasket coefficient of thermal expansion ε_g	Final state; gasket temperature T_g	A free bolt length variable	Equivalent pressure see Eq. (86) of text p^*
Variable	VO	YG	EG	TG[d]	FACE[b]	PBE

Card No. 6 or 9:[a] [FØRMAT (7E10.5); read-in in FLGDW]

Column number	0-10	11-20	21-30	31-40	41-50	51-60	61-70
Quantity	Initial bolt load W_1	Final state temperature of flange, side one T_{f2}	Final state temperature of flange, side two T'_{f2}	Final state flange modulus of elasticity, side one E_{f2}	Final state flange modulus of elasticity, side two E'_{f2}	Final state bolt modulus of elasticity E_{b2}	Final state gasket modulus of elasticity E_{g2}
Variable	W1	TF[d]	TFP[d]	YF2	YFP2	YB2	YG2

[a] First card number applies when MATE = 2; second number applies when MATE = 3 and 4 or 5 and 6.

[b] The effective bolt load is calculated as ℓ_0 = XLB = TH + THP + VO + BSIZE + FACE.

[c] Values for G_1 and A_g are calculated using input variables XGO and XGI.

[d] Initial-state temperatures are defined as zero.

Card No.	Identification
1	Option control card with MATE = 2
2, 3	Data cards per Table 11
4, 5, 6	Data cards per Table 12

When ICØDE = 0 and MATE = 3, the program performs the calculations for a pair of nonidentical flanges, neither of which, however, is blind (i.e., ITYPE = 1 or 2 ≠ 3 on the option-control card). Data for the first flange of the pair follows the option-control card. Data for the second flange in the pair will follow an option-control card with MATE = 4. The three cards described in Table 12 will then complete the data requirements. The complete input data set for analyzing a pair of nonidentical flanges (neither of which is blind) consists of the following nine cards.

Card No.	Identification
1	Option-control card, ITYPE ≠ 3, ICØDE = 0, MATE = 3
2, 3	Data cards per Table 11 for first flange of pair
4	Option-control card, ITYPE ≠ 3, ICØDE = 0, MATE = 4
5, 6	Data cards per Table 11 for second flange of pair
7, 8, 9	Data cards per Table 12

When ICØDE = 0 and MATE = 5, the program performs the calculations for a flanged joint that is closed with a blind flange. For this option, the blind flange is designated as the first flange and the mating flange is designated as the second with MATE = 6. As before, the input data set is completed by using the data cards described in Table 12. The complete input data set for this case consists of the following nine cards.

Card No.	Identification
1	Option-control card, ITYPE = 3, ICØDE = 0, MATE = 5
2 3	Data cards per Table 11 for blind flange
4	Option-control card, ITYPE = 1 or 2, ICØDE = 0, MATE = 6
5 6	Data cards per Table 11 for second flange
7 8 9	Data cards per Table 12

Output from General Purpose Calculations

The amount and format of the data printed out are determined predominantly by the number and types of flanges being analyzed, which in turn are determined by the value of the option-control variable MATE. When MATE = 1, the output consists of one page of printout, which gives (1) the input data; (2) the three sets of stresses for moment loading only (the bolt load for blind flanges), pressure loading only, and temperature-gradient (hub to ring) loading only (except for blind flanges); and (3) the displacements produced by the calculated stresses. The symbols used on the printout are explained in Tables 13 and 14.

When MATE = 2, the output consists of three pages of printout. The first page gives (1) the input data and (2) the parameters involved in the bolt-load-change calculations. The second page gives (1) the loadings, (2) the residual bolt loads, and (3) the initial and residual moments. The symbols used in the first and second page of printout are explained in Tables 15 and 16. The third page gives the stresses and

Table 13. Output data identification, stresses, displacements, and rotation

Theory Symbol	Program symbol	Description
$(\sigma_\ell)_o$	SLSO[a]	Stress, longitudinal, small end of hub, outside surface
$(\sigma_\ell)_i$	SLSI[a]	Stress longitudinal, small end of hub, inside surface
$(\sigma_c)_o$	SCSO[a]	Stress, circumferential, small end of hub, outside surface
$(\sigma_c)_i$	SCSI[a]	Stress, circumferential, small end of hub, inside surface
$(\sigma_\ell)_o$	SLLO	Stress, longitudinal, large end of hub, outside surface
$(\sigma_\ell)_i$	SLLI	Stress, longitudinal, large end of hub, inside surface
$(\sigma_c)_o$	SCLO	Stress, circumferential, large end of hub, outside surface
$(\sigma_c)_i$	SCLI	Stress, circumferential, large end of hub, inside surface
$(\sigma_t)_o$	STH	Stress, tangential, hub side of ring, at $r = b$
$(\sigma_t)_i$	STF	Stress, tangential, face side of ring, at $r = b$
$(\sigma_r)_o$	SRH	Stress, radial, hub side of ring, at $r = b$
$(\sigma_r)_i$	SRF	Stress, radial, face side of ring, at $r = b$
δ_g	ZG	Axial displacement at $r = g$ ($\delta \equiv 0$ at $r = b$)
δ_c	ZC	Axial displacement at $r = c$ ($\delta \equiv 0$ at $r = b$)
$q_f h_G$	QFHG	$-\delta_c + \delta_g$
y_0	YO	Radial displacement, small end of hub
y_1	Y1	Radial displacement, large end of hub
	THETA	Rotation of ring at $r = b$
		<u>For blind flanges</u>[b]
σ_r, σ_t, $r = o$	SORT	Stress, $r = o$, radial and tangential
σ_r, $r = g$	SGR	Stress, $r = g$ radial
σ_t, $r = g$	SGT	Stress, $r = g$, tangential
σ_r, $r = c$	SCR	Stress, $r = c$, radial
σ_t, $r = c$	SCT	Stress, $r = c$, tangential
σ_t, $r = a$	SAT	Stress, $r = a$, tangential
δ_c	ZC	Axial displacement at $r = c$ ($\delta \equiv 0$ at $r = g$)

[a]For "Straight Hub Flange," these are at juncture of hub with ring.

[b]All stresses are for the side of the flange opposite the pressure-bearing side. Stresses on the pressurized side of the flange have reversed signs.

Table 14. Output data identification when MATE = 2, 3 and 4, or 5 and 6

Theory symbol	Program symbol	Description
$q_{f1}h_G$	QFHG	Axial displacement from C to G, unit moment load
$q_{p1}h_G$	QPHG	Axial displacement from C to G, unit pressure load
$q_{t1}h_G$	QTHG[a]	Axial displacement from C to G, unit DELTA
2b	XB[a,b]	Inside diameter
g_0	GO[a,b]	Pipe wall thickness
t	TH	Ring thickness
E_{f1}	YM[b]	Modulus of elasticity of flange material, initial state
E_{f2}	YF2[c]	Modulus of elasticity of flange material, final state
ε_f	EF[b]	Coefficient of thermal expansion of flange material
( )'	( )P	The above nine symbols with a prime mark (') on the theory symbols are for the mating flange. The program symbol has the added final letter "P."

[a]For blind flanges, these values are not significant; an artificial value of -1.0000 is printed out.

[b]These values are input data for flange side one, input cards 2 and 3 (see Table 11). For MATE = 2, these values, along with calculated values of QFHG, QPHG, and QTHG, are used for side one and side two (i.e., an identical pair). If MATE = 3 or 5, the primed values are stored; the unprimed values are read in by input cards 5 and 6, and values of QFHGP, QPHGP, and QTHGP are calculated.

[c]Input from card 6 for MATE = 2, card 9 for MATE = 3 and 4 or 5 and 6 (see Table 11).

Table 15. Output data identification, MATE = 2, 3 and 4, or 5 and 6, bolts, gasket, and loadings data

Theory symbol	Program symbol	Description[a]
ℓ	XLB	Effective bolt length
A_b	AB	Cross-sectional root area of all bolts
C	C	Bolt-circle diameter
E_{b1}	YB	Modulus of elasticity, bolts, initial state
E_{b2}	YB2	Modulus of elasticity, bolts, final state
ε_b	EB	Coefficient of thermal expansion, bolts
v_0	VO	Gasket thickness
	XGO	Outside diameter of gasket
	XGI	Inside diameter of gasket
E_{g1}	YG	Modulus of elasticity of gasket, initial state
E_{g2}	YG2	Modulus of elasticity of gasket, final state
ε_g	EG	Coefficient of thermal expansion, gaskets
W_1	W1	Initial total bolt load
T_b	TB	Temperature of bolts, final state
T_{f2}	TF	Temperature of flange ring, side one, final state
T'_{f2}	TFP	Temperature of flange ring, side two, final state
T_g	TG	Temperature of gasket, final state
Δ	DELTA	Thermal gradient, pipe/hub to ring, side one
Δ'	DELTAP	Thermal gradient, pipe/hub to ring, side two
P	PRESS	Internal pressure

[a]All values are input data, except XLB which is calculated by the equation: XLB = TH + THP + VO + BSIZE + FACE.

Table 16. Output data identification, MATE 2, 3 and 4, or 5 and 6, residual bolt loads and moments

Theory symbol	Program[a] symbol	Effect included
W_{2a}	W2A	Relative change in temperature of bolts, gasket, flange (AXIAL THERMAL)
W_{2b}	W2B	Change in moment arms (MOMENT SHIFT)
W_{2c}	W2C	Total pressure
W_{2d}	W2D	Thermal gradient, pipe/hub to ring (DELTA THERMAL)
W_2	W2	All of the above, plus change in modulus of elasticity (COMBINED)

[a]The change in bolt load (e.g., W1 - W2A) and ratio of residual to initial bolt load (e.g., W2A/W1) are also printed out, along with the corresponding values of the initial moment (M1) and residual moments, M2A, ..., M2P. The residual moment identifiers with final letter P (for prime) are for the first entered of a pair of nonidentical flanges. If the pair of flanges are identical, then M2B = M2BP, etc. The residual moment values are not significant for blind flanges, ITYPE = 3; therefore, residual bolt loads are used for blind flanges.

displacements as for the case when MATE = 1 plus the stresses and displacements for combined loading. The heading includes the value of the residual moments M2 = M2P used for the combined-loading calculations.

When MATE = 3 and 4 or 5 and 6, the output consists of four pages of printout. The first two pages have the same format as for the case when MATE = 2, except input data for both of the (nonidentical) flanges are printed. The residual moments on the last line of page 2 apply to flange one; those on the preceding line apply to flange two. The last two pages of printout are for flange one and flange two, respectively, and are identical in format to the third page of the printout for the case when MATE = 2.

Acknowledgment

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APPENDIX A

EXAMPLES OF APPLICATION OF COMPUTER PROGRAM FLANGE

APPENDIX A

CONTENTS

INTRODUCTION

Several examples have been selected to illustrate the input/output data of the computer program FLANGE and the significance of the results. The flange selected for analysis is one included in API Standard 605.* The particular size and rating selected was the 60-in., 300-lb tapered-hub flange. This particular flange represents a design in which the bolt stresses and flange stresses are close to the upper limits set in API-605.

Six examples are included:

1. A Code stress calculation is performed for a tapered-hub flange at its rated pressure of 720 psi at 100°F. The results show that this particular flange does indeed meet the criteria given in API-605 at 720 psi and 100°F.
2. A Code stress calculation is performed for a blind flange to match the 60-in., 300-lb API-605 tapered-hub flange. The thickness of the blind flange was selected so that its maximum stress was the allowable flange stress of 17,500 psi used in API-605.
3. A blind flange bolted to a tapered-hub flange under pressure loading only is analyzed.
   (a) For an initial bolt stress equal to the API-605 allowable stress for the bolting material of 20,000 psi, the results indicate that the flanged joint will probably leak at its rated pressure of 720 psi at 100°F.
   (b) For an initial bolt stress of 44,300 psi, the results indicate that the flanged joint will pass a hydrostatic test of 1.5 × 720 psi at ambient temperature.
4. A tapered-hub flange bolted to an identical tapered-hub flange with an initial bolt stress of 46,100 psi is analyzed.

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* *Large-Diameter Carbon Steel Flanges (Size: 26 Inches to 30 Inches, Inclusive, Nominal Pressure Rating: 75, 150, and 300 lb)*, API Standard 605, 1st Ed., American Petroleum Inst., New York, 1967.

(a) For pressure loading only, the results indicate that the flanged joint will hold a hydrostatic test pressure of 1.5×720 psi.

(b) For pressure loading of 300 psi (API-605 rated pressure at 850°F) plus an external bending moment that produces an axial stress in the attached pipe of 7500 psi, the results indicate that the flanged joint is adequate to carry these loads.

DETAILS OF THE FLANGE USED IN THE EXAMPLES

A sketch of the tapered-hub flange is shown in Fig. A.1. The dimensions are as specified in API-605. The inside diameter and dimensions B (and therefore g_0 and g_1) are not specified in API-605. For the purpose of checking ratings, the following equation given in API-605 was used to establish B:

$$B = D_o - 2t_p \ , \tag{A.1}$$

where

D_o = nominal outside diameter of pipe, in.;
t_p = $p_1 D_o / 2(0.875)S$ (but not less than 0.25), in.;
p_1 = rated pressure at 100°F, psi;
0.875 = assumed pipe-wall tolerance; and
S = 20,000 psi, the allowable stress at 100°F.

The definition of t_p, with D_o = 60 in. and p_1 = 720 psi, leads to t_p = g_0 = 1.2343 in. Equation (A.1) gives B = 57.5314 in. and g_1 = (X-B)/2 = 2.7030 in.

For the purpose of checking ratings, the hub length h was calculated by the equation given in API-605:

$$h = Y - t + 0.176g_0 + 0.469 \ .$$

Dimensions Y and t are shown in Fig. A.1. For this flange:

$$h = 10.6875 - 5.9375 + 0.176(1.2343) + 0.469 = 5.4362 \text{ in.}$$

The API-605 standard states that flange ratings were based on use of a 1/16-in.-thick, compressed-asbestos, flat ring-shaped gasket, with an inside diameter 1/4 in. larger than the outside diameter of the pipe and with an outside diameter equal to the raised-face diameter. For the 60-in., 300-lb flange, the gasket inside diameter is 60.25 in.; its

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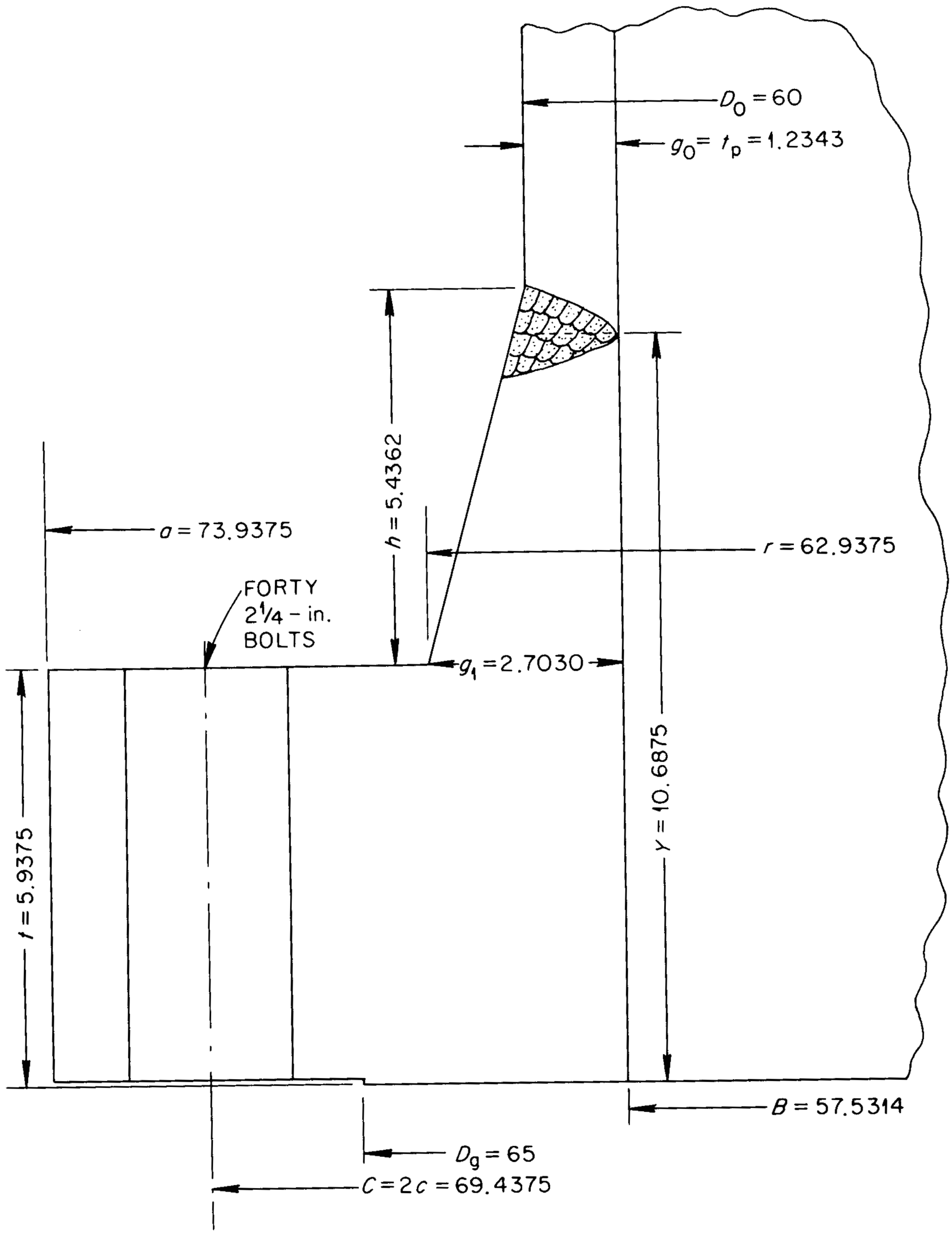

DIMENSIONS IN INCHES

Fig. A.1. Dimensions (in inches) of 60-in., 300-lb API-605 tapered-hub flange. The terms B, R, C, D_o, X, and A are diameters expressed in inches.

outside diameter is 65 in. According to the ASME Code, for a 1/16-in.-thick asbestos gasket, $m = 2.75$, and $y = 3700$ psi.

The 60-in., 300-lb flange has forty 2-1/4-in.-diam. bolts. For an 8-pitch thread, the root area per bolt is 3.423 in.^{2}, giving a total bolt root area of 136.92 in.^{2}.

ASME CODE CALCULATIONS, EXAMPLES 1 AND 2

The input data for examples 1 and 2 are shown in Table A.1. The source of all input for Cards 2 and 3 are contained in the previous section on flange details, except that the thickness of the blind flange was selected* so that the controlling flange stress is 17,500 psi. Note that Card 2 is identical for examples 1 and 2 except for the value of t; however, B, g_0, g_1, and h are not used for example 2 (blind flange), and any number (including zero) can be entered for these dimensions.

Example 1 is a Code stress calculation for the 60-in., 300-lb API-605 tapered-hub flange at its rated pressure of 720 psi at 100°F. The output data are shown in Table A.2. The value of SB1 = 20,033 psi is the controlling bolt stress, which essentially meets the API criterion value of a bolt stress not greater than 20,000 psi. The value of (SH + ST)/2 = 17,293 psi under the heading "ASME FLANGE STRESSES AT OPERATING MOMENT, MOP" is the controlling flange stress and meets the API-605 criterion of a controlling flange stress not greater than 17,500 psi. The results, therefore, confirm that the 60-in., 300-lb API-605 tapered-hub flange meets the stated criteria.

The reader who is accustomed to using hand calculations for checking flange designs according to Code rules will note that the program input does not require either the factors T, U, Y, Z from Code Fig. UA-51.1, or F, V, and f from Code Figs. UA-51.2, UA-51.3, and UA-51.6, respectively. These factors are calculated by the computer program. In addition to simplifying the input, the program accurately calculates F, V, and f values for any values of h/h_0 and g_1/g_0, including those beyond the range of the Code figures.

Example 2 is a Code stress calculation for a blind flange to match the 60-in., 300-lb API-605 tapered-hub flange. The calculation method is that given in UG-34 [Eq. (2)], with C = 0.3. The output data are shown in Table A.3. The controlling flange stress is SOP = 17,500 psi;

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*API-605 does not give blind-flange thicknesses.

Table A.1. Input data for ASME Code stress calculations, examples 1 and 2

First card

Column number	5	10	15	20
Variable	ITYPE	IBØND	ICØDE	MATE
Example 1	1	0	2	1
Example 2	3	0	2	1

Second card

Column number	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80
Variable	A	B	t	g_0	g_1	h	C	P
Example 1	73.9375	57.5314	5.9375	1.2343	2.7030	5.4362	69.4375	720.
Example 2	73.9375	57.5314[a]	7.9044	1.2343[a]	2.7030[a]	5.4362[a]	69.4375	720.

Third card

Column number	0-10	11-20	21-30	31-40	41-50	51-60	61-70[b]	72	73-80
Variable	m	y	G_o	G_i	S_b	S_a	A_b	I	b_o
Example 1	2.75	3700.	65.	60.25	20000.	20000.	136.92	0	0
Example 2	2.75	3700.	65.	60.25	20000.	20000.	136.92	0	0

[a]Not used in calculations for a blind flange.
[b]Column 71 is blank.

Table A.2. Output data for example 1, ASME Code analysis of a tapered-hub flange

FLANGE O.D.,A	FLANGE I.D.,B	FLANGE THICK.,T	PIPE WALL,GO	HUB AT BASE,G1	HUB LENGTH,H	BOLT CIRCLE,C	PRESSURE, P
73.93750	57.53140	5.93750	1.23430	2.70300	5.43620	69.43750	720.000

M	Y	GOUT	GIN	SB	SA	AB
2.75000	3700.00000	65.00000	60.25000	20000.00000	20000.00000	136.92000

BO	WM11	WM12	WM1	SB1	WM2	SB2
1.1875D 00	2.3097D 06	4.3322D 05	2.7430D 06	2.0033D 04	4.0477D 05	2.9563D 03

MOP	MGS	MGS1
1.1719D 07	7.5742D 06	1.1186D 06

ASME FLANGE STRESSES AT OPERATING MOMENT, MOP

(2/3)*SH= 1.5608D 04 ST = 1.1174D 04 SR = 8.4442D 03 (SH+ST)/2= 1.7293D 04 (SH+SR)/2= 1.5928D 04

ASME FLANGE STRESSES AT GASKET SEATING MOMENT, MGS

(2/3)*SH= 1.0087D 04 ST = 7.2216D 03 SR = 5.4576D 03 (SH+ST)/2= 1.1176D 04 (SH+SR)/2= 1.0294D 04

Table A.3. Output data for example 2, ASME Code analysis of a blind flange

FLANGE O.D.,A	FLANGE I.D.,B	FLANGE THICK.,T	PIPE WALL,GO	HUB AT BASE,G1	HUB LENGTH,H	BOLT CIRCLE,C	PRESSURE, P
73.93750	0.0	7.90440	0.0	0.0	0.0	69.43750	720.000

M	Y	GOUT	GIN	SB	SA	AB
2.75000	3700.00000	65.00000	60.25000	20000.00000	20000.00000	136.92000

BO	WM11	WM12	WM1	SB1	WM2	SB2
1.1875D 00	2.3097D 06	4.3322D 05	2.7430D 06	2.0033D 04	4.0477D 05	2.9563D 03

ASME CODE STRESSES FOR BLIND FLANGE

SP	SW1	SOP	SW2	SGS
1.4121D 04	3.3792D 03	1.7500D 04	4.9865D 02	3.3763D 03

the flange thickness of 7.9044 in. was selected to obtain this result. This example was included to illustrate that a blind flange may have to be considerably thicker than a mating flange in order for both to meet the Code stress limitations.

BLIND-TO-TAPERED-HUB FLANGED JOINT, EXAMPLES 3(a) AND 3(b)

Input Data

The input data for examples 3(a) and 3(b) are shown in Table A.4. In addition to the basic purpose of illustrating input/output data for the program FLANGE, this pair of examples was selected to show how the program can be used to estimate required initial bolt stresses. In addition, example 3(a) shows how the general purpose option (ICODE $\neq$ 2) gives stresses as obtained from Code calculations plus deformation data and additonal stresses.

Examples 3(a) and (b) do not involve temperature gradients or temperatures other than ambient; hence, the modulus of elasticity is the same for the initial and final states. Values of temperatures for the flanges, bolts, and gaskets in the final state have been entered as zero. The initial-state reference temperature is zero; hence, a zero in the final state denotes a zero thermal gradient. However, the value of DELTA (the hub-to-ring thermal gradient) cannot be entered as zero without causing a divide-check error, so a value of 0.01 was used. A smaller value could be used (e.g., 0.001 or 0.0001), but the output data shows that DELTA = 0.01 is sufficiently small so that its influence is negligible. A coefficient of thermal expansion of 6×10^{-6} has been entered but is not significant in these examples.

The value of FACE, which is intended to permit use of a bolt length other than ℓ_0 = TH + THP + VO + BSIZE, was entered as zero. The modulus of elasticity for both the flanges and the bolts was assumed to be 3×10^7 psi. The modulus of elasticity for the 1/16-in.-thick asbestos gasket was assumed to be 3×10^6 psi.

Some comments on the use of a modulus of elasticity of 3×10^6 for a 1/16-in. asbestos gasket may be appropriate. The stress-strain relationship for such a gasket, which is confined between the two rigid flange faces, is highly nonlinear and both time and history dependent. Starting out with a new gasket, the first increment of bolt stress to produce a gasket stress of 1000 psi might decrease the gasket thickness

Table A.4. Input data for blind-to-tapered-hub flanged joint, examples[a] 3a and 3b

Card No.	Variables and numerical values								Read format
1	ITYPE	IBOND	ICODE	MATE					
	3	0	0	5					415
2	A	B	t	g_0	g_1	h	C	p	
	73.9375	57.5314	7.9044	1.2343	2.7030	5.4362	69.4375	720.	8E10.5
								(1080.)	
3	XMOA[b]	EF	DELTA[c]	YM	G				
	2.7430D+6	6. D-6	.01	3. D+7	62.625				5E10.5
	(6.0656D+6)								
4	ITYPE	IBOND	ICODE	MATE					
	1	0	0	6					4I5
5	A	B	t	g_0	g_1	h	C	p	
	73.9375	57.5314	5.9375	1.2343	2.7030	5.4362	69.4375	720.	8E10.5
								(1080.)	
6	XMOA	EF	DELTA[c]	YM	G				
	1.1719D+7	6. D-6	.01	3. D+7	62.625				5E10.5
	(2.0661D+7)								
7	BSIZE	YB	EB	TB	XGO	XGI	AB		
	2.25	3. D+7	6. D-6	0	65.	60.25	136.92		7E10.5
8	VO	YG	EG	TG	FACE	PBE			
	.0625	3. D+6	6. D-6	0	0	0			6E10.5
9	W1	TF	TFB	YF2	YFP2	YB2	YG2		
	2.7430D+6	0	0	3. D+7	3. D+7	3. D+7	3. D+6		7E10.5
	(6.0656D+6)								

[a]Values in parentheses are for example 3b.

[b]Initial bolt load is used here since ITYPE = 3; see footnote *b* to Table 11 in the text.

[c]Since DELTA cannot be entered as zero, 0.01 was used as a satisfactorily small value.

by 20%, so that the modulus would be $1000/(0.2 \times 0.0625) = 8 \times 10^4$ psi. Crude observations indicate that, at a bolt stress that produces a gasket stress of 40,000 psi, the gasket thickness is about one-half of its original thickness, so that the average modulus up to this stress is $40{,}000/0.03125 = 1.28 \times 10^6$ psi. These numbers are dependent upon the ratio of width to thickness of the gasket and the time under stress, particularly for low gasket stress. However, for the flanged-joint analysis, we are not interested in the gasket stress-strain characteristics when the bolt load is applied but rather in the gasket stress-strain characteristics when the gasket stress is decreased after the gasket has been under bolt load for several days or many months. No data on the "spring-back" of asbestos gaskets are available, but in most flanged joints using 1/16-in.-thick asbestos gaskets, the assumed modulus of elasticity of the gasket is not very significant provided it is not unrealistically low. This can be shown for example 3 by noting that the change in the bolt load depends upon the sum of the load-displacement characteristics of the bolts, the flanges, and the gasket. The displacements for a unit bolt load are —

$$\text{for bolts:} \quad \frac{\ell_0}{A_b E_b} = \frac{16.15}{136.92 \times 3 \times 10^7} = 3.93 \times 10^{-9} \ ,$$

$$\text{for flanges:} \quad 2 \times \text{QFHG} = 2(1.197 \times 10^{-9}) = 2.40 \times 10^{-9} \ ,$$

and

$$\text{for gasket:} \quad \frac{V_0}{A_G E_G} = \frac{0.0625}{467.26 \times E_G} = \frac{1.34 \times 10^{-4}}{E_G} \ .$$

As E_G varies from 10^5 to 10^7, the sum of these three displacements varies as follows:

E_G	10^5	3×10^5	10^6	3×10^6	10^7
Sum of displacements ($\times 10^9$ in.)	7.67	6.78	6.46	6.37	6.34

From the above, it can be seen that changing the gasket modulus by two orders of magnitude changes the sum of the displacement by only 17%.

The initial bolt stress used in example 3(a) is 20,033 psi, giving an initial bolt load of $W1 = S_b A_b = 20{,}033 \times 136.92 = 2.743 \times 10^6$ lb; W1 is entered in place of XMOA on card 6 (see footnote *b* to Table 11 of text). The initial moment, XMOA, used in example 3(a) is 1.1719×10^7 in.-lb. The initial bolt stress used in example 3(b) is 44,300 psi, giving an initial bolt load of $W1 = 6.0656 \times 10^6$ lb. The initial moment, XMOA, used in example 3(b) is 2.0661×10^7 in.-lb. The reasons for using these particular values of W1 and XMOA are discussed in connection with the output data for these examples.

Output Data

Residual Bolt Loads

The output data for example 3(a) are shown in Table A.5. The output starts with a printout of all input data on the first page (Table A.5a).* The parameters involved in the bolt-load-change calculations are then printed, followed by residual bolt loads and moments, all on the second page (Table A.5b). The initial bolt load under "LOADINGS" is 2.743×10^6 lb; the residual bolt load after application of the pressure of 720 psi is given following "COMBINED" as $W2 = 1.0948 \times 10^6$ lb. The loss in bolt load is given by $W1 - W2 = 1.6482 \times 10^6$ lb, and the ratio of residual to initial bolt load is given by W2/W1 = 0.39911. Calculated stresses for the blind flange and for the tapered-hub flange are printed on the third and fourth pages (Tables A.5c and A.5d, respectively). These are discussed later.

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*For convenience in referring to specific pages of multipage tables, we have used alphabetic suffixes on table numbers. For example, the first page of Table A.5 is designated Table A.5a; the second page is Table A.5b, the third is Table A.5c, etc.

Table A.5a. Output data for example 3(a), blind flange bolted to a tapered-hub flange, with initial bolt stress = 20,033 psi*

FLANGE O.D.,A	FLANGE I.D.,B	FLANGE THICK.,T	PIPE WALL,G0	HUB AT BASE,G1	HUB LENGTH,H	BCLT CIRCLE,C	PRESSURE, P
73.93750	57.53140	7.90440	1.23430	2.70300	5.43620	69.43750	720.000

BOLT LOAD	COEFF. OF THERMAL EXP.	DELTA	MOD. OF ELASTICITY	MEAN GASKET DIAMETER	ITYPE	IBCND	ICODE	MATE
2.743D 06	6.000D-06	1.000D-02	3.000D 07	6.263D 01	3	0	0	5

FLANGE O.D.,A	FLANGE I.D.,B	FLANGE THICK.,T	PIPE WALL,G0	HUB AT BASE,G1	HUB LENGTH,H	BCLT CIRCLE,C	PRESSURE, P
73.93750	57.53140	5.93750	1.23430	2.70300	5.43620	69.43750	720.000

MOMENT	COEFF. OF THERMAL EXP.	DELTA	MOD. OF ELASTICITY	MEAN GASKET DIAMETER	ITYPE	IBCND	ICODE	MATE
1.172D 07	6.000D-06	1.000D-02	3.000D 07	6.263D 01	1	0	0	6

BSIZE	YB	EB	TB	XGO	XGI	AB
2.2500D 00	3.0000D 07	6.0000D-06	0.0	6.5000D 01	6.0250D 01	1.3692D 02
VO	YG	EG	TG	FACE	PBE	
6.2500D-02	3.0000D 06	6.0000D-06	0.0	0.0	0.0	
W1	TF	TFP	YF2	YFP2	YB2	YG2
2.7430D 06	0.0	0.0	3.0000D 07	3.0000D 07	3.0000D 07	3.0000D 06

FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, BLIND TO INTEGER PAIR

FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QFHG= 9.4994D-10 QPHG= 6.5350D-06 QTHG= -1.0000D 00 XB = -1.0000D 00 GO= -1.0000D 00 TH = 7.9044D 00
YM = 3.0000D 07 YF2 = 3.0000D 07 EF = 6.0000D-06

FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QFHG= 1.1968D-09 QPHG= 8.0422D-06 QTHG= 9.5590D-05 XB = 5.7531D 01 GO= 1.2343D 00 TH = 5.9375D 00
YM = 3.0000D 07 YF2 = 3.0000D 07 EF = 6.0000D-06

BOLTING

BOLT LENGTH= 1.6154D 01 BCLT AREA= 1.3692D 02 BOLT CIRCLE= 6.9438D 01
YB = 3.0000D 07 YB2 = 3.0000D 07 EB = 6.0000D-06

GASKET

VO = 6.2500D-02 XGO = 6.5000D 01 XGI = 6.0250D 01
YG = 3.0000D 06 YG2 = 3.0000D 06 EG = 6.0000D-06

*For the convenience of the user, the first page of Table A.5 is designated Table A.5a, the second page is Table A.5b, the third is Table A.5c, etc. This convention is also used in the following tables.

Table A.5b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  2.7430D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0           DELTA=  1.0000D-02   DELTAP=  1.00C0D-02  PRESSURE=  7.2000D 02

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  2.7430D 06  MOMENT SHIFT,W2B=  2.2294D 06

TOTAL PRESSURE,W2C=  1.0949D 06   DELTA THERMAL,W2D=  2.7429D 06

COMBINED,W2=  1.0948D 06


W1-W2A=  0.0          W1-W2B=  5.1359D 05  W1-W2C=  1.6481D 06  W1-W2D=  1.0333D 02  W1-W2=   1.6482D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.1276D-01  W2C/W1=  3.9915D-01  W2D/W1=  9.9996D-01  W2/W1=  3.9911D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  9.3433D 06  M2A=  9.3433D 06  M2B=  1.1646D 07  M2C=  7.7818D 06  M2D=  9.3430D 06  M2=  7.7814D 06

M2BP=  4.2880D 07  M2CP=  3.9015D 07  M2P=  3.9C15D 07
```

Table A.5c (continued)

```
        BLIND FLANGE

   CALCULATIONS FOR BOLT LOADING

SORT=  4.0213D 03   SGR=  4.0213D 03   SGT=  4.0213D 03   SCR= -1.6157D 02   SCT=  2.5764D 03   SAT=  2.4148D 03
    ZC= -2.6057D-03

   CALCULATIONS FOR PRESSURE LOADING

SORT=  1.3144D 04   SGR= -8.3815D 02   SGT=  5.0937D 03   SCR= -2.8472D 02   SCT=  4.5403D 03   SAT=  4.2555D 03
    ZC= -4.7052D-03

  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2,  W2 FOR ITYPE=3,  =   1.0948D 06

SORT=  1.4749D 04   SGR=  7.6681D 02   SGT=  6.6987D 03   SCR= -3.4921D 02   SCT=  5.5685D 03   SAT=  5.2193D 03
    ZC= -5.7452D-03
```

Table A.5d (continued)

```
        TAPERED HUB FLANGE
   CALCULATICNS FOR MOMENT LOADING

SLSO=  2.3042D 04  SLSI= -2.3042D 04  SCSO=  1.9763D 04  SCSI=  5.9379D 03
SLLO=  2.3411D 04  SLLI= -2.3411D 04  SCLO=  7.0234D 03  SCLI= -7.0234D 03
 STH=  1.1173D 04   STF= -1.8482D 04   SRH=  8.4441D 03   SRF= -6.6480D 03
ZG= -1.0421D-02  ZC= -2.4446D-02  QFHG=  1.4026D-02  Y0=  1.2322D-02  Y1=  1.0058D-18  THETA= -4.0579D-03
   CALCULATICNS FOR PRESSURE LOADING

SLSO=  1.4194D 04  SLSI=  2.5863D 03  SCSO=  1.4398D 04  SCSI=  1.0915D 04
SLLO=  1.8645D 03  SLLI=  5.7979D 03  SCLO=  5.5935D 02  SCLI=  1.7394D 03
 STH=  9.3311D 03   STF= -1.1002D 03   SRH= -2.2932D 03   SRF=  2.7038D 02
ZG= -4.5114D-03  ZC= -1.0302D-02  QFHG=  5.7904D-03  Y0=  9.7224D-03  Y1=  6.0715D-18  THETA= -1.8088D-03
   CALCULATIONS FOR TEMPERATURE LOADING

SLSO=  1.2228D 00  SLSI= -1.2228D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.8419D 00  SCLI= -1.7581D 00
 STH=  1.1087D C0   STF= -6.1330D-01   SRH= -2.7247D-01   SRF=  1.5072D-01
ZG= -7.4476D-07  ZC= -1.7007D-06  QFHG=  9.5590D-07  Y0= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9860D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FCR ITYPE=1 OR 2,  W2 FOR ITYPE=3,  =   7.7814D 06

SLSO=  3.3385D C4  SLSI= -1.6605D 04  SCSO=  3.0857D 04  SCSI=  1.5860D 04
SLLO=  2.1362D 04  SLLI= -1.3700D 04  SCLO=  6.4068D 03  SCLI= -4.1117D 03
 STH=  1.8638D 04   STF= -1.6493D 04   SRH=  4.7391D 03   SRF= -5.2661D 03
ZG= -1.3191D-02  ZC= -3.0663D-02  QFHG=  1.7472D-02  Y0=  1.9984D-02  Y1= -1.7259D-06  THETA= -5.1886D-03
```

To avoid leakage,* the residual bolt load must not be less than the critical value W_c, which may be obtained from simple equilibrium considerations; thus,

$$W_c = \frac{\pi}{4} G_0^2 p \ , \qquad (A.2)$$

where

W_c = "critical" bolt load,
G_0 = outside diameter of gasket (65 in. in this example), and
p = pressure (720 psi in this example).

In this example, the value of W_c is

$$W_c = \frac{\pi}{4} \times 65^2 \times 720 = 2.389 \times 10^6 \text{ lb} \ .$$

Because W_c is significantly greater than W2 = 1.0948×10^6 lb, the results for example 3(a) indicate that the joint will leak at the rated pressure with the initial bolt stress of 20,033 psi. The results illustrate an aspect of ASME-designed flanges that is well known to many users; that is, the joints often cannot be made leaktight (especially in order to pass the hydrostatic test) by applying an initial bolt stress equal to the Code-allowable bolt stress.

The output data for example 3(b) are shown in Table A.6. Example 3(b) is the same as 3(a), except that the initial bolt stress has been increased from 20,033 psi to 44,300 psi (W1 input under XMOA increased to 2.0661×10^7); the initial moment has been correspondingly increased; and the pressure has been increased from 720 psi to 1080 psi, the latter being the hydrostatic-test pressure of 1.5 times the cold rating pressure. It can be seen in Table A.6 (on the second page, Table A.6b) that the

---

*Leakage is defined as the gross type of leakage that occurs when the load on the gasket is reduced to zero. Slow, diffusion-type leakage may occur at lower pressures.

Table A.6a. Output data for example 3(b), blind flange bolted to a tapered-hub flange, with initial bolt stress = 44,300 psi

FLANGE O.D.,A	FLANGE I.D.,B	FLANGE THICK.,T	PIPE WALL,GO	HUB AT BASE,G1	HUB LENGTH,H	BOLT CIRCLE,C	PRESSURE, P
73.93750	57.53140	7.90440	1.23430	2.70300	5.43620	69.43750	1080.000

BOLT LOAD	COEFF. OF THERMAL EXP.	DELTA	MOD. OF ELASTICITY	MEAN GASKET DIAMETER	ITYPE	IBOND	ICODE	MATE
6.066D 06	6.000D-06	1.000D-02	3.000D 07	6.263D 01	3	0	0	5

FLANGE O.D.,A	FLANGE I.D.,B	FLANGE THICK.,T	PIPE WALL,GO	HUB AT BASE,G1	HUB LENGTH,H	BOLT CIRCLE,C	PRESSURE, P
73.93750	57.53140	5.93750	1.23430	2.70300	5.43620	69.43750	1080.000

MOMENT	COEFF. OF THERMAL EXP.	DELTA	MOD. OF ELASTICITY	MEAN GASKET DIAMETER	ITYPE	IBOND	ICODE	MATE
2.066D 07	6.000D-06	1.000D-02	3.000D 07	6.263D 01	1	0	0	6

BSIZE	YB	EB	TB	XGO	XGI	AB
2.2500D 00	3.0000D 07	6.0000D-06	0.0	6.5000D 01	6.0250D 01	1.3692D 02
VO	YG	EG	TG	FACE	PBE	
6.2500D-02	3.0000D 06	6.0000D-06	0.0	0.0	0.0	
W1	TF	TFP	YF2	YFP2	YB2	YG2
6.0656D 06	0.0	0.0	3.0000D 07	3.0000D 07	3.0000D 07	3.0000D 06

FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, BLIND TC INTEGER PAIR

FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QFHG= 9.4994D-10 QPHG= 6.5350D-06 QTHG= -1.0000D 00 XB = -1.0000D 00 GO= -1.0000D 00 TH = 7.9044D 00
YM = 3.0000D 07 YF2 = 3.0000D 07 EF = 6.0000D-06

FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QFHG= 1.1968D-09 QPHG= 8.0422D-06 QTHG= 9.5590D-05 XB = 5.7531D 01 GO= 1.2343D 00 TH = 5.9375D 00
YM = 3.0000D 07 YF2 = 3.0000D 07 EF = 6.0000D-06

BOLTING

BOLT LENGTH= 1.6154D 01 BOLT AREA= 1.3692D 02 BOLT CIRCLE= 6.9438D 01
YB = 3.0000D 07 YB2 = 3.0000D 07 EB = 6.0000D-06

GASKET

VO = 6.2500D-02 XGO = 6.5000D 01 XGI = 6.0250D 01
YG = 3.0000D 06 YG2 = 3.0000D 06 EG = 6.0000D-06

Table A.6b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  6.0656D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0          DELTA=  1.0000D-02   DELTAP=  1.0000D-02  PRESSURE=  1.0800D 03

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  6.0656D 06  MOMENT SHIFT,W2E=  5.2952D 06

TOTAL PRESSURE,W2C=  3.5934D 06   DELTA THERMAL,W2D=  6.0655D 06

COMBINED,W2=  3.5933D 06

W1-W2A=  0.0          W1-W2B=  7.7038D 05  W1-W2C=  2.4722D 06  W1-W2D=  1.0333D 02  W1-W2=   2.4723D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.7299D-01  W2C/W1=  5.9242D-01  W2D/W1=  9.9998D-01  W2/W1=  5.9240D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  2.0661D 07  M2A=  2.0661D 07  M2B=  2.4115D 07  M2C=  1.8319D 07  M2D=  2.0661D 07  M2=  1.8318D 07

M2BP=  7.0966D 07  M2CP=  6.5169D 07  M2P=  6.5168D 07
```

Table A.6c (continued)

```
      BLIND FLANGE
   CALCULATIONS FOR BOLT LOADING

SORT=  8.8924D 03   SGR=  8.8924D 03   SGT=  8.8924D 03   SCR= -3.5727D 02   SCT=  5.6971D 03   SAT=  5.3399D 03
    ZC= -5.7620D-03

   CALCULATICNS FOR PRESSURE LOADING

SORT=  1.9716D 04   SGR= -1.2572D 03   SGT=  7.6405D 03   SCR= -4.2709D 02   SCT=  6.8104D 03   SAT=  6.3833D 03
    ZC= -7.0578D-03

  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2,  W2 FOR ITYPE=3,  =   3.5933D 06

SORT=  2.4984D 04   SGR=  4.0107D 03   SGT=  1.2908D 04   SCR= -6.3873D 02   SCT=  1.0185D 04   SAT=  9.5467D 03
    ZC= -1.0471D-02
```

Table A.6d (continued)

TAPERED HUB FLANGE

CALCULATIONS FOR MOMENT LOADING

SLSO= 4.0624D 04 SLSI= -4.0624D 04 SCSO= 3.4843D 04 SCSI= 1.0469D 04

SLLO= 4.1275D 04 SLLI= -4.1275D 04 SCLO= 1.2382D 04 SCLI= -1.2382D 04

STH= 1.9699D 04 STF= -3.2584D 04 SRH= 1.4887D 04 SRF= -1.1721D 04

ZG= -1.8372D-02 ZC= -4.3100D-02 QFHG= 2.4728D-02 Y0= 2.1724D-02 Y1= 2.1553D-19 THETA= -7.1542D-03

CALCULATIONS FOR PRESSURE LOADING

SLSO= 2.1290D 04 SLSI= 3.8794D 03 SCSO= 2.1596D 04 SCSI= 1.6373D 04

SLLO= 2.7967D 03 SLLI= 8.6968D 03 SCLO= 8.3902D 02 SCLI= 2.6090D 03

STH= 1.3997D 04 STF= -1.6503D 03 SRH= -3.4397D 03 SRF= 4.0556D 02

ZG= -6.7671D-03 ZC= -1.5453D-02 QFHG= 8.6856D-03 Y0= 1.4584D-02 Y1= 6.0715D-18 THETA= -2.7132D-03

CALCULATIONS FOR TEMPERATURE LOADING

SLSO= 1.2228D 00 SLSI= -1.2228D 00 SCSO= 1.0649D-01 SCSI= -6.2722D-01

SLLO= -1.3977D-01 SLLI= 1.3977D-01 SCLO= -1.8419D 00 SCLI= -1.7581D 00

STH= 1.1087D 00 STF= -6.1330D-01 SRH= -2.7247D-01 SRF= 1.5072D-01

ZG= -7.4476D-07 ZC= -1.7007D-06 QFHG= 9.5590D-07 Y0= -2.4965D-07 Y1= -1.7259D-06 THETA= -2.9860D-07

CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2, W2 FOR ITYPE=3, = 1.8318D 07

SLSO= 5.7309D 04 SLSI= -3.2139D 04 SCSO= 5.2489D 04 SCSI= 2.5654D 04

SLLO= 3.9392D 04 SLLI= -2.7898D 04 SCLO= 1.1816D 04 SCLI= -8.3712D 03

STH= 3.1463D 04 STF= -3.0541D 04 SRH= 9.7592D 03 SRF= -9.9860D 03

ZG= -2.3057D-02 ZC= -5.3667D-02 QFHG= 3.0610D-02 Y0= 3.3844D-02 Y1= -1.7259D-06 THETA= -9.0565D-03 residual bolt load after application of a pressure of 1080 psi is $W2 = 3.5933 \times 10^6$ lb. The value of the critical bolt load to prevent gross leakage is

$$W_c = \frac{\pi}{4} \times 65^2 \times 1080 = 3.584 \times 10^6 \text{ lb} .$$

With an initial bolt stress of 44,300 psi, the residual bolt load is now greater than W_c. Accordingly, the results of example 3(b) indicate that an initial bolt stress of 44,300 psi is sufficient for the joint to pass a hydrostatic test to 1080 psi, albeit with no margin of safety. As the reader may have surmised, the initial bolt stress of 44,300 psi was preselected for example 3(b) to achieve this final result. It is pertinent to note that, because of the linear nature of the calculations, it is not necessary to iterate in order to find a value for the initial bolt stress that would make $W2 = W_c$. Note that $(W1 - W2) = 1.648 \times 10^6$ in example 3(a) and that (W1 - W2) varies linearly with pressure. To find the required value of W1 to make $W2 = W_c$ at an arbitrary pressure p, we need only solve the equation:

$$W1 = \frac{\pi}{4} G_0^2 \, p + \frac{p}{720} (1.648 \times 10^6) . \qquad \text{(A.3)}$$

For p = 1080, Eq. (A.3) gives $W1 = 6.056 \times 10^6$, and the corresponding initial bolt stress is $W1/A_b = 6.056 \times 10^6/136.92 = 44{,}228$ psi, which was rounded off to 44,300 psi for Example 3(b).

Blind Flange Stresses, Example 3(a)

Example 3(a) was run with an initial bolt stress of 20,033 psi to permit direct comparison of the blind-flange stresses with the stresses calculated in example 2, where the controlling bolt stress was SB1 = 20,033 psi.

Stresses for the blind flange are shown in Table A.5c. The maximum stress due to initial bolt loading only is SORT = 4021.3 psi. A comparable stress from the Code calculation (Table A.3), is SGS = 3376.3 psi.

This also represents a stress at the center of the blind flange due to bolt loading only. The maximum stress due to pressure loading only of the blind flange (Table A.5c) is SORT = 13,144 psi. A Comparable stress from the Code calculation (Table A.3) is SP = 14,121 psi.

The maximum stress due to combined bolt loading and pressure loading (Table A.5c) is SORT = 14,749 psi. Note that this combined stress is not the sum of the stress due to the initial bolt load and the stress due to pressure. Rather, the program recognizes that the pressure changes the bolt load — in this example, from 2.743×10^6 lb down to 1.0948×10^6 (Table A.5b). Stresses for combined loadings are related to stresses for initial bolt loading only and pressure only by the equation

$$\sigma_c = \sigma_b \cdot \frac{W2}{W1} + \sigma_p \ , \tag{A.4}$$

where σ_c = combined stress, σ_b = stress due to initial bolt load only, W2 = bolt load at pressure, W1 = initial bolt load, and σ_p = stress due to pressure only.

The Code equation for combined stresses [i.e., $S = (d/t)^2(0.3p + 1.78Wh_G)$ from paragraph UG-34 and Figs. UG-34 (j) and (k)] can be derived by assuming that the blind flange is a flat circular plate of outside diameter equal to the effective gasket diameter d. The metal outside the diameter d is ignored. The plate is simply supported along d and loaded by edge moment Wh_G and pressure p. Wh_G is either the operating moment or the gasket-seating moment, as obtained in Appendix II of the Code. The method used in this report is theoretically more accurate than that used in the Code, and the relatively good agreement between stresses in Table A.5c and those in Table A.3 is, in part, coincidental. Large differences can exist, particularly when there is a significant amount of flange material outside the gasket diameter d.

Tapered-Hub Flange Stresses, Example 3(a)

Example 3(a) was run with an initial moment of 1.1719×10^7 in.-lb to permit direct comparison with the stresses given for example 1 in

Table A.2 under the heading "ASME FLANGE STRESSES AT OPERATING MOMENT, MOP." In example 1, the value for MOP was determined to be 1.1719×10^7 in.-lb. To be consistent with the Code calculations in this example [3(a)], we chose IBØND = 0.

Calculated stresses for the tapered-hub flange are shown in Table A.5d. The Code method covers only moment loading. The stresses in Table A.5d for initial moment loading only are the same as those in Table A.2 for operating moment, MOP:

Stress values from Table A.5d	Stress values from Table A.2
SLLO = 23,411 psi	SH = 23,412 psi
STH = 11,173 psi	ST = 11,174 psi
SRH = 8,444 psi	SR = 8,444 psi

The Code method gives stresses at the small end of the hub if the Code factor f is greater than 1.0; otherwise, it gives stresses for the large end of the hub. The Code method calculates radial and tangential stresses on the hub side of the flange only. Usually these are higher than the corresponding stresses on the face side of the flange, but in this example, STH = 11,173 psi is less than STF = -18,482 psi in absolute magnitude. The Code method does not give circumferential stresses in the hub.

Stresses for pressure loading only, temperature loading only, and combined loadings are shown as the 2nd, 3rd, and 4th groups of stresses in Table A.5d. The small values under the heading "CALCULATIONS FOR TEMPERATURE LOADINGS" come from using DELTA = 0.01, since DELTA = 0 is not a permissible input value.

Combined stresses are not the sum of the stresses due to the three individual loads. Rather, the program recognizes that pressure and temperature change the moment from M1 = 9.3433×10^6 in.-lb to M2 = 7.7814×10^6 in.-lb in this example* (Table A.5b). The maximum stress

*It should be noted that M1 is not the same as the input moment XMOA. The program will accept any value for calculating stresses but, for calculating bolt load changes, it assumes that the moment is equal to W(C-G)/2.

under combined loads (in this example, residual moment and pressure) is SLSO = 33,385 psi. Under initial moment only, the maximum stress is SLLO = 23,411 psi.

Blind and Tapered-Hub Flange Stresses, Example 3(b)

Stresses are shown in Table A.6c and A.6d for blind and tapered-hub flanges, respectively. It can be seen that maximum stresses are quite high for the realistic initial bolt stress of 44,300 psi needed to pass the hydrostatic test pressure of 1080 psi [i.e., SORT = 24,984 psi for the blind flange (Table A.6c) and SLSO = 57,309 psi for the tapered-hub flange (Table A.6d]. Comments on the significance of these high calculated stresses are included later in the discussion of examples 4a and 4b.

Displacements

Tables A.5 and A.6 include, along with stresses, the displacements ZC for the blind flange or ZG, ZC, QFHG, Y0, Y1, and THETA for the tapered-hub flange. One potential application for these displacements is discussed later in connection with examples 4(a) and 4(b).

IDENTICAL PAIR OF TAPERED-HUB FLANGES, EXAMPLES 4(a) AND 4(b)

Input Data

The input data for Examples 4(a) and 4(b) are shown in Table A.7. The initial bolt stress of 46,100 psi and corresponding W1 = 6.312×10^6 lb were selected by a preliminary calculation so that W2 would equal W_c at the hydrostatic-test pressure of 1080 psi. The value of W1 = 6.312×10^6 lb leads to initial moment XMOA = W1(C-G)/2 = 2.1500×10^7 in.-lb. Example 4(a) is for hydrostatic test conditions at atmospheric temperature. Example 4(b) is for steady-state operating conditions at the rated pressure of 300 psi and corresponding API-605 temperature of 850°F.

The modulus of elasticity of the flange, bolt, and gasket materials was assumed to be 2.25×10^7 psi at 800°F, as compared with 3.0×10^7 at atmospheric temperature. It is assumed that at steady-state operating conditions there is an external bending moment such that the axial stress in the attached pipe is 7500 psi. This axial stress gives 617 psi as the input value for PBE for example 4(b), as shown below:

$$\text{PBE} = 4\ S_b g_0/D_o = 4 \times 7500 \times 1.2343/60 = 617 \text{ psi} .$$

Output Data

Residual Bolt Loads

The output data for example 4(a) are shown in Table A.8. The output data starts with a printout of all input data. The parameters involved in the bolt-load-change calculations are then printed, followed by residual bolt loads and moments (Table A.8b).

The residual bolt load is given by W2 = 3.585×10^6 lb. The critical bolt load, derived from Eq. (A.2), is $W_c = \pi G_0^2\ p/4 = 3.584 \times 10^6$ lb. Accordingly, the results of example 4(a) indicate that an initial bolt stress of 46,100 psi is sufficient for the joint to pass a hydrostatic test to 1080 psi, albeit with no margin of safety.

Table A.7. Input data for tapered-hub-to-tapered-hub flanged joint, examples[a] 4a and 4b

Card No.	Variables and numerical values								Read format
1	ITYPE	IBOND	ICODE	MATE					
	1	0	0	2					4I5
2	A	B	t	g_0	g_1	h	C	p	
	73.9375	57.5314	5.9375	1.2343	2.7030	5.4362	69.4375	1080.	8E10.5
								(300.)	
3	XMOA	EF	DELTA[b]	YM	G				
	2.1500D+7	6. D-6	.01	3. D+7	62.625				5E10.5
4	BSIZE	YB	EB	TB	XGO	XGI	AB		
	2.25	3. D+7	6. D-6	0	65.	60.25	136.92		7E10.5
5	VO	YG	EG	TG	FACE	PBE			
	.0625	3. D+6	6. D-6	0	0	0			6E10.5
						(617.)			
6	W1	TF	TFP	YF2	YFP2	YB2	YG2		
	6.3120D+6	0	0	3. D+7	3. D+7	3. D+7	3. D+6		7E10.5
				(2.25D+7)	(2.25D+7)	(2.25D+7)	(2.25D+6)		

[a]Values in parentheses are for example 4b.

[b]Since DELTA cannot be entered as zero, 0.01 was used as a satisfactorily small value.

Table A.8a. Output data for example 4(a), identical pair of tapered-hub flanges, with initial bolt stress of 46,100 psi

```
 FLANGE     FLANGE     FLANGE      PIPE      HUB AT      HUB       BOLT    PRESSURE,
 O.D.,A     I.D.,B    THICK.,T   WALL,GO    BASE,G1   LENGTH,H  CIRCLE,C     P
73.93750   57.53140    5.93750    1.23430    2.70300    5.43620  69.43750  1080.000

 MOMENT   COEFF. OF    DELTA     MOD. OF MEAN GASKET  ITYPE     IBOND     ICODE     MATE
          THERMAL EXP.         ELASTICITY DIAMETER
2.150D 07 6.000D-06 1.000D-02 3.000D 07 6.263D 01      1          0         0          2


     BSIZE             YB              EB               TB              XGO             XGI             AB
   2.2500D 00      3.0000D 07      6.0000D-06      0.0             6.5000D 01      6.0250D 01      1.3692D 02
     VO                YG              EG               TG              FACE            PBE
   6.2500D-02      3.0000D 06      6.0000D-06      0.0             0.0             0.0
     W1                TF              TFP              YF2             YFP2            YB2             YG2
   6.3120D 06      0.0             0.0             3.0000D 07      3.0000D 07      3.0000D 07      3.0000D 06


    FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, IDENTICAL PAIR

      FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QFHG=  1.1968D-09  QPHG=  8.0422D-06  QTHG=  9.5590D-05  XB =  5.7531D 01    GO=  1.2343D 00     TH  =  5.9375D 00
      YM =  3.0000D 07         YF2 =  3.0000D 07    EF =  6.0000D-06

      FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QFHG=  1.1968D-09  QPHG=  8.0422D-06  QTHG=  9.5590D-05  XB =  5.7531D 01    GO=  1.2343D 00     TH  =  5.9375D 00
      YM =  3.0000D 07         YF2 =  3.0000D 07    EF =  6.0000D-06

        BOLTING

BOLT LENGTH=  1.4188D 01  BOLT AREA=  1.3692D 02  BOLT CIRCLE=  6.9438D 01
      YB =  3.0000D 07        YB2 =  3.0000D 07    EB =  6.0000D-06

        GASKET

  VO  =  6.2500D-02  XGO =  6.5000D 01  XGI =  6.0250D 01
     YG  =  3.0000D 06        YG2 =  3.0000D 06    EG =  6.0000D-06
```

Table A.8b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  6.3120D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0          DELTA=  1.0000D-02  DELTAP=  1.0000D-02  PRESSURE=  1.0800D 03

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  6.3120D 06  MOMENT SHIFT,W2B=  5.0760D 06

TOTAL PRESSURE,W2C=  3.5852D 06   DELTA THERMAL,W2D=  6.3118D 06

COMBINED,W2=  3.5850D 06

W1-W2A=  0.0          W1-W2B=  1.2360D 06  W1-W2C=  2.7268D 06  W1-W2D=  1.6408D 02  W1-W2=   2.7270D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.0418D-01  W2C/W1=  5.6799D-01  W2D/W1=  9.9997D-01  W2/W1=  5.6796D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAI PRESSURE LOADS.

M1=  2.1500D 07  M2A=  2.1500D 07  M2B=  2.3369D 07  M2C=  1.8291D 07  M2D=  2.1500D 07  M2=  1.8290D 07

M2BP=  2.3369D 07  M2CP=  1.8291D 07  M2P=  1.8290D 07
```

Table A.8c (continued)

```
        TAPERED HUB FLANGE
   CALCULATIONS FOR MOMENT LOADING

SLSO=  4.2273D 04  SLSI= -4.2273D 04  SCSO=  3.6258D 04  SCSI=  1.0894D 04
SLLO=  4.2951D 04  SLLI= -4.2951D 04  SCLO=  1.2885D 04  SCLI= -1.2885D 04
 STH=  2.0499D 04   STF= -3.3907D 04   SRH=  1.5492D 04   SRF= -1.2197D 04
ZG= -1.9118D-02  ZC= -4.4850D-02  QFHG=  2.5732D-02  YO=  2.2606D-02  Y1=  1.6524D-18  THETA= -7.4448D-03
   CALCULATICNS FOR PRESSURE LOADING

SLSO=  2.1290D 04  SLSI=  3.8794D 03  SCSO=  2.1596D 04  SCSI=  1.6373D 04
SLLO=  2.7967D 03  SLLI=  8.6968D 03  SCLO=  8.3902D 02  SCLI=  2.6090D 03
 STH=  1.3997D 04   STF= -1.6503D 03   SRH= -3.4397D 03   SRF=  4.0556D 02
ZG= -6.7671D-03  ZC= -1.5453D-02  QFHG=  8.6856D-03  YO=  1.4584D-02  Y1=  6.0715D-18  THETA= -2.7132D-03
   CALCULATICNS FOR TEMPERATURE LOADING

SLSO=  1.2228D 00  SLSI= -1.2228D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.8419D 00  SCLI= -1.7581D 00
 STH=  1.1087D 00   STF= -6.1330D-01   SRH= -2.7247D-01   SRF=  1.5072D-01
ZG= -7.4476D-07  ZC= -1.7007D-06  QFHG=  9.5590D-07  YO= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9860D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2, W2 FOR ITYPE=3,  =   1.8290D 07

SLSO=  5.7253D 04  SLSI= -3.2083D 04  SCSO=  5.2441D 04  SCSI=  2.5640D 04
SLLO=  3.9335D 04  SLLI= -2.7841D 04  SCLO=  1.1799D 04  SCLI= -8.3541D 03
 STH=  3.1436D 04   STF= -3.0496D 04   SRH=  9.7386D 03   SRF= -9.9698D 03
ZG= -2.3032D-02  ZC= -5.3608D-02  QFHG=  3.0576D-02  YO=  3.3814D-02  Y1= -1.7259D-06  THETA= -9.0466D-03
```

The output data for example 4(b) are shown in Table A.9, which is identical in format to Table A.8 for example 4(a). The residual bolt load for example 4(b) is given by W2 = 3.2718×10^6 lb. The pressure is lower in example 4(b) than in 4(a), but there is a modulus-of-elasticity decrease which, by itself, makes W2 = W1 $\times 2.25 \times 10^7/(3 \times 10^7)$ and makes the effect of the equivalent pressure correspond to the external moment PBE. We can check to see if the residual bolt load is sufficient to prevent leakage by an extension of the concept of the initial bolt load W_c, which was discussed in the previous section. We made the conservative assumption that the maximum tensile stress due to the external bending moment (which exists only at one point on the pipe circumference) acts around the complete circumference of the pipe. The value of W_c, the critical bolt load to prevent gross leakage, is then the sum of Eq. (A.2) and the axial load due to the bending moment; thus

$$W_c = \frac{\pi}{4} G_0^2 p + A_p S_b , \tag{A.5}$$

where

$A_p = \pi(B + g_0)\ g_0$ = cross-sectional area of attached pipe, and

S_b = axial stress in attached pipe due to an external moment.

For example 4(b), Eq. (A.5) gives:

$$W_c = \left(\frac{\pi}{4} \times 65^2 \times 300\right) + (\pi \times 58.7657 \times 1.2343 \times 7500)$$

$$= 2.7045 \times 10^6 \text{ lb} .$$

Because W2 = 3.2718×10^6 lb is greater than $W_c = 2.7045 \times 10^6$ lb, the results indicate that the flanged joint with an initial bolt stress of 46,100 psi can carry, at least for a short time at 850°F, an external moment giving both an axial bending stress of 7500 psi in the attached pipe of 1.2343-in. wall thickness and an internal pressure of 300 psi.

At 850°F, the carbon-steel flanges and bolts would be expected to undergo significant relaxation due to creep in the flanges and bolts,

Table A.9a. Output data for example 4(b), identical pair of tapered-hub flanges, steady-state operation at 300 psi and 850°F

```
FLANGE     FLANGE     FLANGE      PIPE     HUB AT      HUB       BCLT    PRESSURE,
O.D.,A     I.D.,B    THICK.,T   WALL,GO   BASE,G1   LENGTH,H  CIRCLE,C     P
73.93750  57.53140   5.93750    1.23430    2.70300   5.43620  69.43750   300.000

MOMENT  COEFF. OF    DELTA     MOD. OF MEAN GASKET  ITYPE      IBOND     ICODE      MATE
        THERMAL EXP.          ELASTICITY DIAMETER
2.150D 07 6.000D-06 1.000D-02 3.000D 07 6.263D 01     1          0          0          2


    BSIZE            YB             EB             TB             XGO            XGI            AB
  2.2500D 00     3.0000D 07     6.0000D-06     0.0            6.5000D 01     6.0250D 01     1.3692D 02
     VO              YG             EG             TG             FACE           PBE
  6.2500D-02     3.0000D 06     6.0000D-06     0.0            0.0            6.1700D 02
     W1              TF             TFP            YF2            YFP2           YB2            YG2
  6.3120D 06     0.0            0.0            2.2500D 07     2.2500D 07     2.2500D 07     2.2500D 07

    FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOADS, IDENTICAL PAIR

      FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)

QFHG=  1.1968D-09  QPHG=  8.0422D-06  QTHG=  9.5590D-05   XB =  5.7531D 01      GO=  1.2343D 00        TH  =  5.9375D 00
      YM =  3.0000D 07          YF2 =  2.2500D 07     EF =  6.0000D-06

      FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)

QFHG=  1.1968D-09  QPHG=  8.0422D-06  QTHG=  9.5590D-05   XB =  5.7531D 01      GO=  1.2343D 00        TH  =  5.9375D 00
      YM =  3.0000D 07          YF2 =  2.2500D 07     EF =  6.0000D-06

        BOLTING

BOLT LENGTH=  1.4188D 01  BOLT AREA=  1.3692D 02  BOLT CIRCLE=  6.9438D 01
      YB =  3.0000D 07         YB2 =  2.2500D 07     EB =  6.0000D-06

        GASKET

  VO  =  6.2500D-02  XGO =  6.5000D 01  XGI =  6.0250D 01
     YG  =  3.0000D 06         YG2 =  2.2500D 07     EG =  6.0000D-06
```

Table A.9b (continued)

```
        LOADINGS

INITIAL BOLT LOAD=  6.3120D 06  BOLT TEMP.=  0.0          FLANGE ONE TEMP.=  0.0          FLANGE TWO TEMP.=  0.0
GASKET TEMP.=  0.0          DELTA=  1.0000D-02   DELTAF=  1.0000D-02  PRESSURE=  3.0000D 02

   RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS

AXIAL THERMAL,W2A=  6.3120D 06  MOMENT SHIFT,W2B=  5.2625D 06

TOTAL PRESSURE,W2C=  4.8484D 06   DELTA THERMAL,W2D=  6.3118D 06

COMBINED,W2=  3.2718D 06

W1-W2A=  0.0          W1-W2B=  1.0495D 06  W1-W2C=  1.4636D 06  W1-W2D=  1.6408D 02  W1-W2=   3.0402D 06

W2A/W1=  1.0000D 00  W2B/W1=  8.3374D-01  W2C/W1=  7.6813D-01  W2D/W1=  9.9997D-01  W2/W1=  5.1835D-01

    INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE LOADS.

M1=  2.1500D 07  M2A=  2.1500D 07  M2B=  1.9614D 07  M2C=  1.8203D 07  M2D=  2.1500D 07  M2=  1.2833D 07

M2BP=  1.9614D 07  M2CP=  1.8203D 07  M2P=  1.2833D 07
```

Table A.9c (continued)

```
        TAPERED HUB FLANGE
   CALCULATICNS FOR MOMENT LOADING

SLSO=  4.2273D 04  SLSI= -4.2273D 04  SCSO=  3.6258D 04  SCSI=  1.0894D 04
SLLO=  4.2951D 04  SLLI= -4.2951D 04  SCLO=  1.2885D 04  SCLI= -1.2885D 04
 STH=  2.0499D 04   STF= -3.3907D 04   SRH=  1.5492D 04   SRF= -1.2197D 04
ZG= -1.9118D-02  ZC= -4.4850D-02  QFHG=  2.5732D-02  Y0=  2.2606D-02  Y1=  1.6524D-18  THETA= -7.4448D-03
   CALCULATIONS FOR PRESSURE LOADING

SLSO=  5.9140D 03  SLSI=  1.0776D 03  SCSO=  5.9990D 03  SCSI=  4.5481D 03
SLLO=  7.7687D 02  SLLI=  2.4158D 03  SCLO=  2.3306D 02  SCLI=  7.2473D 02
 STH=  3.8880D 03   STF= -4.5841D 02   SRH= -9.5549D 02   SRF=  1.1266D 02
ZG= -1.8798D-03  ZC= -4.2924D-03  QFHG=  2.4127D-03  Y0=  4.0510D-03  Y1=  8.6736D-19  THETA= -7.5365D-04
   CALCULATIONS FOR TEMPERATURE LOADING

SLSO=  1.2228D 00  SLSI= -1.2228D 00  SCSO=  1.0649D-01  SCSI= -6.2722D-01
SLLO= -1.3977D-01  SLLI=  1.3977D-01  SCLO= -1.8419D 00  SCLI= -1.7581D 00
 STH=  1.1087D 00   STF= -6.1330D-01   SRH= -2.7247D-01   SRF=  1.5072D-01
ZG= -7.4476D-07  ZC= -1.7007D-06  QFHG=  9.5590D-07  Y0= -2.4965D-07  Y1= -1.7259D-06  THETA= -2.9860D-07
  CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITYPE=1 OR 2,  W2 FOR ITYPE=3,  =    1.2833D 07

SLSO=  3.1147D 04  SLSI= -2.4156D 04  SCSO=  2.7641D 04  SCSI=  1.1050D 04
SLLO=  2.6413D 04  SLLI= -2.3221D 04  SCLO=  7.9222D 03  SCLI= -6.9680D 03
 STH=  1.6125D 04   STF= -2.0698D 04   SRH=  8.2910D 03   SRF= -7.1671D 03
ZG= -1.3292D-02  ZC= -3.1064D-02  QFHG=  1.7772D-02  Y0=  1.7544D-02  Y1= -1.7259D-06  THETA= -5.1976D-03
```

particularly with the high bolt stresses and flange stresses involved in example 4(b). For long-term service (many years) at 850°F, one might expect the flanges and/or bolts to creep so that a residual bolt stress of around 20,000 psi would exist, at which time W2 = 2000 × 136.92 = 2.7384×10^6 lb. Because this is larger than $W_c = 2.7045 \times 10^6$ lb obtained from Eq. (A.5), indications are that the flanged joint could still carry the external moment and pressure, albeit with almost no margin of safety.

It should be noted that, if bolts relax in high-temperature service, then the bolt load does <u>not</u> return to its initial value upon returning to initial conditions. The permanent loss in bolt load would be W2 - $S_{br}A_b$, where S_{br} = relaxed bolt stress, assumed here to be 20,000 psi. The permanent loss in bolt load, in this example, is 3.2718×10^6 - 20,000 × 136.92 = 533,400 lb. The load is theoretically not sufficient to pass a hydrotest of 1080 psi, but it is extremely unlikely such a hydrotest would be required for a system operating at 300 psi and 850°F.

Flange Stresses

Tables A.8c and A.9c show the flange stresses for examples 4(a) and 4(b), respectively. The maximum calculated stress occurs in example 4(a) where SLSO = 57,253 psi for combined loadings. Note that this is not the sum of the stresses due to initial moment loading only plus pressure loading only (first two groups of stresses), but rather it is the stress due to the moment as changed by pressure, M2 = M2P = 1.829×10^7 in.-lb, plus the stress due to pressure only.

The question arises as to whether the flanges in the flanged joint are strong enough to pass the hydrostatic test. To pursue this question, it is appropriate to tabulate the tangential and radial stresses at initial and pressurized conditions:

Condition	STH	STF	SRH	SRF
Initial	20,499	-33,907	15,492	-12,197
Pressurized	31,436	-30,496	9,739	-9,970

It should be noted that the stresses are, in large part, bending stresses. Before large plastic deformations occur, these stresses must reach about $1.5S_y$, where S_y is the yield strength of the flange material. Further, high stresses in the hub will not lead to large plastic deformations if there is reserve strength in the flange ring as indicated by relatively low tangential and radial stresses. If the capability for calculating these stresses has been attained, the next logical step is to conduct an extensive study to develop suitable design criteria for stress limits in flanged joints. Until such a study is conducted, however, the following limits are suggested as appropriate for stresses under hydrostatic test conditions:

Stress	Limit
Longitudinal hub stresses	$\leq 1.5S_y$
Radial stress or tangential stress	$\leq S_y$
Averages of radial or tangential stress and longitudinal hub stress	$\leq S_y$

The above criterion makes the average of SLSO and STH under pressurized conditions [i.e., $1/2(5.7253 \times 10^4 + 3.1436 \times 10^4) = 44{,}344$ psi] the controlling stress and infers that the flanged joint is acceptable, provided the flange-material yield strength is not less than 44,344 psi.

Displacements

In tightening the bolts to 46,100 psi, the question arises as to whether the flanges will rotate so that contact occurs on the outer edge. Table A.8c shows values of THETA, the rotation of the ring at the mean radius of the pipe wall. An estimate* of the displacement of the ring edge with respect to the gasket centerline can be obtained by

---

*The deformation of the ring is not exactly linear across the ring, but in this example it is sufficiently close to linear.

multiplying THETA by (A-G)/2, the radial distance between the ring edge and gasket centerline. In example 4(a), A = 73,9375, G = 62.625, and THETA = -9.0466×10^{-3} under combined loading; the minus sign means that the rotation is such that clearance is reduced at the outer edge. The displacement of A with respect to C is $9.0466 \times 10^{-3} \times (73.9375 - 62.625)/2 = 0.0512$ in. Because API-605 flanges have 1/16-in. raised faces, the outer edges of the flanges will not contact each other. The clearance will then be $(0.0625 - 0.0512) \times 2 = 0.0056$ in. plus the thickness of the gasket.

COMPUTER TIME

The six examples discussed in this appendix were run on Battelle's CDC 6400 computer and also on ORNL's IBM 360/91. The IBM FORTRAN source deck (converted to double precision for use on the IBM machine) has 1583 cards. The total length of the program is 80K bytes (10,240 actual words), and it needs no auxiliary storage devices except standard read and write units. The program requires 270K bytes for compilation and has a compilation time of 19.4 sec. The total execution time for the six examples was 1.15 sec.

APPENDIX B

FLOWCHARTS AND LISTING OF COMPUTER PROGRAM FLANGE AND ATTENDANT SUBROUTINES

APPENDIX B

CONTENTS

ORNL-DWG 75-4300

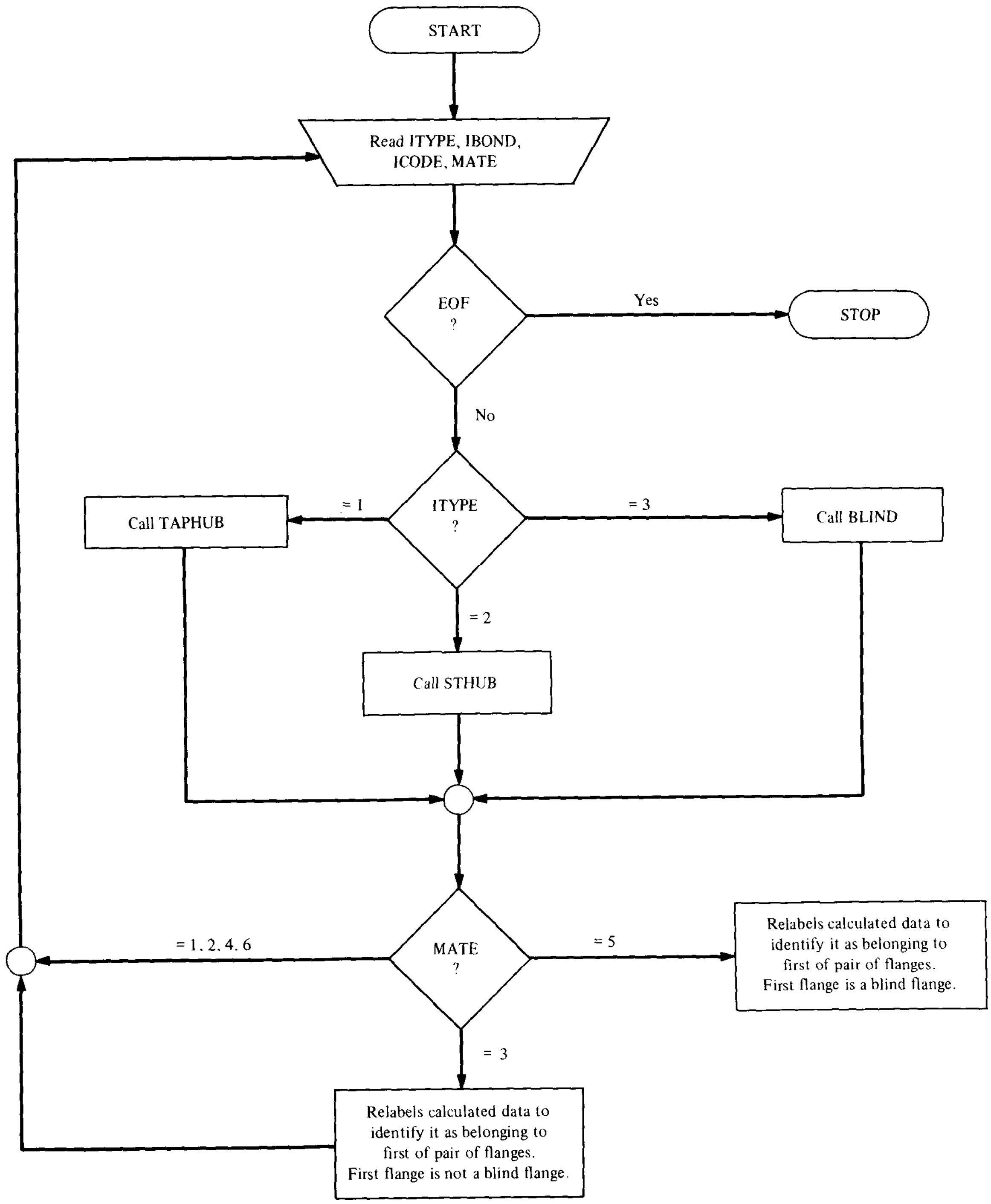

Fig. B.1. Program FLANGE.

ORNL-DWG 75-4301R

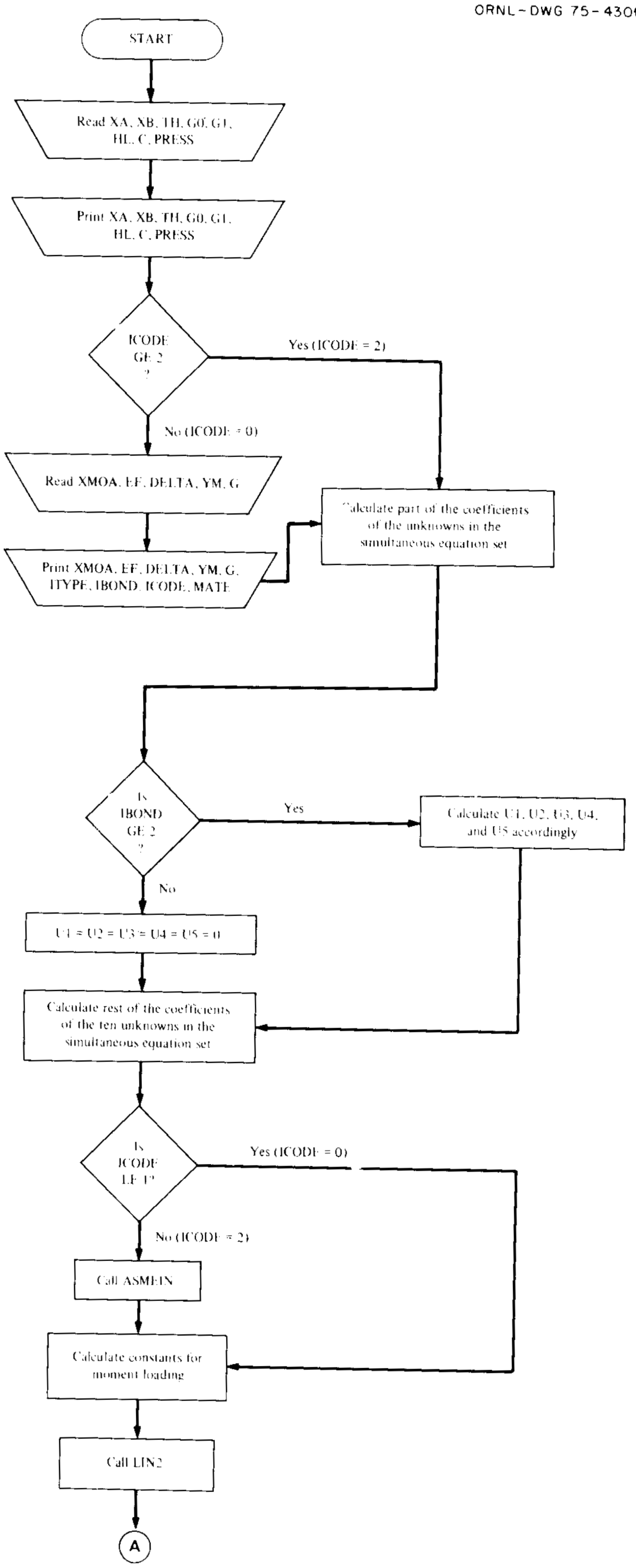

Fig. B.2. Subroutine TAPHUB (Part 1).

ORNL-DWG 75-4302R

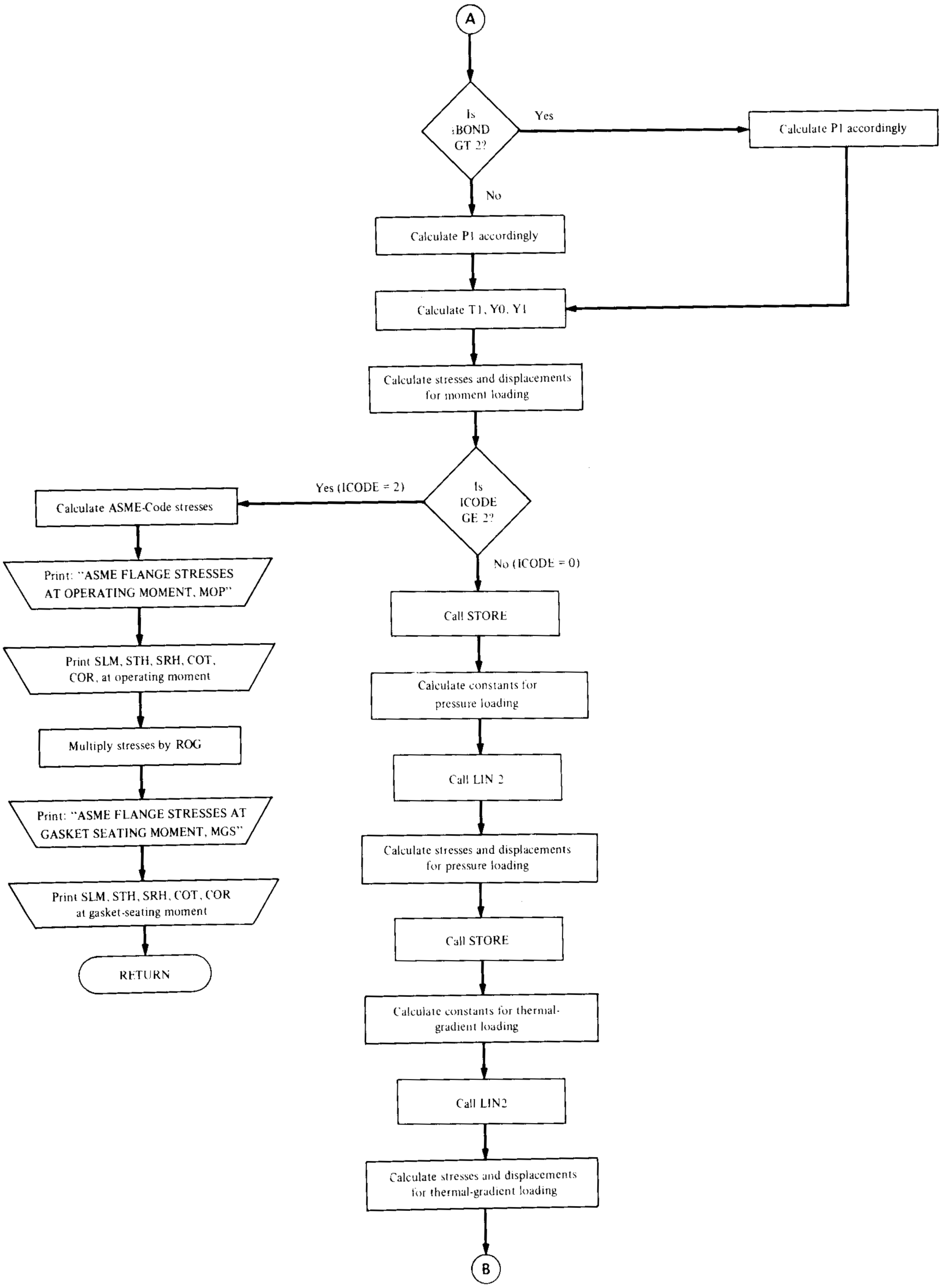

Fig. B.2. Subroutine TAPHUB (Part 2).

ORNL-DWG 75-4303R

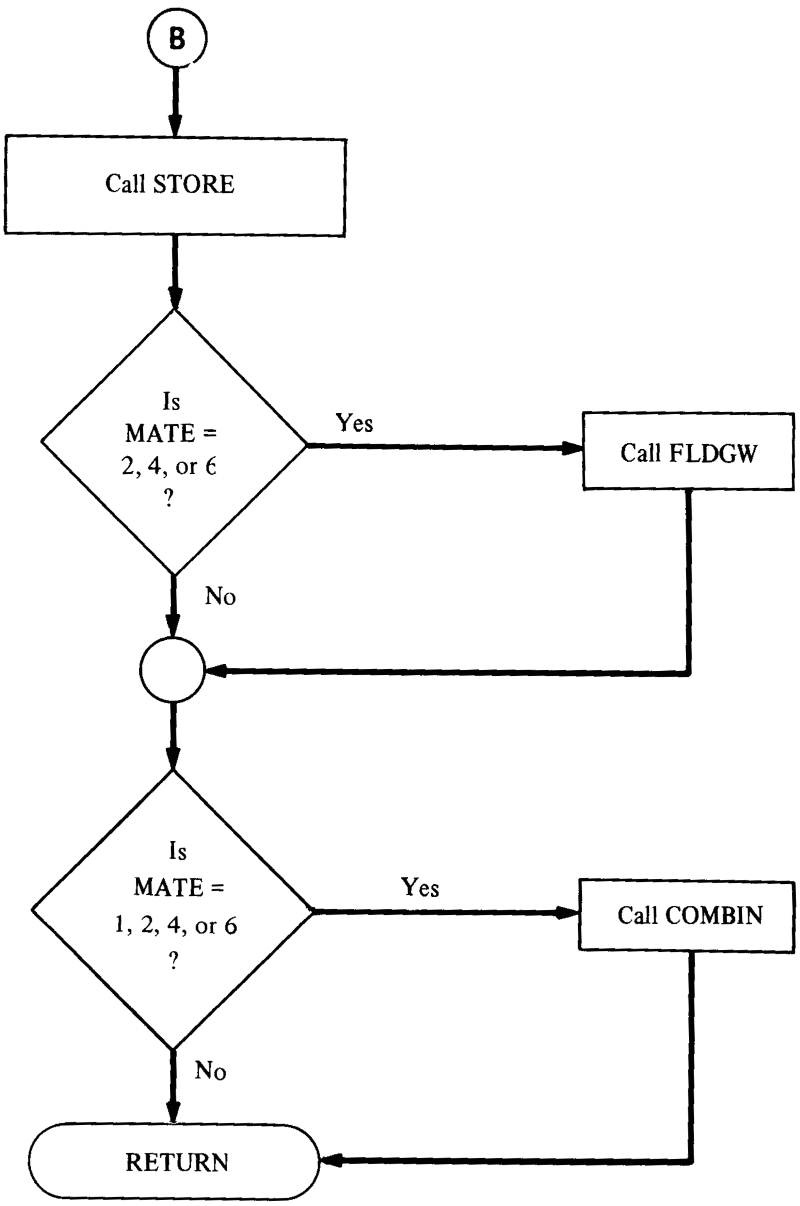

Fig. B.2. Subroutine TAPHUB (Part 3).

ORNL-DWG 75-4304

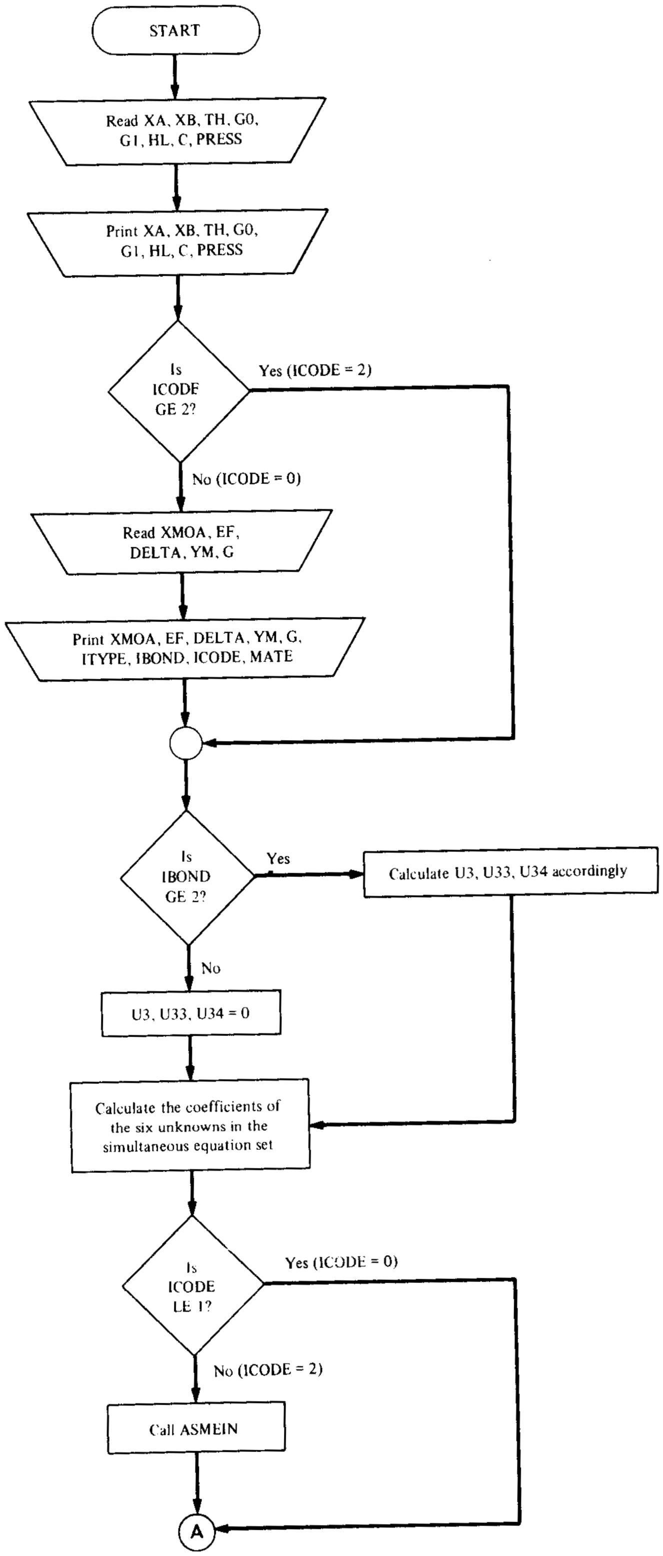

Fig. B.3. Subroutine STHUB (Part 1).

ORNL-DWG 75-4305R

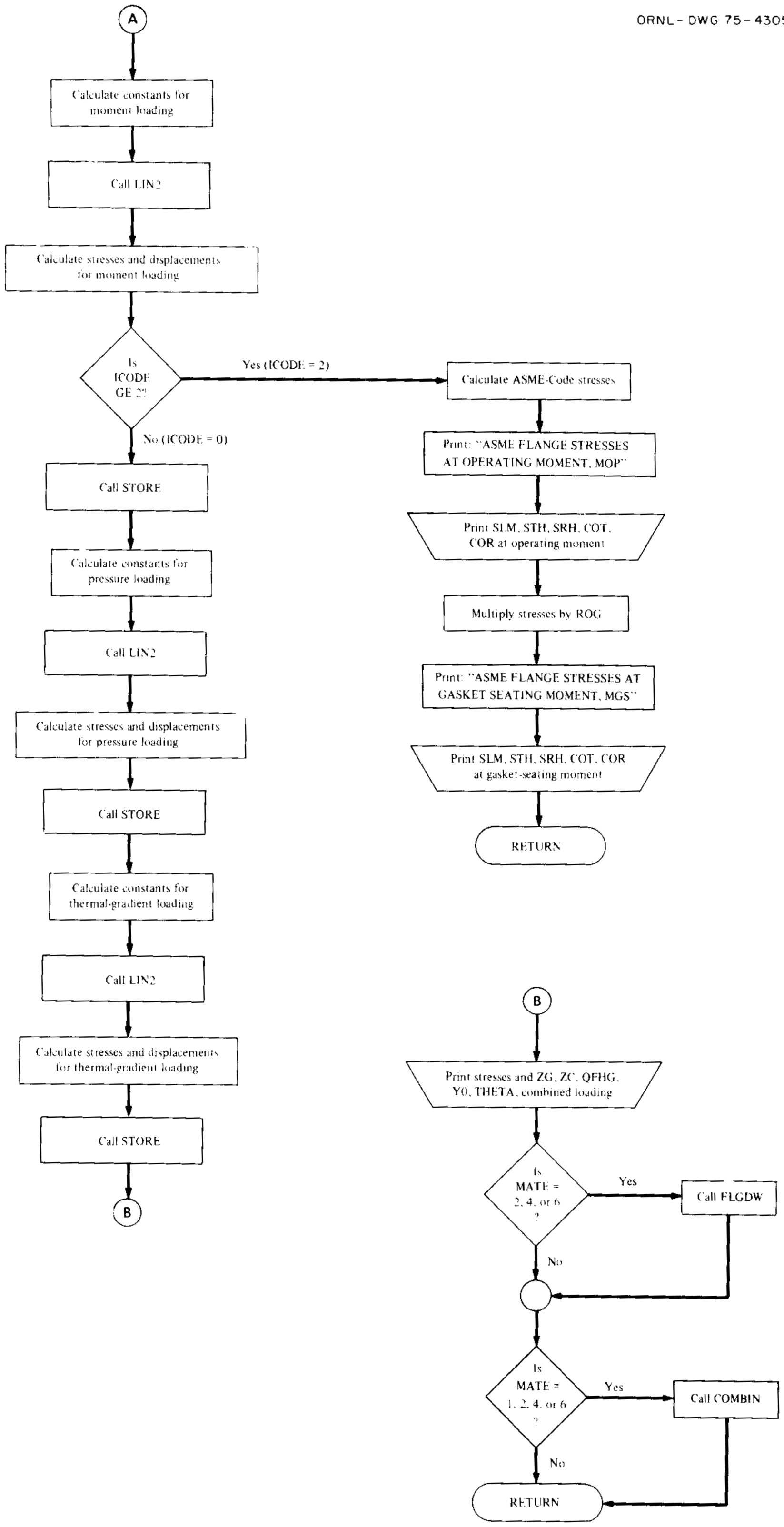

Fig. B.3. Subroutine STHUB (Part 2).

ORNL-DWG 75-4306R

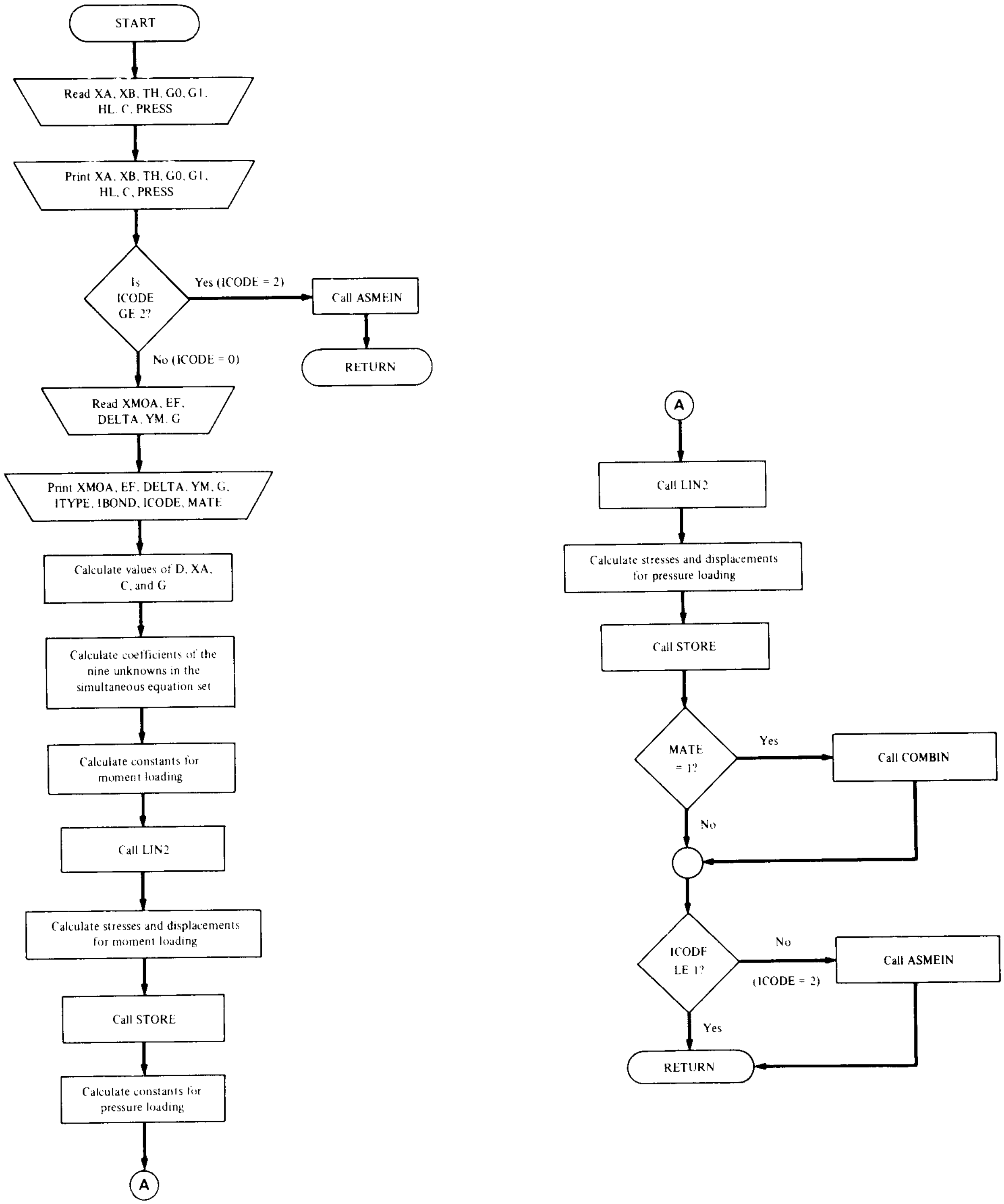

Fig. B.4. Subroutine BLIND.

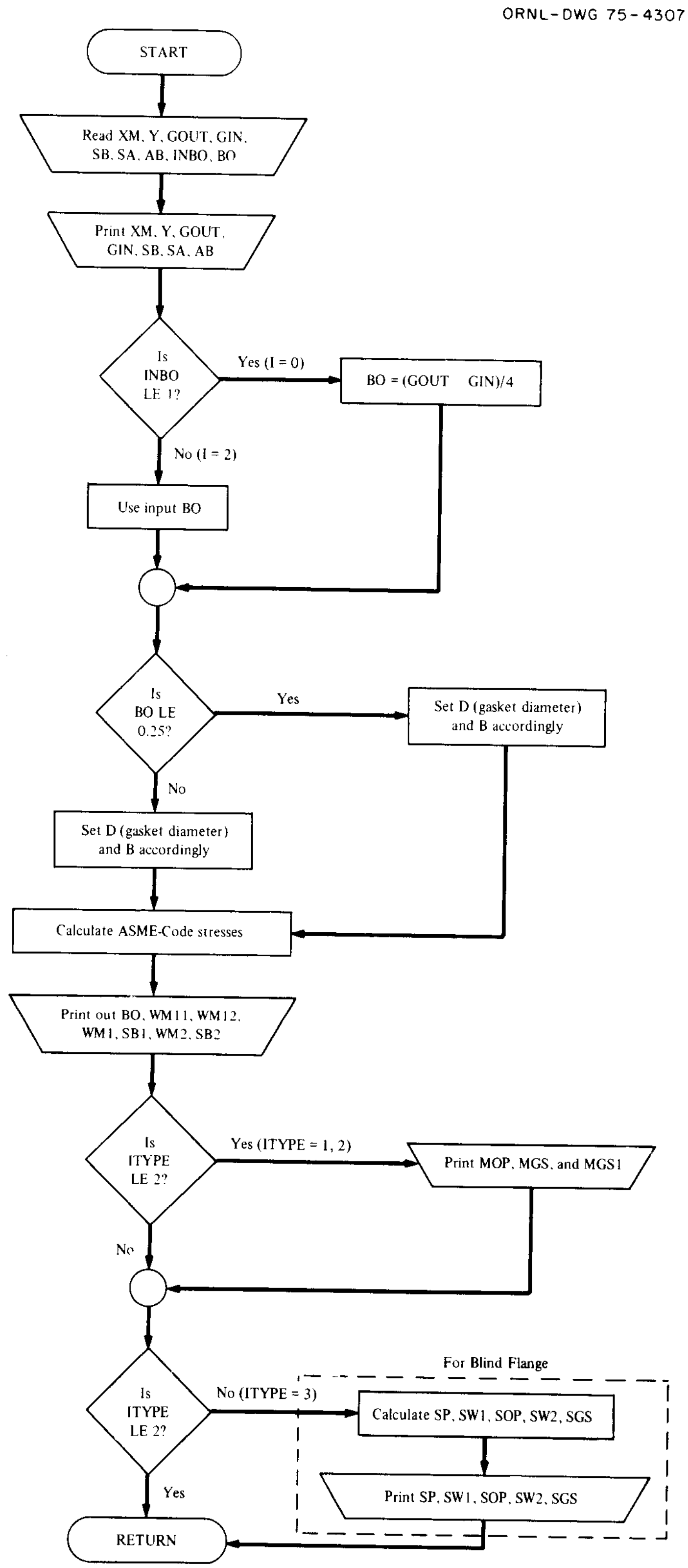

Fig. B.5. Subroutine ASMEIN.

ORNL-DWG 75-4308R

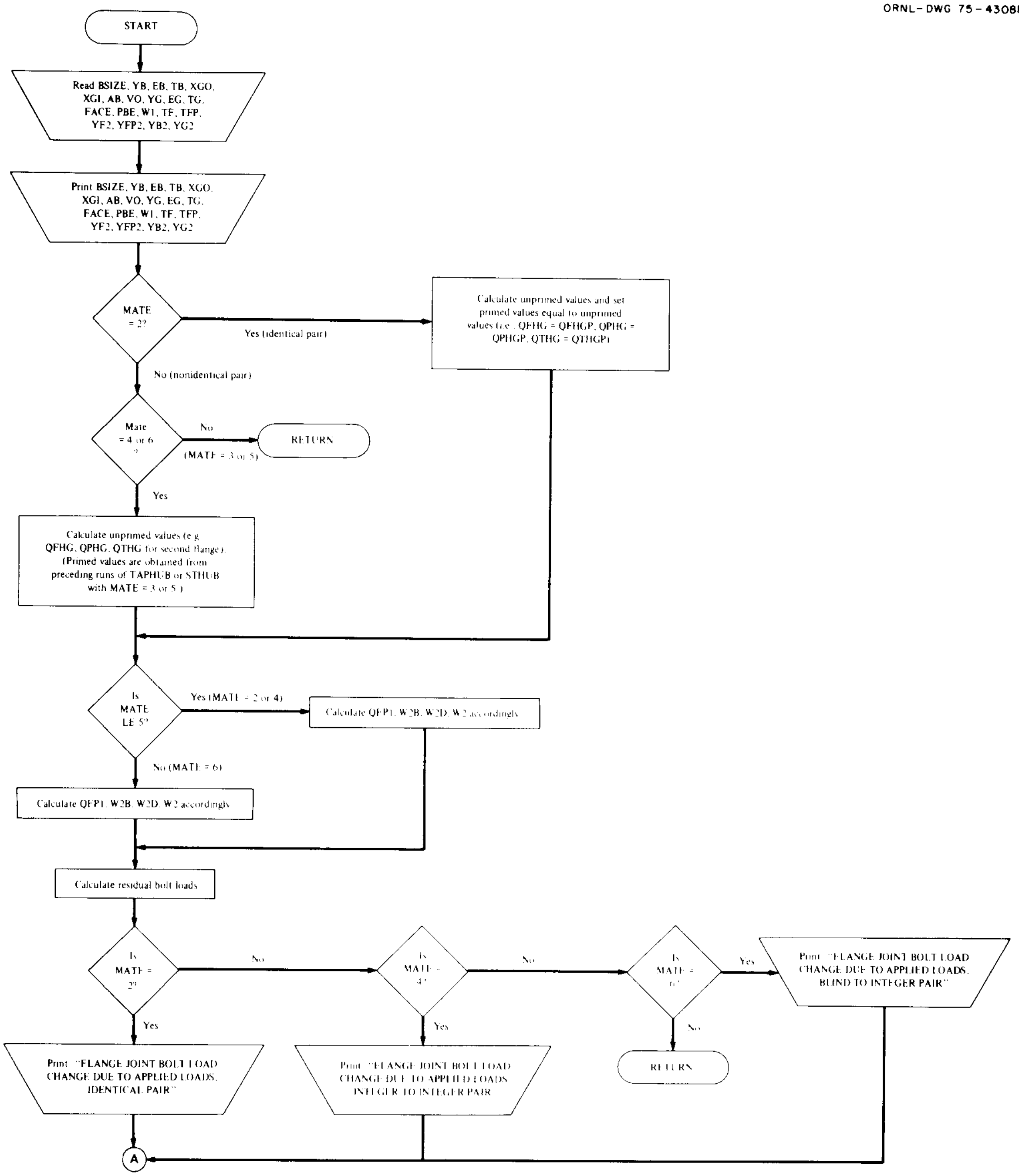

Fig. B.6. Subroutine FLGDW (Part 1).

ORNL-DWG 75-4309R

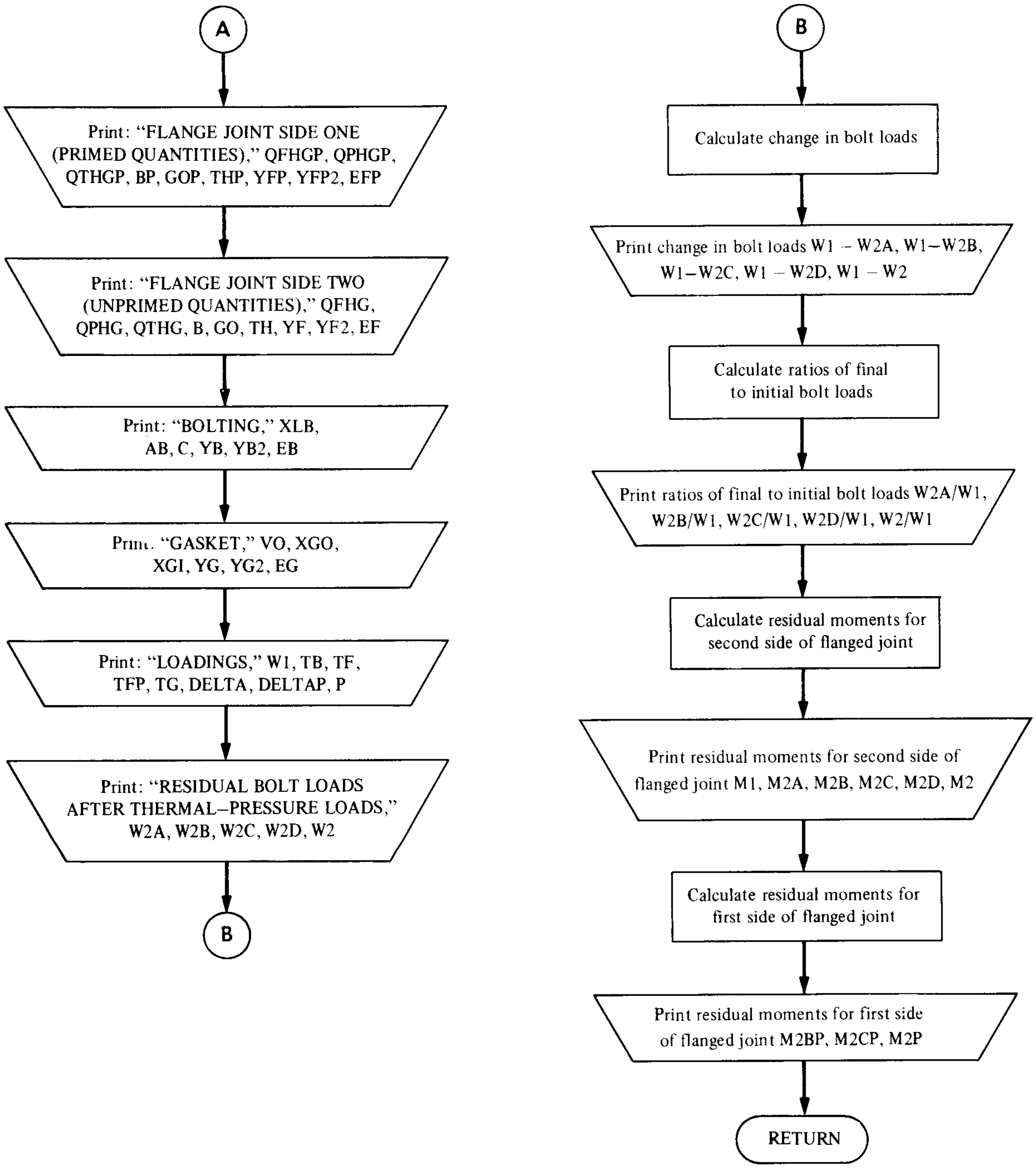

Fig. B.6. Subroutine FLGDW (Part 2).

ORNL-DWG 75-14884

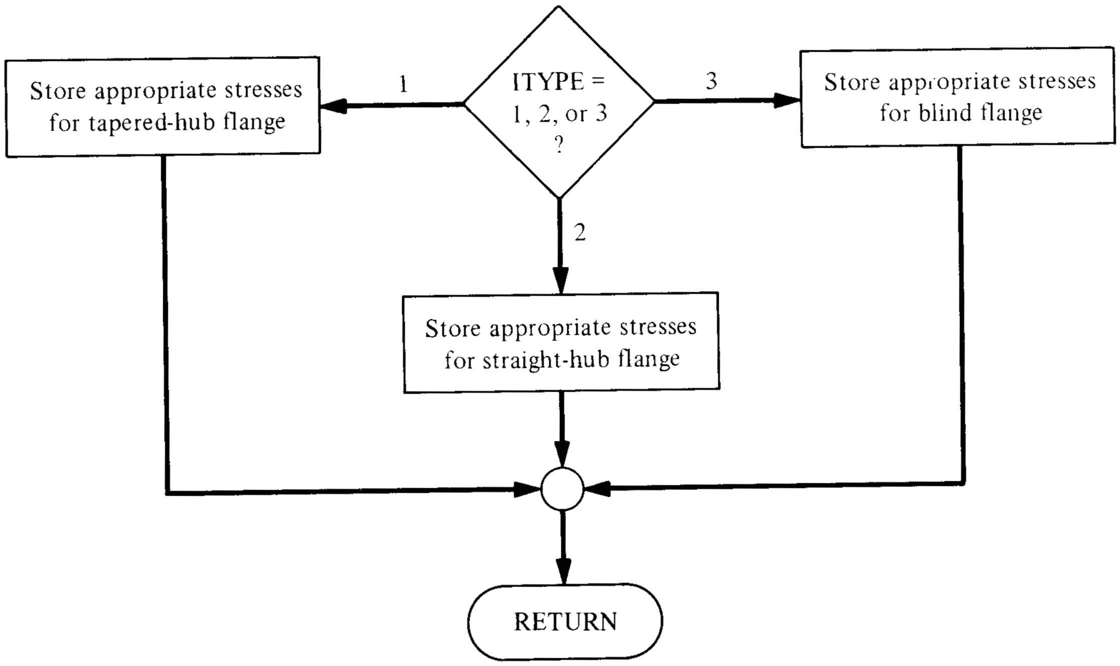

Fig. B.7. Subroutine STORE.

ORNL-DWG 75-14885

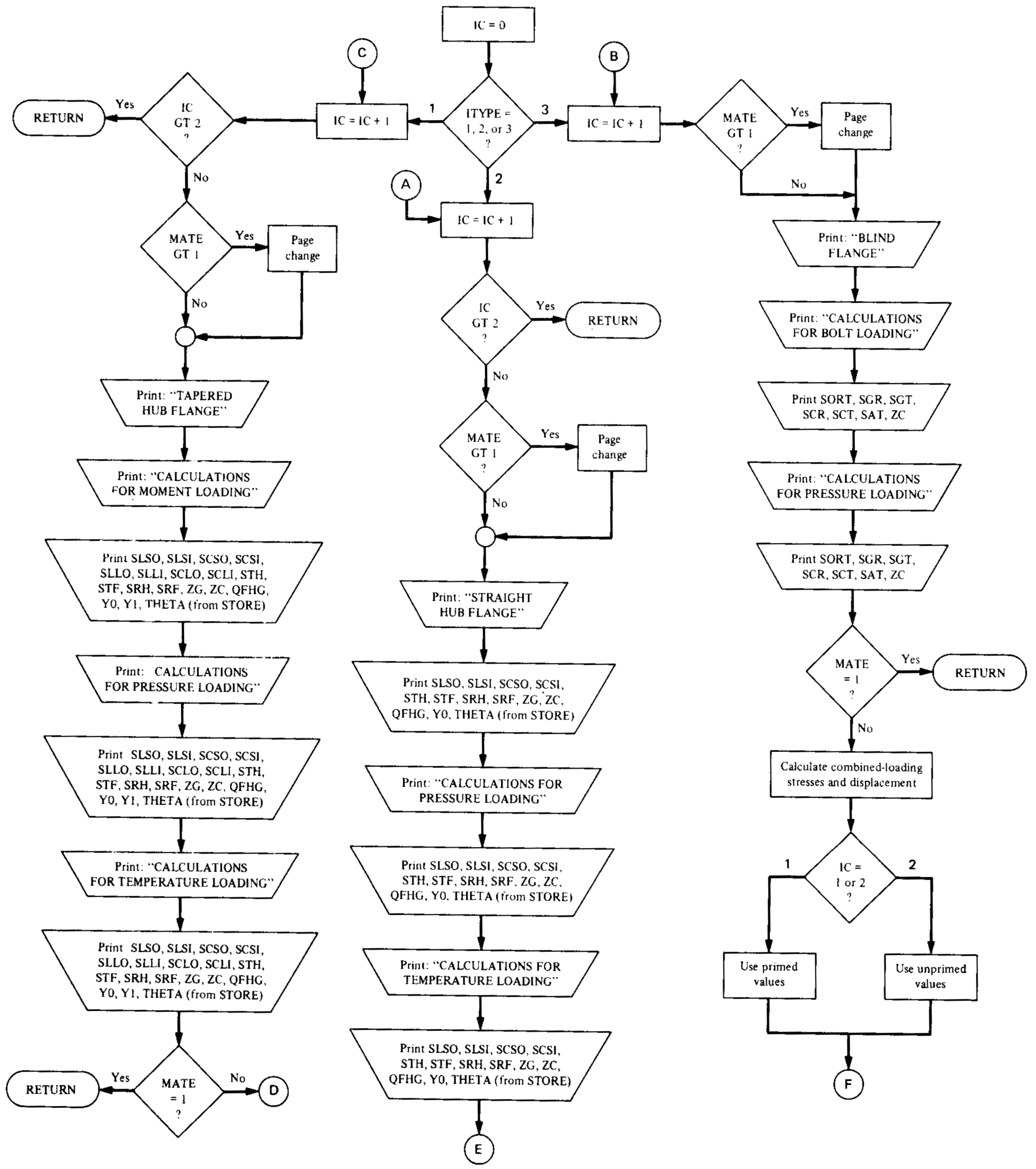

Fig. B.8. Subroutine COMBIN (Part 1).

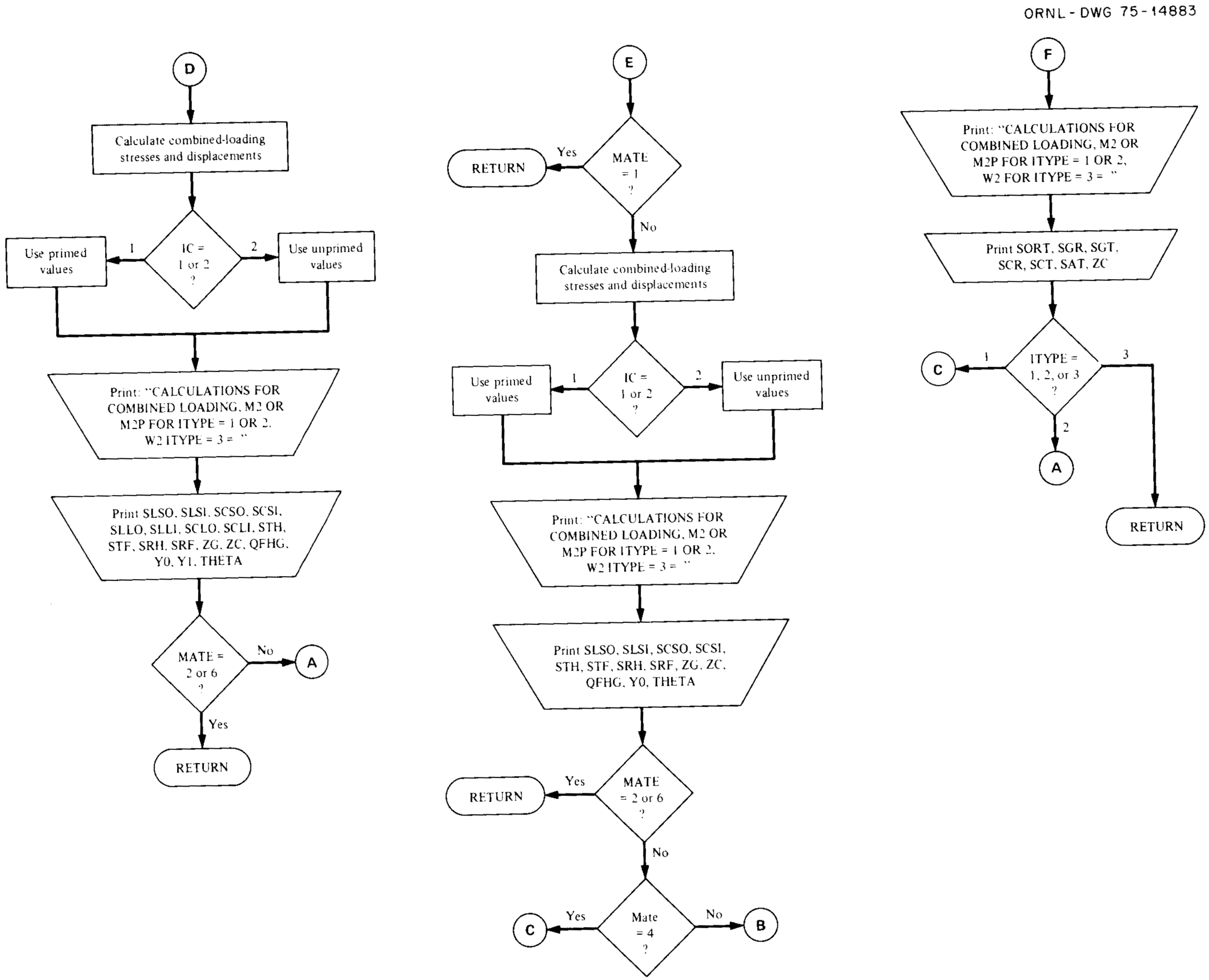

Fig. B.8. Subroutine COMBIN (Part 2).

LISTING OF PROGRAM FLANGE AND ATTENDANT SUBROUTINES

```
COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=60,SIZE=0000K,
                   SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,NOXREF
C       PROGRAM FLANGE (INPUT,OUTPUT,TAPE60=INPUT)
C       REVISED 6/21/74                                                  FLA    1
C       CONVERTED TO IBM/360 W/STANDARD INPUT = 5, OUTPUT = 6.           FLA    2
C       FLANGE PROGRAM CHANGES TO BLANK COMMON, 02-19-75.                01-22-75
C **  MODIF. TO FLANGE PROGRAMS, 09-17-75.                               FLANGE
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(10,10), B(10), LTEMP(10), LPA(10), LPC(10), AM(10,10)  01-28-75
      DIMENSION SB(6,18),SC(18)                                          FLA    3
      COMMON ITYPE,IBOND,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,  FLA   3A
     1AB,QFHR(4),AL,DELTA,XMO,XMOA,QFHGP,QPHGP,QTHGP,BP,G0P,THP,YFP,EFP,FLA    4
     2DELTAP,GOUT,GIN,RCG                                                FLA    5
     3,SLSO,SLSI,SCSO,SCSI,SLIO,SLII,SCLO,SCLI,SRH                        FLA    6
     4,SRF,SRH,SFF,ZG,ZC,QFHG,YC,Y1,T1,THETA,SOFT,SGR,SGI,SCR,SCI,SAT     FLA   6A
     5,W2,W1,SB,MA,II,XM1,XM2,XM2P,IT2                                    FLA   6B
C                                                                        FLA   6C
C       ITYPE = 1    TAPERED HUB
C       ITYPE = 2    STRAIGHT HUB                                        FLA    7
C       ITYPE = 3    BLIND                                               FLA    8
C       IBOND = 0  BOUNDARY PER ASME CODE, Y(X=H) EQUAL ZERO             FLA    9
C       IBOND = 2  BOUNDARY Y(X=H) NOT EQUAL TO ZERO                     FLA   10
C       IBOND = 3 INCLUDES EFFECT OF OUTWARD TAPER, TAPERED HUB FLANGE   FLA   11
C       ICODE = 0  CALCULATES STRESSES FOR INPUT XMOA, PRESS, DELTA AND COFLA  12
C       ICODE = 2  CALCULATES STRESSES FOR ASME OPERATING MOMENT         FLA   13
C       MATE = 1  DOES NOT CALCULATE LOAD CHANGES                        FLA   14
C       MATE = 2  CALCULATES LOAD CHANGES FOR IDENTICAL PAIR             FLA   15
C       MATE = 3  CALCULATES LOAD CHANGES FOR INTEGER TO INTEGER         FLA   16
C       MATE = 4  CALCULATES LOAD CHANGES FOR INTEGER TO INTEGER         FLA   17
C       MATE = 5  CALCULATES LOAD CHANGES FOR BLIND TO INTEGER           FLA   18
C       MATE = 6  CALCULATES LOAD CHANGES FOR BLIND TO INTEGER           FLA   19
                                                                         FLA   20
C       PRINT 11
C     1 READ 12, ITYPE,IBOND,ICODE,MATE                                  FLA  21A
C       IF (EOF,60) 10,2                                                 FLA   22
    2 IT2=ITYPE                                                          FLA   23
    1 READ( 5,12,END=10 ) ITYPE,IBOND,ICODE,MATE
      IF (ITYPE-2) 3,4,5                                                 01-22-75
    3 CALL TAPHUB                                                        FLA   24
      GO TO 6                                                            FLA   25
    4 CALL STHUB                                                         FLA   26
      GO TO 6                                                            FLA   27
    5 CALL BLIND                                                         FLA   28
      GO TO 6                                                            FLA   29
    6 GO TO (7,7,8,7,9,7), MATE                                          FLA   30
    7 GO TO 1                                                            FLA   31
    8 QFHGP=QFHR(1)/XMOA                                                 FLA   32
      QPHGP=QFHR(2)/PRESS                                                FLA   33
      QTHGP=QFHR(3)/DELTA                                                FLA   34
      BP=XB*2.                                                           FLA   35
      G0P=G0                                                             FLA   36
      THP=TH                                                             FLA   37
      YFP=YM                                                             FLA   38
      EFP=AL                                                             FLA   39
      DELTAP=DELTA                                                       FLA   40
      II = ITYPE                                                         FLA   41
      GO TO 1                                                            FLA  41A
    9 QFHGP=-QFHR(1)/XMOA                                                FLA   42
      QPHGP=-QFHR(2)/PRESS                                               FLA   43
      QTHGP=-1.                                                          FLA   44
      BP=-1.                                                             FLA   45
      G0P=-1.                                                            FLA   46
      THP=TH                                                             FLA   47
      YFP=YM                                                             FLA   48
      EFP=AL                                                             FLA   49
                                                                         FLA   50
```

```
      DELTAP=DELTA                                                      FLA  51
      IT = ITYPE                                                        FLA  51A
      GO TO 1                                                           FLA  52
   10 RETURN                                                            01-27-75
C                                                                       FLA  54
   11 FORMAT (1H1)                                                      FLA  55
   12 FORMAT (4I5)                                                      FLA  56
      END                                                               FLA  57
```

```
      SUBROUTINE TAPHUB                                                 TAP   2
C     THIS CALCULATION IS FOR ITYPE = 1, TAPERED HUB FLANGES            TAP   4
      IMPLICIT REAL*8 (A-H,C-Z)                                         01-28-75
      DIMENSION A(10,10), B(10), LTEMP(10), LPR(10), LPC(10), AM(10,10) TAP   6
      DIMENSION SB(6,18),SC(18)                                         TAP  7A
      COMMON ITYPE,IBOND,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,TAP   8
     1AB,QFHR(4),AL,DELTA,XMO,XMOA,QFHGP,QPHGP,QTHGP,BF,GOP,THP,YFP,EFP,TAP  10
     2DELTAP,GOUT,GIN,RCG                                               TAP  12
     3,SLSO,SLSI,SCSO,SCSI,SLIO,SLII,SCLO,SCLI,SFH                      TAP  7A
     4,STF,SRH,SPF,ZG,ZC,QFHG,Y0,Y1,T1,THETA,SORT,SGR,SGI,SCR,SCT,SAT   TAP  7B
     5,W2,W1,SB,MA,IT,XM1,XM2,XM2E                                      TAP  7C
      DATA A/100*0./,B/10*0./,LTEMP/10*0/,LPR/10*0/,LPC/10*0/,AM/100*0./
C
    1 READ 48, XA,XB,TH,G0,G1,HL,C,PRESS                                TAP  14
      PRINT 49                                                          TAP  16
      PRINT 50, XA,XB,TH,G0,G1,HL,C,PRESS                               TAP  18
      G=1.                                                              TAP  20
      YM=1.                                                             TAP  22
      IF (ICODE.GE.2) GO TO 2                                           TAP  24
      READ 51, XMOA,EF,DELTA,YM,G                                       TAP  26
      PRINT 52                                                          TAP  28
      AL=EF                                                             TAP  30
      PRINT 53, XMOA,EF,DELTA,YM,G,ITYPE,IBOND,ICODE,MATE               TAP  32
    2 HHO = HL/DSQRT(XB*G0)                                             TAP  34A
      XA=XA/2.                                                          TAP  36
      XB=XB/2.                                                          TAP  38
      G=G/2.                                                            TAP  40
      C=C/2.                                                            TAP  42
      RHO=G1/G0                                                         TAP  44
      ALPHA=RHO-1                                                       TAP  46
      GAMMA = (10.92**0.25)*HL/DSQRT(XB*G0)                             TAP  48A
      PHI0=1./ALPHA                                                     TAP  50
      PHI1=RHO/ALPHA                                                    TAP  52
      ETA0=2.*GAMMA/ALPHA                                               TAP  54
      ETA1=(RHO**.5)*ETA0                                               TAP  56
      XK=XA/XB                                                          TAP  58
      J=1                                                               TAP  60
      X=ETA0                                                            TAP  62
      PS=(.85*XB/(YM*G0))*PRESS                                         TAP  64
    3 CONTINUE                                                          TAP  66
      IF (X-10.0) 4,4,5                                                 TAP  68
    4 T=X/10.0                                                          TAP  70
      C3 = DLOG(X/2.0)                                                  TAP  72A
      T2=T*T                                                            TAP  74
      T3=T2*T                                                           TAP  76
      T4=T3*T                                                           TAP  78
      T8=T4*T4                                                          TAP  80
      T12=T8*T4                                                         TAP  82
      T16=T12*T4                                                        TAP  84
      T20=T16*T4                                                        TAP  86
```

```
      T24=T20*T4                                                        TAP   88
      T28=T24*T4                                                        TAP   90
      T32=T28*T4                                                        TAP   92
C ** CORR. TO CARDS TAP94-149 OF SUBR. TAPHUB, 02-27-75.
      BERX=.99999999999974D0-156.2499999995701D0*T4+678.1684027663091D0*TTAP  94A
     18-470.9502795889968D0*T12+93.859669297172 6D0*T16-7.24225672782 07D0TAP  96A
     2*T20+.25977730007D0*T24-.0048987125727D0*T28+.000051607 0465D0*T32 TAP  98A
      BEIX=-T2*(-24.9999999999998D0+434.0277777777748D0*T4-678.168402776 9TAP 100A
     1807D0*T8+240.2807549442574D0*T12-28.9690338786499D0*T16+1.49633427TAP 102A
     249742D0*T20-.0384288282734D0*T24+.0005444243175D0*T28-.44913D-5*T3TAP 104A
     42)                                                                TAP 105A
      DBERX=T3*(-62.499999999999D0+542.5347222222147D0*T4-565.14033564 7TAP 106A
     19486D0*T8+150.1754718432278D0*T12-14.4845169498403D0*T16+.6234726 3TAP 108A
     248243D0*T20-.0137246036 19D0*T24+.1701453451D-3*T28-.12506046D-5*T3TAP 110A
     32)                                                                TAP 111A
      DBEIX=-T*(-4.9999999999993D0+260.4166666665533D0*T4-678.168402774 7TAP 112A
     1539D0*T8+336.3930569023651D0*T12-52.1442608975905D0*T16+3.29193521TAP 114A
     208579D0*T20-.0999147064932D0*T24+.0016331100837D0*T28-.0000152269 8TAP 116A
     384D0*T32)                                                         TAP 117A
      R1X=T2*(24.999999999993D0-795.7175925924866D0*T4+1548.4845196730 9TAP 118A
     192D0*T8-623.0136717405201D0*T12+81.9524771606 2D0*T16-4.5187459132 6TAP 120A
     239D0*T20+.1222087382192D0*T24-.0018064777860D0*T28+.15436304 7D-4* TAP 122A
     3T32)                                                              TAP 123A
      R2X=T4*(234.375-1412.8508391203636D0*T4+1153.8281852814561D0*T8-25TAP 124A
     15.0971742710479D0*T12+21.2123451660231D0*T16-.8061529027876D0*T20+TAP 126A
     2.01593801497 05D0*T24-.0001797627986D0*T28+.0000012161109D0*T32)    TAP 128A
      DR1X=T*(4.9999999999975D0-477.4305555551536D0*T4+1548.4845196652 03TAP 130A
     15D0*T8-872.2191403672455D0*T12+147.5144585913337D0*T16-9.94124032 0TAP 132A
     29725D0*T20+.3177418434686D0*T24-.0054188558408D0*T28+.0000523294 31TAP 134A
     34D0*T32)                                                          TAP 135A
      DR2X=T3*(93.749999999998D0-1130.2806712962694D0*T4+1384.59382233 7TAP 136A
     12452D0*T8-408.1554788292578D0*T12+42.4246903131088D0*T16-1.934766 9TAP 138A
     2229237D0*T20+.0446263862145D0*T24-.0005752042283D0*T28+.000004368 2TAP 140A
     3053D0*T32)                                                        TAP 141A
      CEIX= -.785398164 39745D0* BERX+ R1X- (.5772156649D0+C3) *BEIX     TAP 142A
      CERX= +.78539816439745D0* BEIX- R2X- (.5772156649D0+C3) *BERX     TAP 144A
      DKERX=+.78539816439745D0*DBEIX-DR2X-(BERX/X)-(.5772156649D0+C3)*DBTAP 146A
     1ERX                                                               TAP 147A
      DKEIX=-.78539816439745D0*DBERX+DR1X-(BEIX/X)-(.5772156649D0+C3)*DBTAP 148A
     1EIX                                                               TAP 149A
      GO TO 6                                                           TAP  150
    5 T=10.0/X                                                          TAP  152
      C1 = (DEXP(+X/1.41421356237 1D0) /DSQRT(6.283185 03718D0*X))      TAP 154B
      C2 = (DEXP(-X/1.41421356237 1D0) *DSQRT(1.5707963267 9D0/X))      TAP 156B
      SIN1 = DSIN((X/1.4142135623 71D0)+(.3926990816 99D0))             TAP 158B
      SIN2 = DSIN((X/1.4142135623 71D0)-(.3926990816 99D0))             TAP 160B
      COS1 = DCOS((X/1.4142135623 71D0)+(.3926990816 99D0))             TAP 162B
      COS2 = DCOS((X/1.4142135623 71D0)-(.3926990816 99D0))             TAP 164B
      T2=T*T                                                            TAP  166
      T3=T2*T                                                           TAP  168
      T4=T3*T                                                           TAP  170
      T5=T4*T                                                           TAP  172
      T6=T5*T                                                           TAP  174
      T7=T6*T                                                           TAP  176
      T8=T7*T                                                           TAP  178
      S=1.+.0088388346D0*T+.7D-9*T2-.0000517869D0*T3-.0000112207D0*T4-.0TAP 180A
     1000016192D0*T5+.135D-8*T6+.1452D-6*T7+.492D-7*T8                  TAP 182A
      TT=-.0088388340D0*T-.0007031241D0*T2-.0000518006D0*T3-.72D-8*T4+.1TAP 184A
     164310D-5*T5+.5929D-6*T6+.750D-7*T7-.243D-7*T8                     TAP 186A
      U=1.-.0265165040D0*T-.8D-9*T2+.725024D-4*T3+.144255D-4*T4+.19780D-TAP 188A
     15*T5-.147D-7*T6-.1671D-6*T7-.563D-7*T8                            TAP 190A
      V=+.0265165034D0*T+.0011718740D0*T2+.725179D-4*T3+.79D-8*T4-.20042TAP 192A
     1D-5*T5-.6992D-6*T6-.883D-6*T7+.269D-8*T8                          TAP 194A
      BERX=C1*((S*COS2)-(TT*SIN2))                                      TAP  196
      BEIX=C1*((TT*COS2)+(S*SIN2))                                      TAP  198
      DBERX=C1*((U*COS1)-(V*SIN1))                                      TAP  200
      DBEIX=C1*((V*COS1)+(U*SIN1))                                      TAP  202
      T=-T                                                              TAP  204
      T2=T*T                                                            TAP  206
      T3=T2*T                                                           TAP  208
```

```
      T4=T3*T
      T5=T4*T
      T6=T5*T
      T7=T6*T
      T8=T7*T
      S=1.+.0088388346D0*T+.7D-9*T2-.517869D-4*T3-.112207D-4*T4-.16192D-
     15*T5+.135D-8*T6+.1452D-6*T7+.492D-7*T8
      TT=-.8838834D-2*T-.7031241D-3*T2-.518006D-4*T3-.72D-8*T4+.16431D-5
     1*T5+.5929D-6*T6+.750D-7*T7-.243D-7*T8
      U=1.-.026516504D0*T-.8D-9*T2+.725024D-4*T3+.144255D-4*T4+.1978D-5*
     1T5-.147D-7*T6-.1671D-6*T7-.563D-7*T8
      V=+.0265165034D0*T+.1171874D-2*T2+.725179D-4*T3+.79D-8*T4-.20042D-
     15*T5-.6992D-6*T6-.883D-6*T7+.269D-8*T8
      CBRX=C2*((S*COS1)+(TT*SIN1))
      CBIX=C2*((TT*COS1)-(S*SIN1))
      DKERX=-C2*((U*COS2)+(V*SIN2))
      DKEIX=-C2*((V*COS2)-(U*SIN2))
    6 CONTINUE
      IF (J-1) 7,7,8
    7 PO=(1./(RHO-1.))**.5
      J=J+1
      A(1,1)=DBERX
      A(1,2)=DBEIX
      A(1,3)=DKERX
      A(1,4)=DKEIX
      A(1,5)=0.
      A(1,6)=-PO
      A(1,7)=0.
      A(1,8)=0.
      A(1,9)=0.
      A(1,10)=0.
      A(2,1)=-X*BEIX-2.*DBERX
      A(2,2)=X*BERX-2.*DBEIX
      A(2,3)=-X*CEIX-2.*DKERX
      A(2,4)=X*CERX-2.*DKEIX
      A(2,5)=-(X*PO/(2.**.5))
      A(2,6)=A(2,5)
      A(2,7)=0.
      A(2,8)=0.
      A(2,9)=0.
      A(2,10)=0.
      A(3,1)=4.*X*BEIX+8.*DBERX-X*X*DBEIX
      A(3,2)=-4.*X*BERX+8.*DBEIX+X*X*DBERX
      A(3,3)=4.*X*CEIX+8.*DKERX-X*X*DKEIX
      A(3,4)=-4.*X*CERX+8.*DKEIX+X*X*DKERX
      A(3,5)=-X*X*PO
      A(3,6)=0.
      A(3,7)=0.
      A(3,8)=0.
      A(3,9)=0.
      A(3,10)=0.
      A(4,1)=(-X*BERX+2.*DBEIX)
      A(4,2)=(-X*BEIX-2.*DBERX)
      A(4,3)=(-X*CERX+2.*DKEIX)
      A(4,4)=(-X*CEIX-2.*DKERX)
      A(4,5)=A(2,5)
      A(4,6)=-A(2,5)
      A(4,7)=0.
      A(4,8)=0.
      A(4,9)=0.
      A(4,10)=0.
      X=X*RHO**.5
      GO TO 3
    8 PO=(RHO/(RHO-1.))**.5
      IF (IBOND-1) 9,10,10
    9 U1=0.
      U2=0.
      U3=0.
      U4=0.
      U5=0.
```

```
      GO TO 11
   10 PHI1=PO*PO
      P=PRESS
      XK2=XK*XK
      U1=TH/(4.*PHI1*HL)
      U2=X*X*YM*G1**3/(87.36*TH*(PHI1*HL)**3)
      U3=(XB/YM)*((1.3*XK2+.7)/(XK2-1.))
      U4=-TH*XB*ALPHA*PS/(2.*HL*(1.+ALPHA)**2)
      U5=ALPHA*GO*XE*P/(4.*HL*TH)
   11 AA11=DBERX
      AA12=DBEIX
      AA13=DKERX
      AA14=DKEIX
      AA21=-X*BEIX-2.*DBERX
      AA22=X*BERX-2.*DBEIX
      AA23=-X*CEIX-2.*DKERX
      AA24=X*CERX-2.*DKEIX
      AA41=(-X*BERX+2.*DBEIX)
      AA42=(-X*BEIX-2.*DBERX)
      AA43=(-X*CERX+2.*DKEIX)
      AA44=(-X*CEIX-2.*DKERX)
      A(5,1)=AA11+U1*AA21-U2*U3*AA41
      A(5,2)=AA12+U1*AA22-U2*U3*AA42
      A(5,3)=AA13+U1*AA23-U2*U3*AA43
      A(5,4)=AA14+U1*AA24-U2*U3*AA44
      A(5,5)=0.
      A(5,6)=0.
      A(5,7)=0.
      A(5,8)=0.
      A(5,9)=0.
      A(5,10)=0.
      A(6,1)=-X*BEIX-2.*DBERX
      A(6,2)=X*BERX-2.*DBEIX
      A(6,3)=-X*CEIX-2.*DKERX
      A(6,4)=X*CERX-2.*DKEIX
      A(6,5)=0.
      A(6,6)=0.
      A(6,7) = -2.0*PHI1**1.5*HL*(2.0*DLOG(XB)+1.0)
      A(6,8)=-4.*PHI1**1.5*HL
      A(6,9)=-2.*PHI1**1.5*HL/(XB*XB)
      A(6,10)=0.
      A(7,1)=4.*X*BEIX+8.*DBERX-X*X*DBEIX+((GAMMA**2.*TH)/(HL*ALPHA))*(-
     1X*BERX+2.*DBEIX)
      A(7,2)=-4.*X*BERX+8.*DBEIX+X*X*DBERX+((GAMMA**2.*TH)/(HL*ALPHA))*(
     1-X*BEIX-2.*DBERX)
      A(7,3)=4.*X*CEIX+8.*DKERX-X*X*DKEIX+((GAMMA**2.*TH)/(HL*ALPHA))*(-
     1X*CERX+2.*DKEIX)
      A(7,4)=-4.*X*CERX+8.*DKEIX+X*X*DKERX+((GAMMA**2.*TH)/(HL*ALPHA))*(
     1-X*CEIX-2.*DKERX)
      A(7,5)=0.
      A(7,6)=0.
      TEMP=-4.*PHI1**2.5*HL*HI*TH**3./((G1**3.)*XB)
      A(7,7) = TEMP*(2.6*DLOG(XB)+3.3)
      A(7,8)=TEMP*2.6
      A(7,9)=-TEMP*0.7/(XB*XB)
      A(7,10)=0.
      A(8,1)=0.
      A(8,2)=0.
      A(8,3)=0.
      A(8,4)=0.
      A(8,5)=0.
      A(8,6)=0.
      A(8,7) = XB*XB*DLOG(XB)
      A(8,8)=XB*XB
      A(8,9) = DLOG(XB)
      A(8,10)=1.0
      A(9,1)=0.
      A(9,2)=0
      A(9,3)=0
      A(9,4)=0
```

```
      A(9,5)=0
      A(9,6)=0
      A(9,7) = 2.6*DLOG(XA)+3.3
      A(9,8)=2.6
      A(9,9)=-0.7/(XA*XA)
      A(9,10)=0.
      A(10,1)=0.
      A(10,2)=0.
      A(10,3)=0.
      A(10,4)=0.
      A(10,5)=0.
      A(10,6)=0.
      A(10,7)=1.0
      A(10,8)=0.
      A(10,9)=0.
      A(10,10)=0.
C     PRINT 3,B(1), B(2), B(3), B(4), B(5), B(6),B(7),B(8),B(9),B(10)
      DO 13 I=1,10
      DO 12 J=1,10
      AM(I,J)=A(I,J)
   12 CONTINUE
   13 CONTINUE
C     CALCULATIONS FOR MOMENT LOADING, TAPERED HUB
      P=0.
      PS=0.
      DELT=0.
      IF (ICODE-1) 14,14,15
   14 XMO=XMOA
      GO TO 16
   15 CALL ASMEIN
      XMO=XOP
      G=(GOUT+GIN)/2.
C  16 PRINT 54
   16 CONTINUE
      DO 17 I=1,10
      B(I)=0.
   17 CONTINUE
      B(10)=-(2.73/(6.2832*YM*TH**3.*(XA-XB)))*XMO
      CALL LIN2 (A,10,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)
      B17=(-X*BERX+2.*DEEIX)
      B18=(-X*BEIX-2.*DEERX)
      B19=(-X*CERX+2.*DKEIX)
      B20=(-X*CEIX-2.*DKERX)
      P1=(-YM*G1**3.*XB*ETA1**2./(87.36*PHI1**3.5*HL**3.))*(B17*B(1)+B18
     1*B(2)+B19*B(3)+B20*B(4))
      B9=4.*X*BEIX+8.*DEERX-X*X*DEEIX
      B10=-4.*X*BERX+8.*DBEIX+X*X*DBERX
      B11=4.*X*CEIX+8.*DKERX-X*X*DKEIX
      B12=-4.*X*CERX+8.*DKEIX+X*X*DKERX
      A1=(1./(4.*PHI1**2.5))*(B9*B(1)+B10*B(2)+B11*B(3)+B12*B(4))+2.*ALP
     1HA**2*PS/((1.+ALPHA)**3)
      T1 = B(7)*(2.0*XB*DLOG(XB)+XB)+2.0*B(8)*XB+B(9)/XB
      P1A1=P1/A1
      COF=-(YM*GO*HI*HHC**3.)/(XB*2.73**.25*GAMMA**3.)
      F=P1A1/COF
      T1A1=T1/A1
      COV=(XB*2.73**.25*RHO**3.)/(HL*GAMMA)
      V=T1A1/COV
C-----------------------------------------------------------------01-17-75
C     IF (IBOND-1) 18,18,19
C  18 CONTINUE
C-----------------------------------------------------------------01-17-75
   19 IP=0
      MA=1
   20 SLBS=1.816*YM*B(5)
      IF (IBOND-2) 21,21,22
   21 P1=(-YM*G1**3*XB*ETA1**2/(87.36*PHI1**3.5*HL**3))*(B17*B(1)+B18*B(
     12)+B19*B(3)+B20*B(4))
      GO TO 23
   22 P1=(-YM*G1**3*XB*ETA1**2/(87.36*PHI1**3.5*HL**3))*(B17*B(1)+B18*B(
```

```
     12)+B19*B(3)+B20*B(4))+ALPHA*GC*XB*P/(4.*HI)                        TAP  624
  23 T1 = B(7)*(2.0*XB*DLOG(XB)+XB)+2.0*B(8)*XB+B(9)/XB                   TAP  626A
     Y0=XB*(B(6)+PS)                                                      TAP  628
     Y1=(XB/PO)*(DBERX*B(1)+DBEIX*B(2)+DKERX*B(3)+DKEIX*B(4))+XB*PS/RHOTAP  630
     SLSO=-SLBS+P*XB/(2.*G0)                                              TAP  632
     SLSI=SLBS+P*XB/(2.*G0)                                               TAP  634
     SCSO=.3*SLSO+YM*Y0/XB                                                TAP  636
     SCSI=.3*SLSI+YM*Y0/XB                                                TAP  638
     SLBL=(YM*G1/1.82)*((XB/(4.*PHI1**2.5*HL*HL))*(B9*B(1)+B10*B(2)+B11TAP  640
    1*B(3)+B12*B(4))+2.*XB*ALPHA**2*PS/(HL*HL*(1.+ALPHA)**3))             TAP  642
     SLLO=-SLBL+P*XB/(2.*G1)                                              TAP  644
     SLLI=SLBL+P*XB/(2.*G1)                                               TAP  646
     SCLO=.3*SLLO+YM*Y1/XB                                                TAP  648
     SCLI=.3*SLLI+YM*Y1/XB                                                TAP  650
     STB = -(YM*TH/1.82)*((2.6*DLOG(XB)+1.9)*B(7)+2.6*B(8)+(0.7/(XB*XB)TAP  652A
    1)*B(9))                                                              TAP  654A
     STM=((XK*XK+1.)/(XK*XK-1.))*(P-P1/TH)                                TAP  656
     STH=STB+STM                                                          TAP  658
     STF=-STB+STM                                                         TAP  660
     SRB = -(YM*TH/1.82)*((2.6*DLOG(XB)+3.3)*B(7)+2.6*B(8)-0.7*B(9)/(XBTAP  662A
    1*XB))                                                                TAP  664A
     SRH=SRB-P+P1/TH                                                      TAP  666
     SRF=-SRB-P+P1/TH                                                     TAP  668
     FR=SLSO/SLLO                                                         TAP  670
     ZG = B(7)*G*G*DLOG(G)+B(8)*G*G+B(9)*DLOG(G)+B(10)                    TAP  672A
     ZC = B(7)*C*C*DLOG(C)+B(8)*C*C+B(9)*DLOG(C)+B(10)                    TAP  674A
     QFHG=-ZC+ZG                                                          TAP  676
     QFHR(MA)=QFHG                                                        TAP  678
     IF (ICODE-2) 24,25,25                                                TAP  680
  24 CALL STORE                                                           TAP  681A
C 24 PRINT 55, ETC,ETC.                                                   TAP  682A
C    1,ETC,ETC.                                                           TAP  684A
     GO TO 26                                                             TAP  686
  25 SLMAX = DMAX1( DABS(SLSO),DABS(SLLO) )                               TAP  688A
     SLM=.66667*SLMAX                                                     TAP  690
     COT=(SLMAX+STH)/2.                                                   TAP  692
     COR=(SLMAX+SRH)/2.                                                   TAP  694
     PRINT 56                                                             TAP  696
     PRINT 57, SLM,STH,SRH,COT,COR                                        TAP  698
     PRINT 58                                                             TAP  700
     SLM=SLM*ROG                                                          TAP  702
     STH=STH*ROG                                                          TAP  704
     SRH=SRH*ROG                                                          TAP  706
     COT=COT*ROG                                                          TAP  708
     COR=COR*ROG                                                          TAP  710
     PRINT 57, SLM,STH,SRH,COT,COR                                        TAP  712
     PRINT 62                                                             TAP  714
     GO TO 47                                                             TAP  716
  26 IP=IP+1                                                              TAP  718
C    GO TO( 27,36,40,44 ),IP                                              TAP  720A
     GO TO( 27,36,40    ),IP                                              TAP  721A
C    CALCULATION FOR PRESSURE LOADING, TAPERED HUB                        TAP  722
  27 XMO=0.                                                               TAP  724
     P=PRESS                                                              TAP  726
     DELT=0.                                                              TAP  728
     PS=(.85*XB/(YM*G0))*P                                                TAP  730
C    PRINT 59                                                             TAP  732A
     DO 28 I=1,10                                                         TAP  734
     B(I)=0.                                                              TAP  736
  28 CONTINUE                                                             TAP  738
     PO=(1./(RHO-1.))**.5                                                 TAP  740
     B(2)=-2.*PO*PS                                                       TAP  742
     B(3)=8.*PO*PS                                                        TAP  744
C-----------------------------------------------------------------------01-17-75
C ** THESE TWO STATEMENTS NO LONGER COMMENTS, 09-17-75.
     IF( IBOND-2 ) 30,30,29                                               TAP  746A
  29 B(4) = -1.944*EC*IS                                                  TAP  748A
C-----------------------------------------------------------------------01-17-75
  30 EC=(RHO/(RHO-1.))**.5                                                TAP  750
     IF (IBOND-2) 31,31,32                                                TAP  752
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```
   31 B(5)=(PO/XB)*((XB*PS/(1.+ALPHA))-U3*P+U4+XB*AL*DELT)
      B(7)=8.*PO*PS/(RHC)
      GO TO 33
   32 B(5)=(PO/XB)*((XB*PS/(1.+ALPHA))-U3*P+U4+U3*U5+XB*AL*DELT)
      B(7)=8.*PO*PS/(RHC)-5.46*TH*HL*P/(GO*GO*RPO**.5*ALPHA**1.5*YM)
   33 B(6)=-2.*PO*PS/(1.+ALPHA)
      DO 35 I=1,10
      DO 34 J=1,10
      A(I,J)=AM(I,J)
   34 CONTINUE
   35 CONTINUE
      CALL LIN2 (A,10,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)
      MA=2
      GO TO 20
C     CALCULATION FOR DELTA TEMPERATURE, TAPERED HUB
   36 P=0.
      PS=0.
      DELT=DELTA
C     PRINT 60
      DO 37 I=1,10
      B(I)=0.
   37 CONTINUE
      B(5)=(PO/XB)*(XB*AL*DELTA)
      DO 39 I=1,10
      DO 38 J=1,10
      A(I,J)=AM(I,J)
   38 CONTINUE
   39 CONTINUE
      CALL LIN2 (A,10,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)
      MA=3
      GO TO 20
C ** CARDS TAP816-864 DELETED 09-19-75.
C  44 PRINT 62
   40 CONTINUE
      GO TO (46,45,46,45,46,45), MATE
   45 CALL FLGDW
   46 CONTINUE
      GO TO( 70,70,71,70,71,70 ),MATE
   70 CALL COMBIN
   71 CONTINUE
   47 RETURN
C
   48 FORMAT (8E10.5)
   49 FORMAT (84H  FLANGE    FLANGE    FLANGE     PIPE      HUB A.    HUB
     1B        BOLT      PRESSURE,     /84H  O.D.,A     I.D.,B    THICK.,T   WA
     2LL,GO    BASE,G1    LENGTH,H  CIRCLE,C      P          )
   50 FORMAT (7F10.5,1F10.3/)
   51 FORMAT (5E10.5)
   52 FORMAT (98H  MOMENT  COEFF. OF   DELTA     MOD. OF MEAN GASKET  IT
     1YPE      IBOND     ICODE      MATE              /51H           THERMAL E
     2XP.           ELASTICITY DIAMETER  )
   53 FORMAT (1P5E10.3,I6,3I10//)
   54 FORMAT (52H CALCULATIONS FOR MOMENT LOADING, TAPERED HUB FLANGE//)
   55 FORMAT (7H  SLSO=1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=E1
     12.4//7H  SLLO=E12.4,7H  SLLI=E12.4,7H  SCLO=E12.4,7H  SCLI=E12.4//
     27H  STH=E12.4,7H  STF=E12.4,7H  SRH=E12.4,7H  SRF=E12.4//5H  Z
     3G=E12.4,5H  ZC=E12.4,7H  QFHG=E12.4,5H  YC=E12.4,5H  Y1=E12.4,8H
     4THETA=E12.4/)
   56 FORMAT (49H   ASME FLANGE STRESSES AT OPERATING MOMENT, MOP //)
   57 FORMAT (11H   (2/3)*SH=,1PE12.4,6H  ST =,E12.4,6H  SR =,E12.4,13H
     1(SH+ST )/2=,E12.4,13H   (SH+SR )/2=,E12.4///)
   58 FORMAT (55H   ASME FLANGE STRESSES AT GASKET SEATING MOMENT, MGS
     1//)
   59 FORMAT (34H CALCULATIONS FOR PRESSURE LOADING//)
   60 FORMAT (37H CALCULATIONS FOR TEMPERATURE LOADING//)
   61 FORMAT (34H CALCULATIONS FOR COMBINED LOADING//)
   62 FORMAT (1H1)
      END
```

```
      SUBROUTINE STHUB                                                  STH    2
C     THIS CALCULATION IS FOR ITYPE = 2, STRAIGHT HUB FLANGES           STH    4
      IMPLICIT REAL*8 (A-H,O-Z)                                         01-28-75
      DIMENSION A(10,10), B(10), ITEMP(10), LPR(10), LPC(10), AM(10,10) STH    6
      DIMENSION SB(6,18),SC(18)                                         STH    6A
      COMMON ITYPE,IBOND,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,STH    8
     1AB,QFHR(4),AL,DELTA,XMO,XMOA,QFHGP,QPHGP,QTHGP,BF,GOP,THP,YFP,EFP,STH   10
     2DELTAF,GOUT,GIN,RCG                                               STH   12
     3,SLSO,SLSI,SCSO,SCSI,SLLO,SLLI,SCLO,SCLI,STH                      STH    8A
     4,STF,SRH,SRF,ZG,ZC,QFHG,YC,Y1,T1,THETA,SORT,SGR,SGT,SCR,SCT,SAT   STH    8B
     5,W2,W1,SB,MA,IT,XM1,XM2,XM2F                                      STH    8C
      DATA A/100*0./,B/10*0./,LTEMP/10*0/,LPR/10*0/,LPC/10*0/,AM/100*0./
C
    1 READ 32, XA,XB,TH,G0,G1,HL,C,PRESS                                STH   14
      PRINT 33                                                          STH   16
      PRINT 34, XA,XB,TH,G0,G1,HL,C,PRESS                               STH   18
      G=1.                                                              STH   20
      YM=1.                                                             STH   22
      IF (ICODE.GE.2) GO TO 2                                           STH   24
      READ 35, XMOA,EF,DELTA,YM,G                                       STH   26
      PRINT 36                                                          STH   28
      AL=EF                                                             STH   30
      PRINT 37, XMOA,EF,DELTA,YM,G,ITYPE,IBOND,ICODE,MATE               STH   32
    2 XA=XA/2.                                                          STH   34
      XB=XB/2.                                                          STH   36
      XK=XA/XB                                                          STH   38
      XK2=XK*XK                                                         STH   40
      G=G/2.                                                            STH   42
      C=C/2.                                                            STH   44
      BETA = 2.73**0.25/DSQRT(XB*G0)                                    STH   46A
      IF (IBOND-1) 3,4,4                                                STH   48
    3 U3=0.                                                             STH   50
      U33=0.                                                            STH   52
      U34=0.                                                            STH   54
      GO TO 5                                                           STH   56
    4 U3=(XB/YM)*((1.3*XK2+.7)/(XK2-1.))                                STH   58
      U33=2.*U3*YM*(G0*BETA)**3/(TH*10.92)                              STH   60
      U34=TH*BETA/2.                                                    STH   62
    5 XT1=U34-U33                                                       STH   64
      XT2=1.+U34+U33                                                    STH   66
      PS=(.85*XB/(YM*G0))*PRESS                                         STH   68
      A(1,1)=XT1                                                        STH   70
      A(1,2)=XT2                                                        STH   72
      A(1,3)=0.                                                         STH   74
      A(1,4)=0.                                                         STH   76
      A(1,5)=0.                                                         STH   78
      A(1,6)=0.                                                         STH   80
      A(2,1)=BETA                                                       STH   82
      A(2,2)=BETA                                                       STH   84
      A(2,3) = -(2.0*XB*DLOG(XB)+XB)                                    STH   86A
      A(2,4)=-2.*XB                                                     STH   88
      A(2,5)=-1./XB                                                     STH   90
      A(2,6)=0.                                                         STH   92
      A(3,1)=2.*BETA**2*(1.+BETA*TH/2.)                                 STH   94
      A(3,2)=-2.*BETA**3*TH/2.                                          STH   96
      A(3,3) = -(2.6*DLOG(XB)+3.3)*(TH/G0)**3                           STH   98A
      A(3,4)=-2.6*(TH/G0)**3                                            STH  100
      A(3,5)=(.7/(XB*XB))*(TH/G0)**3                                    STH  102
      A(3,6)=0.                                                         STH  104
      A(4,1)=0.                                                         STH  106
      A(4,2)=0                                                          STH  108
      A(4,3) = XB*XB*DLOG(XB)                                           STH  110A
      A(4,4)=XB*XB                                                      STH  112
      A(4,5) = DLOG(XB)                                                 STH  114A
      A(4,6)=1.                                                         STH  116
      A(5,1)=0.                                                         STH  118
      A(5,2)=0.                                                         STH  120
      A(5,3) = 2.6*DLOG(XA)+3.3                                         STH  122A
      A(5,4)=2.6                                                        STH  124
```

```
      A(5,5)=-.7/(XA*XA)                                                 STH 126
      A(5,6)=0.                                                          STH 128
      A(6,1)=0.                                                          STH 130
      A(6,2)=0.                                                          STH 132
      A(6,3)=1.                                                          STH 134
      A(6,4)=0.                                                          STH 136
      A(6,5)=0.                                                          STH 138
      A(6,6)=0.                                                          STH 140
      DO 7 I=1,6                                                         STH 142
      DO 6 J=1,6                                                         STH 144
      AM(I,J)=A(I,J)                                                     STH 146
    6 CONTINUE                                                           STH 148
    7 CONTINUE                                                           STH 150
C     CALCULATIONS FOR MOMENT LOADING, STRAIGHT HUB                      STH 152
      P=0.                                                               STH 154
      PS=0.                                                              STH 156
      DELT=0.                                                            STH 158
      IF (ICODE-1) 8,8,9                                                 STH 160
    8 XMO=XMOE                                                           STH 162
      GO TO 10                                                           STH 164
    9 CALL ASMLIN                                                        STH 166
      XMO=XOP                                                            STH 168
C  10 PRINT 38                                                           STH 170A
   10 CONTINUE                                                           STH 170B
      DO 11 I=1,6                                                        STH 172
      B(I)=0.                                                            STH 174
   11 CONTINUE                                                           STH 176
      B(6)=-2.73*XMO/(6.2832*YM*TH**3*(XA-XB))                           STH 178
      CALL LIN2 (A,6,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)       STH 180
      IP=0                                                               STH 182
      MA=1                                                               STH 184
   12 C5=B(1)                                                            STH 186
      C6=B(2)                                                            STH 188
      D1=B(3)                                                            STH 190
      D2=B(4)                                                            STH 192
      D3=B(5)                                                            STH 194
      D4=B(6)                                                            STH 196
      THETA=BETA*(C5+C6)                                                 STH 198
      THETA1 = D1*(2.0*XB*DLOG(XB)+XB)+2.0*D2*XB+D3/XB                   STH 200A
      XHO=YM*(G0**3)*(BETA**2)*C5/5.46                                   STH 202
      PO=YM*G0**3*BETA**3*(-C5+C6)/5.46                                  STH 204
      YO=C6+XB*PS                                                        STH 206
      SLBS=6.*XHO/(G0*G0)                                                STH 208
      SLSO=-SLBS+P*XB/(2.*G0)                                            STH 210
      SLSI=SLBS+P*XB/(2.*G0)                                             STH 212
      SCSO=.3*SLSO+YM*YO/XB                                              STH 214
      SCSI=.3*SLSI+YM*YO/XB                                              STH 216
      STB = -(YM*TH/1.82)*(2.6*D2+0.7*D3/(XB*XB)+D1*(2.6*DLOG(XB)+1.9))  STH 218A
      STM=((XK*XK+1.)/(XK*XK-1.))*(P-PO/TH)                              STH 220
      STH=STB+STM                                                        STH 222
      STP=-STB+STM                                                       STH 224
      SRB = -(YM*TH/1.82)*(2.6*D2-0.7*D3/(XB*XB)+D1*(2.6*DLOG(XB)+3.3))  STH 226A
      SRH=SRB-P+PO/TH                                                    STH 228
      SRF=-SRB-P+PO/TH                                                   STH 230
      ZG = D2*G*G+D3*DLOG(G)+D4+D1*(G*G*DLOG(G))                         STH 232A
      ZC = D2*C*C+D3*DLOG(C)+D4+D1*(C*C*DLOG(C))                         STH 234A
      QFHG=-ZC+ZG                                                        STH 236
      QFHR(MA)=QFHG                                                      STH 238
      IF (ICODE-2) 13,14,14                                              STH 240
C  13 PRINT 39, ELC, ETC.                                                STH 242A
   13 CALL STORE                                                         STH 242B
      GO TO 15                                                           STH 244
   14 SLM=.66667*SLSO                                                    STH 246
      COT=(SLSO+STH)/2.                                                  STH 248
      COR=(SLSO+SRH)/2.                                                  STH 250
      PRINT 40                                                           STH 252
      PRINT 41, SLM,STH,SRH,COT,COR                                      STH 254
      PRINT 42                                                           STH 256
      SLM=SLM*XOG                                                        STH 258
      STH=STH*XOG                                                        STH 260
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      SRH=SRH*ROG                                                       STH  262
      COT=COT*ROG                                                       STH  264
      COR=COR*ROG                                                       STH. 266
      PRINT 41, SLM,STH,SRH,COT,COR                                     STH  268
      PRINT 46                                                          STH  270
      GO TO 31                                                          STH  272
   15 IP=IP+1                                                           STH  274
C     GO TO( 16,20,24,28 ),IP                                           STH 276A
      GO TO( 16,20,24    ),IP                                           STH 276B
C     CALCULATIONS FOR PRESSURE LOADING, STRAIGHT HUB                   STH  278
   16 XMO=0.                                                            STH  280
      DELT=0.                                                           STH  282
      P=PRESS                                                           STH  284
      PS=(.85*XB/(YM*GO))*P                                             STH  286
C     PRINT 43                                                          STH 288A
      DO 17 I=1,6                                                       STH  290
      B(I)=0.                                                           STH  292
   17 CONTINUE                                                          STH  294
      B(1)=+XB*PS+XB*AL*DELT-U3*PRESS                                   STH  296
      DO 19 I=1,6                                                       STH  298
      DO 18 J=1,6                                                       STH  300
      A(I,J)=AM(I,J)                                                    STH  302
   18 CONTINUE                                                          STH  304
   19 CONTINUE                                                          STH  306
      CALL LIN2 (A,6,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)      STH  308
      MA=2                                                              STH  310
      GO TO 12                                                          STH  312
C     CALCULATIONS FOR DELTA TEMPERATURE LOADING, STRAIGHT HUB          STH  314
   20 P=0.                                                              STH  316
      PS=0.                                                             STH  318
      DELT=DELTA                                                        STH  320
C     PRINT 44                                                          STH 322A
      DO 21 I=1,6                                                       STH  324
      B(I)=0.                                                           STH  326
   21 CONTINUE                                                          STH  328
      B(1)=XB*AL*DELT                                                   STH  330
      DO 23 I=1,6                                                       STH  332
      DO 22 J=1,6                                                       STH  334
      A(I,J)=AM(I,J)                                                    STH  336
   22 CONTINUE                                                          STH  338
   23 CONTINUE                                                          STH  340
      CALL LIN2 (A,6,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)      STH  342
      MA=3                                                              STH  344
      GO TO 12                                                          STH  346
C ** DELETED CARDS STH348-384 OF SUBR. STHUB 09-19-75.
C  28 PRINT 46                                                          STH 386A
   24 CONTINUE                                                          STH 386B
      GO TO (30,29,30,29,30,29), MATE                                   STH  388
   29 CALL FLGDW                                                        STH  390
   30 CONTINUE                                                          STH  392
      GO TO( 70,70,71,70,71,70 ),MATE                                   STH 392A
   70 CALL COMBIN                                                       STH 392B
   71 CONTINUE                                                          STH 392C
   31 RETURN                                                            STH  394
C                                                                       STH  396
   32 FORMAT (8E10.5)                                                   STH  398
   33 FORMAT (84H  FLANGE    FLANGE    FLANGE     PIPE     HUB AT     HUSTH  400
     1B      BOLT    PRESSURE,    /84H  O.D.,A     I.D.,B    THICK.,T  WASTH  402
     2LL,GO    BASE,G1    LENGTH,H  CIRCLE,C     P          )           STH  404
   34 FORMAT (7F10.5,1P10.3/)                                           STH  406
   35 FORMAT (5E10.5)                                                   STH  408
   36 FORMAT (98H  MOMENT  COEFF. OF   DELTA     MOD. OF MEAN GASKET  ITSTH  410
     1YPE      IBOND    ICODE     MATE           /51H         THERMAL ESTH  412
     2XP.      ELASTICITY DIAMETER  )                                   STH  414
   37 FORMAT (1P5E10.3,I6,3I10//)                                       STH  416
   38 FORMAT (53H CALCULATIONS FOR MOMENT LOADING, STRAIGHT HUB FLANGE//STH  418
     1)                                                                 STH  420
   39 FORMAT (7H  SLSO=1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=E1STH  422
     12.4//7H   STH=E12.4,7H   STF=E12.4,7H   SRH=E12.4,7H   SRF=E12.4//STH  424
     25H  ZG=E12.4,5H  ZC=E12.4,7H  QPHG=E12.4,5H  YO=E12.4,8H  THETA=E1STH  426
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  32.4/)                                                               STH   428
40 FORMAT (49H   ASME FLANGE STRESSES AT OPERATING MOMENT, MOP //)     STH   430
41 FORMAT (11H   (2/3)*SH=,1PE12.4,6H   SI =,E12.4,6H   SR =,E12.4,13H STH   432
  1(SH+ST )/2=,E12.4,13H   (SH+SR )/2=,E12.4///)                       STH   434
42 FORMAT (55H   ASME FLANGE STRESSES AT GASKET SEATING MOMENT, MGS    STH   436
  1//)                                                                 STH   438
43 FORMAT (34H CALCULATIONS FOR PRESSURE LOADING//)                    STH   440
44 FORMAT (37H CALCULATIONS FOR TEMPERATURE LOADING//)                 STH   442
45 FORMAT (34H CALCULATIONS FOR COMBINED LOADING//)                    STH   444
46 FORMAT (1H1)                                                        STH   446
   END                                                                 STH   448
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      SUBROUTINE BLIND                                                  BLI     2
C     THIS CALCULATION IS FOR ITYPE = 3, BLIND FLANGES                  BLI     4
      IMPLICIT REAL*8 (A-H,O-Z)                                         01-28-75
      DIMENSION A(10,10), B(10) , LTEMP(10) , LPR(10) , LPC(10) , AM(10,10) BLI     6
      DIMENSION SB(6,18),SC(18)                                         BLI    6A
      COMMON ITYPE,IBOND,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,BLI     8
     1AB,QFHP(4),AL,DELTA,XMO,XMCA,QFHGP,QPHGP,QTHGP,BP,GOP,THP,YFP,EFP,BLI    10
     2DELTAP,GOUT,GIN,BCG                                               BLI    12
     3,SLSO,SLSI,SCSO,SCSI,SLLO,SLLI,SCLO,SCLI,STH                      BLI   12A
     4,STF,SRH,SRF,ZG,ZC,QFHG,Y0,Y1,T1,THETA,SOFT,SGR,SGT,SCR,SCT,SAT   BLI   12B
     5,W2,W1,SB,MA,IT,XM1,XM2,XM2P                                      BLI   12C
      DATA A/100*0./,B/10*0./,LTEMP/10*0/,LPR/10*0/,LPC/10*0/,AM/100*0./
C
    1 READ 17, XA,XB,TH,G0,G1,HL,C,PRESS                                BLI    14
      PRINT 18                                                          BLI    16
      PRINT 19, XA,XB,TH,G0,G1,HL,C,PRESS                               BLI    18
      G=1.                                                              BLI    20
      YM=1.                                                             BLI    22
      IF (ICODE.GE.2) GO TO 15                                          BLI    24
      READ 20, XMCA,EF,DELTA,YM,G                                       BLI    26
      PRINT 21                                                          BLI    28
      AL=EF                                                             BLI    30
      PRINT 22, XMOA,EF,DELTA,YM,G,ITYPE,IBOND,ICODE,MATE               BLI    32
      D=YM*TH**3/10.92                                                  BLI    34
      XA=XA/2.                                                          BLI    36
      C=C/2.                                                            BLI    38
      G=G/2.                                                            BLI    40
      A(1,1)=G*G                                                        BLI    42
      A(1,2)=1.                                                         BLI    44
      A(1,3)=0.                                                         BLI    46
      A(1,4)=0.                                                         BLI    48
      A(1,5)=0.                                                         BLI    50
      A(1,6)=0.                                                         BLI    52
      A(1,7)=0.                                                         BLI    54
      A(1,8)=0.                                                         BLI    56
      A(1,9)=0.                                                         BLI    58
      A(2,1)=-2.*G                                                      BLI    60
      A(2,2)=0.                                                         BLI    62
      A(2,3) = 2.0*G*DLOG(G)+G                                          BLI   64A
      A(2,4)=2.*G                                                       BLI    66
      A(2,5)=1./G                                                       BLI    68
      A(2,6)=0.                                                         BLI    70
      A(2,7)=0.                                                         BLI    72
      A(2,8)=0.                                                         BLI    74
      A(2,9)=0.                                                         BLI    76
      A(3,1)=0.                                                         BLI    78
      A(3,2)=0.                                                         BLI    80
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      A(3,3)=1.                                                    BLI  82
      A(3,4)=0.                                                    BLI  84
      A(3,5)=0.                                                    BLI  86
      A(3,6)=0.                                                    BLI  88
      A(3,7)=0.                                                    BLI  90
      A(3,8)=0.                                                    BLI  92
      A(3,9)=0.                                                    BLI  94
      A(4,1)=0.                                                    BLI  96
      A(4,2)=0.                                                    BLI  98
      A(4,3) = G*G*DLOG(G)                                         BLI 100A
      A(4,4)=G*G                                                   BLI 102
      A(4,5) = DLOG(G)                                             BLI 104A
      A(4,6)=1.                                                    BLI 106
      A(4,7)=0.                                                    BLI 108
      A(4,8)=0.                                                    BLI 110
      A(4,9)=0.                                                    BLI 112
      A(5,1)=-2.6                                                  BLI 114
      A(5,2)=0.                                                    BLI 116
      A(5,3) = 2.6*DLOG(G)+3.3                                     BLI 118A
      A(5,4)=2.6                                                   BLI 120
      A(5,5)=-.7/(G*G)                                             BLI 122
      A(5,6)=0.                                                    BLI 124
      A(5,7)=0.                                                    BLI 126
      A(5,8)=0.                                                    BLI 128
      A(5,9)=0.                                                    BLI 130
      A(6,1)=0.                                                    BLI 132
      A(6,2)=0.                                                    BLI 134
      A(6,3) = 2.0*C*DLOG(C)+C                                     BLI 136A
      A(6,4)=2.*C                                                  BLI 138
      A(6,5)=1./C                                                  BLI 140
      A(6,6)=0.                                                    BLI 142
      A(6,7)=-2.*C                                                 BLI 144
      A(6,8)=-1./C                                                 BLI 146
      A(7,4)=2.6                                                   BLI 156
      A(7,8)=.7/(C*C)                                              BLI 164
      A(6,9)=0.                                                    BLI 148
      A(7,1)=0.                                                    BLI 150
      A(7,2)=0.                                                    BLI 152
      A(7,3) = 2.6*DLOG(C)+3.3                                     BLI 154A
      A(7,5)=-.7/(C*C)                                             BLI 158
      A(7,6)=0.                                                    BLI 160
      A(7,7)=-2.6                                                  BLI 162
      A(7,9)=0.                                                    BLI 166
      A(8,1)=0.                                                    BLI 168
      A(8,2)=0.                                                    BLI 170
      A(8,3)=0.                                                    BLI 172
      A(8,4)=0.                                                    BLI 174
      A(8,5)=0.                                                    BLI 176
      A(8,6)=0.                                                    BLI 178
      A(8,7)=2.6                                                   BLI 180
      A(8,8)=-.7/(XA*XA)                                           BLI 182
      A(8,9)=0.                                                    BLI 184
      A(9,1)=0.                                                    BLI 186
      A(9,2)=0.                                                    BLI 188
      A(9,3) = C*C*DLOG(C)                                         BLI 190A
      A(9,4)=C*C                                                   BLI 192
      A(9,5) = DLOG(C)                                             BLI 194A
      A(9,6)=1.                                                    BLI 196
      A(9,7)=-C*C                                                  BLI 198
      A(9,8) = -DLOG(C)                                            BLI 200A
      A(9,9)=-1.                                                   BLI 202
      DO 3 I=1,9                                                   BLI 204
      DO 2 J=1,9                                                   BLI 206
      AM(I,J)=A(I,J)                                               BLI 208
    2 CONTINUE                                                     BLI 210
    3 CONTINUE                                                     BLI 212
C     CALCULATION FOR MOMENT LOADING, BLIND FLANGES                BLI 214
      MA = 1                                                       BLI 215A
      P=0.                                                         BLI 216
      W=XMOA                                                       BLI 218
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C       PRINT 23                                                          BLI 220A
        DO 4 I=1,9                                                        BLI  222
        B(I)=0.                                                           BLI  224
      4 CONTINUE                                                          BLI  226
        B(3)=-W/(25.1328*D)                                               BLI  228
        CALL LIN2 (A,9,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)      BLI  230
        IP=0                                                              BLI  232
      5 ZC = C*C*B(7) +DLOG(C)*B(8) +B(9)                                 BLI 234A
        QFHR(IP+1)=ZC                                                     BLI  236
        SORT=-(YM*TH/1.82)*2.6*B(1)                                       BLI  238
        SGR=-(YM*TH/1.82)*(2.6*B(1)+G*G*P*3.3/(16.*D))                    BLI  240
        SGT=-(YM*TH/1.82)*(2.6*B(1)+G*G*1.9*P/(16.*D))                    BLI  242
        SCR=-(YM*TH/1.82)*(2.6*B(7)-.7*B(8)/(C*C))                        BLI  244
        SCT=-(YM*TH/1.82)*(2.6*B(7)+.7*B(8)/(C*C))                        BLI  246
        SAT=-(YM*TH/1.82)*(2.6*B(7)+.7*B(8)/(XA*XA))                      BLI  248
C       PRINT 24, ETC, ETC.                                               BLI 250A
        IP=IP+1                                                           BLI  252
        CALL STORE                                                        BLI 254A
C       GO TO( 6, 10, 14 ), IP                                            BLI 254B
        GO TO( 6,10     ),IP                                              BLI 254C
C       CALCULATION FOR PRESSURE LOADING, BLIND FLANGES                   BLI  256
      6 P=PRESS                                                           BLI  258
        MA = 2                                                            BLI 259A
        W=0.                                                              BLI  260
C       PRINT 25                                                          BLI 262A
        DO 7 I=1,9                                                        BLI  264
        B(I)=0.                                                           BLI  266
      7 CONTINUE                                                          BLI  268
        B(1)=G**4*P/(64.*D)                                               BLI  270
        B(2)=-G**3*P/(16.*D)                                              BLI  272
        B(5)=-G*G*P*3.3/(16.*D)                                           BLI  274
        DO 9 I=1,9                                                        BLI  276
        DO 8 J=1,9                                                        BLI  278
        A(I,J)=AM(I,J)                                                    BLI  280
      8 CONTINUE                                                          BLI  282
      9 CONTINUE                                                          BLI  284
        CALL LIN2 (A,9,10,0.,B,1,10,LTEMP,IERR,DET,NPIV,PIV,LPR,LPC)      BLI  286
        GO TO 5                                                           BLI  288
C ** DELETED CARDS BLI290-322 OF SUBR. BLIND, 09-19-75.
C    14 CONTINUE                                                          BLI 324A
     10 CONTINUE                                                          BLI 324B
        IF( MATE.EQ.1 ) CALL COMBIN                                       BLI 324C
        IF( CODE-1 )  16,16,15                                            BLI 326A
     15 C=C/2.                                                            BLI  328
        CALL ASMEIN                                                       BLI  330
C       FLGDW IS CALLED THRU TAPHUB OR STHUB, 2ND TIME THRU               BLI  332
        PRINT 27                                                          BLI 334A
     16 CONTINUE                                                          BLI 334B
        RETURN                                                            BLI  336
C                                                                         BLI  338
     17 FORMAT (8E10.5)                                                   BLI  340
     18 FORMAT (84H   FLANGE     FLANGE     FLANGE      PIPE      HUB AT  HUBLI  342
       1B        BOLT     PRESSURE,     /84H  O.D.,A     I.D.,B    THICK.,T  WABLI  344
       2LL,GO    BASE,G1     LENGTH,H  CIRCLE,C     P           )          BLI  346
     19 FORMAT (7F10.5,1F10.3/)                                           BLI  348
     20 FORMAT (5E10.5)                                                   BLI  350
     21 FORMAT (98H   BOLT    COEFF. OF    DELTA     MOD. OF MEAN GASKET  ITBLI  352
       1YPE      IBOND     ICODE      MATE                 /               BLI  354
       2              51H  LOAD    THERMAL EXP.         ELASTICITY DIAMETER  )BLI  356
     22 FORMAT (1P5E10.3,I6,3I10//)                                       BLI  358
     23 FORMAT (46H CALCULATIONS FOR  BOLT  LOADING, BLIND FLANGE//)      BLI  360
     24 FORMAT (7H  SORT= 1PE12.4,7H    SGR=E12.4,7H    SGT=E12.4,7H   SCR=E1BLI  362
       12.4,7H    SCT=E12.4,7H    SAT=E12.4//9H       ZC=E12.4//)         BLI  364
     25 FORMAT (34H CALCULATIONS FOR PRESSURE LOADING//)                  BLI  366
     26 FORMAT (34H CALCULATIONS FOR COMBINED LOADING//)                  BLI  368
     27 FORMAT (1H1)                                                      BLI  370
        END                                                               BLI  372
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      SUBROUTINE ASMEIN                                                 ASM    2
      IMPLICIT REAL*8 (A-H,O-Z)                                         01-28-75
      DIMENSION SS(6,18),SI(18)                                         ASM   3A
      COMMON ITYPE,IBCNI,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,ASM    4
     1AB,QFHR(4),AL,DELTA,XMO,XMOA,QFHGP,QPHGE,QTHGE,BP,GOP,THP,YFP,EFP,ASM    6
     2DELTAP,GOUT,GIN,ROG                                               ASM    8
     3,SLSO,SLSI,SCSO,SCSI,SLLO,SLLI,SCLO,SCLI,STH                      ASM   8A
     4,STF,SRH,SFF,ZG,ZC,QFHG,Y0,Y1,T1,THETA,SOPT,SGP,SGT,SCR,SCT,SAT   ASM   8B
     5,W2,W1,SS,MA,IT,XM1,XM2,XM2P                                      ASM   8C
C
      READ 10, XM,Y,GOUT,GIN,SB,SA,AB,INBO,BO                           ASM   10
      PRINT 11                                                          ASM   12
      PRINT 12                                                          ASM   14
      PRINT 13, XM,Y,GOUT,GIN,SB,SA,AB                                  ASM   16
      XA=XA*2.                                                          ASM   18
      XB=XB*2.                                                          ASM   20
      C=C*2.                                                            ASM   22
      IF (INBO-1) 1,1,2                                                 ASM   24
    1 BO=(GOUT-GIN)/4.                                                  ASM   26
    2 IF (BO-.25) 3,3,4                                                 ASM   28
C     D = GASKET DIAMETER IN THIS SUBROUTINE                            ASM   30
    3 D=(GOUT+GIN)/2.                                                   ASM   32
      B=BO                                                              ASM   34
      GO TO 5                                                           ASM   36
    4 B = DSQRT(BO)/2.0                                                 ASM  38A
      D=GOUT-2.*B                                                       ASM   40
    5 P=PRESS                                                           ASM   42
      WM11=.7854*D*D*P                                                  ASM   44
      WM12=6.2832*B*D*XM*P                                              ASM   46
      WM1=.7854*D*D*P+6.2832*B*D*XM*P                                   ASM   48
      SB1=WM1/AB                                                        ASM   50
      WM2=3.1416*B*D*Y                                                  ASM   52
      SB2=WM2/AB                                                        ASM   54
      AM1=WM1/SB                                                        ASM   56
      AM2=WM2/SA                                                        ASM   58
      AM = DMAX1(AM1,AM2)                                               ASM  60A
      WGS=(AM+AB)*SA/2.                                                 ASM   62
      XGS=WGS*(C-D)/2.                                                  ASM   64
      XGS1=WM2*(C-D)/2.                                                 ASM   66
      R=(C-XB)/2.-G1                                                    ASM   68
      H=WM11                                                            ASM   70
      HD=.7854*XB*XB*P                                                  ASM   72
      HT=H-HD                                                           ASM   74
      HG=WM1-H                                                          ASM   76
      XD=(R+.5*G1)*HD                                                   ASM   78
      XT=((R+G1+(C-D)/2.)/2.)*HT                                        ASM   80
      XG=((C-D)/2.)*HG                                                  ASM   82
      XOP=XD+XT+XG                                                      ASM   84
      ROG=XGS/XOP                                                       ASM   86
      PRINT 14                                                          ASM   88
      PRINT 15, BO,WM11,WM12,WM1,SB1,WM2,SB2                            ASM   90
      IF (ITYPE-2) 6,6,7                                                ASM   92
    6 PRINT 16                                                          ASM   94
      PRINT 17, XOP,XGS,XGS1                                            ASM   96
C     IN PRINT OUT, MOP=XOP, MGS=XGS, MGS1=XGS1                         ASM   98
    7 IF (ITYPE-2) 9,9,8                                                ASM  100
    8 SP=((D/TH)**2)*(.3*P)                                             ASM  102
      SW1=((D/TH)**2)*(1.78*WM1*(C-D)/2./(D**3))                        ASM  104
      SOP=SP+SW1                                                        ASM  106
      SW2=((D/TH)**2)*(1.78*WM2*(C-D)/2./(D**3))                        ASM  108
      SGS=((D/TH)**2)*(1.78*WGS*(C-D)/2./(D**3))                        ASM  110
      PRINT 18                                                          ASM  112
      PRINT 19                                                          ASM  114
      PRINT 20, SP,SW1,SOP,SW2,SGS                                      ASM  116
    9 XA=XA/2.                                                          ASM  118
      XB=XB/2.                                                          ASM  120
      C=C/2.                                                            ASM  122
      RETURN                                                            ASM  124
C                                                                       ASM  126
   10 FORMAT (7E10.5,I12,1E8.5)                                         ASM  128
```

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11 FORMAT  (1H0)                                                               ASM   130
12 FORMAT  (108H          M               Y               GOUT                 ASM   132
  1 GIN            SB             SA              AB          )                ASM   134
13 FORMAT  (7F15.5//)                                                          ASM   136
14 FORMAT  (110H          BC             WM11            WM12                  WASM   138
  1M1              SB1            WM2             SB2           )              ASM   140
15 FORMAT  (1P7E15.4//)                                                        ASM   142
16 FORMAT  (50H           MOE            MGS             MGS1         )        ASM   144
17 FORMAT  (1P3E15.4//)                                                        ASM   146
18 FORMAT  (47H           ASME CODE STRESSES FOR BLIND FLANGE  //)            ASM   148
19 FORMAT  (100H          SP             SW1             SOP                   SASM   150
  1W2              SGS                            )                            ASM   152
20 FORMAT  (1P5E15.4/)                                                         ASM   154
   END                                                                         ASM   156
```

```
      SUBROUTINE FLGDW                                                        FLG      2
C     THIS SUBROUTINE IS CALLED ONLY IF MATE = 2,4,6                          FLG      4
      IMPLICIT REAL*8 (A-H,O-Z)                                               01-28-75
      DIMENSION SB(6,18),SC(18)                                               FLG     4A
      COMMON ITYPE,IBOND,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,FLG      6
     1AB,QFHR(4),AL,DELTA,XMO,XMCA,QFHGP,QPHGP,QTHGP,BP,GOP,THP,YFP,EFP,FLG      8
     2DELTAP,GOUT,GIN,ROG                                                     FLG    10A
     3,SLSO,SLSI,SCSO,SCSI,SLIO,SLII,SCLO,SCLI,STH                            FLG    10B
     4,STF,SRH,SRF,ZG,ZC,QFHG,Y0,Y1,T1,THETA,SOFT,SGR,SGT,SCR,SCT,SAT         FLG    10C
     5,W2,W1,SB,MA,IT,XM1,XM2,XM2P                                            FLG    10D
C
      READ 21, BSIZE,YB,EB,TB,XGO,XGI,AB,VO,YG,EG,TG,FACE,PBE,W1,TF,TFP,FLG     12
     1YF2,YFP2,YB2,YG2                                                        FLG     14
      PRINT 22                                                                FLG     16
      PRINT 25, BSIZE,YB,EB,TB,XGO,XGI,AB                                     FLG     18
      PRINT 23                                                                FLG     20
      PRINT 26, VO,YG,EG,TG,FACE,PBE                                          FLG     22
      PRINT 24                                                                FLG     24
      PRINT 27, W1,TF,TFP,YF2,YFP2,YB2,YG2                                    FLG     26
      C=2.*C                                                                  FLG     28
      GO TO (1,1,20,2,20,2) , MATE                                            FLG     30
    1 QFHR(1)=QFHR(1)/XMCA                                                    FLG     32
      QFHR(2)=QFHR(2)/PRESS                                                   FLG     34
      QFHR(3)=QFHR(3)/DELTA                                                   FLG     36
      QFHGP=QFHR(1)                                                           FLG     38
      QFHG=QFHGP                                                              FLG     40
      QPHGP=QFHR(2)                                                           FLG     42
      QPHG=QPHGP                                                              FLG     44
      QTHGP=QFHR(3)                                                           FLG     46
      QTHG=QTHGP                                                              FLG     48
      BP=XB*2.                                                                FLG     50
      B=BP                                                                    FLG     52
      GOP=G0                                                                  FLG     54
      THP=TH                                                                  FLG     56
      YFP=YM                                                                  FLG     58
      YF=YFP                                                                  FLG     60
      EFP=AL                                                                  FLG     62
      EF=EFP                                                                  FLG     64
      DELTAP=DELTA                                                            FLG     66
      XLB=2.*TH+VO+FACE+BSIZE                                                 FLG     68
      TFP=TF                                                                  FLG     70
      YFP2=YF2                                                                FLG     72
      GO TO 3                                                                 FLG     74
    2 QFHG=QFHR(1)/XMCA                                                       FLG     76
```

```
      QPHG=QFHP(2)/PRESS
      QTHG=QFHP(3)/DELTA
      B=XB*2.
      YF=YM
      EF=EM
      XLB=THB+TH+VC+FACE+BSIZE
    3 P=PRESS
      QB1=XLB/(AB*YB)
      QB2=XLB/(AB*YB2)
      G=(XGO+XGI)/2.
      AG=(XGO-XGI)*1.5708*G
      QG1=VO/(AG*YG)
      QG2=VO/(AG*YG2)
      HG=(C-G)/2.
      QF1=QFHG/HG
      QF2=QF1*(YF/YF2)
      IF (MATE-5) 5,5,4
    4 QFP1=QFHG/(HG*HG)
      GO TO 6
    5 QFP1=QFHGP/HG
    6 QFP2=QFP1*(YFP/YFP2)
      Q1=QB1+QG1+HG*HG*(QF1+QFP1)
      Q2=QB2+QG2+HG*HG*(QF2+QFP2)
      HT=(C-(G+B)/2.)/2.
      HTP=(C-(G+BP)/2.)/2.
      HD=(C-B-GO)/2.
      HDP=(C-BP-GOP)/2.
      COFAL=.7854*HG/Q1
      W2A=W1+(1./Q1)*(-TB*EB*XLB+TG*EG*VO+TF*EF*TH+TFP*EFP*THP)
      IF (MATE-5) 8,8,7
    7 W2B=W1+COFAL*((QG1/HG-QF1*(HT-HG))*G*G-QF1*B*B*(HD-HT))*P
      GO TO 9
    8 W2B=W1+COFAL*(((QG1/HG-QF1*(HT-HG)-QFP1*(HTP-HG))*G*G-(QF1*B*B*(HD-
     1HT)+QFP1*BP*BP*(HDP-HTP)))*(P+PBE)
    9 W2C=W2B-(QPHG/HG+QPHGP/HG)*P*HG/Q1
      IF (MATE-5) 11,11,10
   10 W2D=W1-(QTHG/HG)*DELTA*HG/Q1
      GO TO 12
   11 W2D=W1-(QTHG*DELTA+QTHGP*DELTAP)/Q1
   12 IF (MATE-5) 14,14,13
   13 W2=(Q1/Q2)*W1+(1./Q2)*(-TB*EB*XLB+TG*EG*VC+TF*EF*TH+TFP*EFP*THP)+(
     1Q1/Q2)*COFAL*((QG2/HG-QF2*(HT-HG))*G*G-QF2*B*B*(HD-HT))*P-((QPHG/H
     2G)*(YF/YF2)+(QPHGP/HG)*(YFP/YFP2))*P*HG/Q2-(QTHG/HG)*(YF/YF2)*DELT
     3A*HG/Q2
      GO TO 15
   14 W2=(Q1/Q2)*W1+(1./Q2)*(-TB*EB*XLB+TG*EG*VC+TF*EF*TH+TFP*EFP*THP)+(
     1Q1/Q2)*COFAL*((QG2/HG-QF2*(HT-HG)-QFP2*(HTP-HG))*G*G-(QF2*B*B*(HD-
     2HT)+QFP2*BP*BP*(HDP-HTP)))*(P+PBE)-((QPHG/HG)*(YF/YF2)+(QPHGP/HG)*
     3(YFP/YFP2))*P*HG/Q2-(QTHG*DELTA*(YF/YF2)+QTHGP*DELTAP*(YFP/YFP2))/
     4Q2
   15 GO TO (20,16,20,17,20,18), MATE
   16 PRINT 28
      GO TO 19
   17 PRINT 29
      GO TO 19
   18 PRINT 30
   19 PRINT 31
      PRINT 32, QPHGP,QPHGP,QTHGP,BP,GOP,THP,YFP,YFP2,EFP
      PRINT 33
      PRINT 32, QPHG,QPHG,QTHG,B,GO,TH,YF,YF2,EF
      PRINT 34
      PRINT 35, XLB,AB,C,YB,YB2,EB
      PRINT 36
      PRINT 37, VO,XGO,XGI,YG,YG2,EG
      PRINT 46
      PRINT 38
      PRINT 39, W1,TB,TF,TFP,TG,DELTA,DELTAP,P
      PRINT 40
      PRINT 41, W2A,W2B,W2C,W2D,W2
      DWA=W1-W2A
```

```
      DWB=W1-W2B
      DWC=W1-W2C
      DWD=W1-W2D
      DWCO=W1-W2
      PRINT 42, DWA,DWB,DWC,DWD,DWCO
      RA=W2A/W1
      RB=W2B/W1
      RC=W2C/W1
      RD=W2D/W1
      RCO=W2/W1
      PRINT 43, RA,RB,RC,RD,RCO
      PRINT 47
   47 FORMAT(//6X,'INITIAL AND RESIDUAL MOMENTS AFTER THERMAL PRESSURE',
     E,' LOADS.' / )
      XM1=W1*HG
      XM2A=W2A*HG
      XM2B=W2B*HG+.7854*P*(B*B*HD+(G*G-B*B)*HT-G*G*HG)
      XM2C=W2C*HG+.7854*P*(B*B*HD+(G*G-B*B)*HT-G*G*HG)
      XM2D=W2D*HG
      XM2=W2*HG+.7854*P*(B*B*HD+(G*G-B*B)*HT-G*G*HG)
      PRINT 44, XM1,XM2A,XM2B,XM2C,XM2D,XM2
      XM2BP=W2B*HG+.7854*P*(BP*BP*HDP+(G*G-BP*BP)*HTP-G*G*HG)
      XM2CP=W2C*HG+.7854*P*(BP*BP*HDP+(G*G-BP*BP)*HTP-G*G*HG)
      XM2P=W2*HG+.7854*P*(BP*BP*HDP+(G*G-BP*BP)*HTP-G*G*HG)
      PRINT 45, XM2BP,XM2CP,XM2P
C     PRINT 30,QE1,QE2,G,AG,QG1,QG2,HG,QF1,QF2,QFP1,QFP2,Q1,Q2,
C    1 HT, HTP, HD, HDP, COFAI
C     30 FORMAT (//10E12.4// 8E12.4)
C  20 PRINT 46
   20 CONTINUE
      RETURN
C
   21 FORMAT (7E10.5/6E10.5/7E10.5)
   22 FORMAT (106H       BSIZE                YB                 EB        T
     1B              XGO               XGI                AB        )
   23 FORMAT (106H                VO                YG                 EG        T
     1G              FACE              FBE                          )
   24 FORMAT (106H                W1                TF                TFP       YF
     12              YFP2              YB2                YG2       )
   25 FORMAT (1P7E15.4)
   26 FORMAT (1P6E15.4)
   27 FORMAT (1P7E15.4//)
   28 FORMAT (80H        FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOAD
     1S, IDENTICAL PAIR          //)
   29 FORMAT (82H        FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOAD
     1S, INTEGER TO INTEGER PAIR //)
   30 FORMAT (80H        FLANGE JOINT BOLT LOAD CHANGE DUE TO APPLIED LOAD
     1S, BLIND TO INTEGER PAIR //)
   31 FORMAT (54H         FLANGE JOINT SIDE ONE (PRIMED QUANTITIES)     /
     1)
   32 FORMAT (7H   QFHG=1PE12.4,7H   QPHG=E12.4,7H   QTHG=E12.4,7H   XB =E1
     12.4,9H       GO=E12.4,12H       TH   =E12.4/12H          YM =E12.4,14H
     2         YF2 =E12.4,8H     EF =E12.4/)
   33 FORMAT (54H         FLANGE JOINT SIDE TWO (UNPRIMED QUANTITIES)   /
     1)
   34 FORMAT (17H          BOLTING/)
   35 FORMAT (14H  BOLT LENGTH=1PE12.4,12H  BOLT AREA=E12.4,14H  BOLT CI
     1RCLE=E12.4/12H          YB =E12.4,13H          YB2 =E12.4,8H    EB =E1
     22.4/)
   36 FORMAT (16H          GASKET/)
   37 FORMAT (9H   VO  =1PE12.4,7H  XGO =E12.4,7H  XGI =E12.4/12H
     1 YG  =E12.4,13H         YG2 =E12.4,8H      EG =E12.4/)
   38 FORMAT (18H          LOADINGS/)
   39 FORMAT (20H  INITIAL BOLT LOAD=1PE12.4,13H  BOLT TEMP.=E12.4,20H
     1 FLANGE ONE TEMP.=E12.4,20H  FLANGE TWO TEMP.=E12.4/15H  GASKET T
     2EMP.=E12.4,9H   DELTA=E12.4,10H   DELTAP=E12.4,11H PRESSURE=E12.4/
     3/)
   40 FORMAT (53H       RESIDUAL BOLT LOADS AFTER THERMAL-PRESSURE LOADS/)
   41 FORMAT (20H   AXIAL THERMAL,W2A=1PE12.4,19H  MOMENT SHIFT,W2B=E12.4
     1//21H  TOTAL PRESSURE,W2C=E12.4,21H   DELTA THERMAL,W2D=E12.4//14H
```

```
  2  COMBINED,W2=E12.4)                                                 FLG    348
42 FORMAT (//9H  W1-W2A=1PE12.4,9H  W1-W2B=E12.4,9H  W1-W2C=E12.4,9H FLG    350
  1 W1-W2D=E12.4,9H  W1-W2= E12.4)                                    FLG    352
43 FORMAT (/9H  W2A/W1=1PE12.4,9H  W2B/W1=E12.4,9H  W2C/W1=E12.4,9H  FLG    354
  1W2D/W1=E12.4,,8H  W2/W1=E12.4)                                     FLG    356
44 FORMAT (/5H  M1=1PE12.4,6H  M2A=E12.4,6H  M2B=E12.4,6H  M2C=E12.4,FLG    358
  16H  M2D=E12.4,5H  M2=E12.4)                                        FLG    360
45 FORMAT (/7H  M2BP=1PE12.4,7H  M2CP=E12.4,6H  M2P=E12.4)            FLG    362
46 FORMAT (1H1)                                                       FLG    364
   END                                                                FLG    366
```

```
      SUBROUTINE LIN2(A,N,NN,EPS,B,M,MM,LTEMP,IERR,DET,NPIV,PIV,LPR,    8046A001
     1               LPC)                                                8046A002
      IMPLICIT REAL*8 (A-H,O-Z)                                          LIN2 02A
      DIMENSION A(NN,N),B(MM,M)                                          8046A003
      DIMENSION LTEMP(1),LPR(1),LPC(1)                                   8046A004
C                                                                        8046A005
C SUBROUTINE LIN2                                                        8046A006
C DECK 8046A                                                             8046A007
C                                                                        8046A008
C SUBROUTINES CALLED - NONE                                              8046A009
C                                                                        8046A010
C THIS ROUTINE SOLVES THE MATRIX EQUATION AX+B=C OVERWRITING B WITH THE 8046A011
C SOLUTION MATRIX X. A MUST BE SQUARE AND NON-SINGULAR. B MUST           8046A012
C HAVE THE SAME NUMBER OF ROWS AS A. THE DETERMINANT OF A IS             8046A013
C COMPUTED. BOTH A AND B ARE DESTROYED.                                  8046A014
C                                                                        8046A015
C THIS ROUTINE IS RECOMMENDED FOR THE SOLUTION OF SIMULTANEOUS LINEAR    8046A016
C EQUATIONS.                                                             8046A017
C                                                                        8046A018
C THE METHOD CONSISTS OF GAUSSIAN ELIMINATION FOLLOWED BY BACK           8046A019
C SUBSTITUTIONS. THIS IS MORE EFFICIENT THAN SOLUTION BY MATRIX          8046A020
C INVERSION REGARDLESS OF THE NUMBER OF COLUMNS IN B. BOTH ROWS AND      8046A021
C COLUMNS ARE SEARCHED FOR MAXIMAL PIVOTS. INTERCHANGING OF ROWS OR      8046A022
C COLUMNS OF A IS AVOIDED. CHAPTER 1 OF E.L. STIEFLE,INTRODUCTION TO     8046A023
C NUMERICAL MATHEMATICS,ACADEMIC PRESS,N.Y.,1963,SHOULD BE HELPFUL IN    8046A024
C FOLLOWING THE CODE.                                                    8046A025
C                                                                        8046A026
C THE CALLING PROGRAM MUST SET A,N,NN,EPS,B,M,MM,LTEMP TO-               8046A027
C                                                                        8046A028
C     A-THE COEFFICIENT MATRIX                                           8046A029
C                                                                        8046A030
C     N-THE ORDER OF A                                                   8046A031
C                                                                        8046A032
C     NN-THE NUMBER OF WORDS OF STORAGE PROVIDED FOR EACH COLUMN OF      8046A033
C        A IN THE CALLING PROGRAM                                        8046A034
C                                                                        8046A035
C     EPS-A NON-NEGATIVE NUMBER WHICH EACH PIVOT IN THE ELIMINATION      8046A036
C          PROCESS IS REQUIRED TO EXCEED IN ABSOLUTE VALUE (CUSTOMARILY  8046A037
C          ZERO)                                                         8046A038
C                                                                        8046A039
C     B-THE CONSTANT TERM MATRIX                                         8046A040
C                                                                        8046A041
C     M-THE NUMBER OF COLUMNS OF B                                       8046A042
C                                                                        8046A043
C        B IN THE CALLING PROGRAM                                        8046A044
C     MM-THE NUMBER OF WORDS OF STORAGE PROVIDED FOR EACH COLUMN OF      8046A045
C                                                                        8046A046
C     LTEMP-A BLOCK OF AT LEAST N WORDS OF TEMPORARY INTEGER STORAGE     8046A047
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C
C IN ADDITION TO OVERWRITING B WITH THE SOLUTION MATRIX X,THE ROUTINE
C SETS IERR,DET,NPIV,PIV,LPR,AND LPC TO
C
C     IERR-   2 IF NO COLUMNS OF X ARE FOUND, THE ELIMINATION PROCESS
C               BEING HALTED BECAUSE THE CURRENT PIVOT FAILS TO EXCEED
C               EPS IN MAGNITUDE
C
C             C IF ALL COLUMNS OF X ARE FOUND, NO TROUBLE BEING DETECTED
C
C     DET-PLUS OR MINUS THE PRODUCT OF THE CURRENT AND ALL PRECEDING
C         PIVOTS
C
C     NPIV-THE NUMBER OF THE CURRENT PIVOT (FIRST,SECOND,ETC.)
C
C     PIV-THE CURRENT PIVOT
C
C     LPR-THE FIRST NPIV POSITIONS LIST THE PIVOT ROW INDICES IN ORDER
C         OF USE,A VECTOR OF LENGTH N
C
C     LPC-THE FIRST NPIV POSITIONS LIST THE PIVOT COLUMN INDICES IN
C         ORDER OF USE,A VECTOR OF LENGTH N
C
C IF THE ELIMINATION PROCESS IS HALTED PREMATURELY (IERR NEGATIVE),THEN
C THE DATA NPIV,PIV,LPR,LPC,MAY BE HELPFUL IN DIAGNOSING THE UNDERLYING
C CAUSE OF THE TROUBLE. IF THE PROCESS GOES TO COMPLETION THEN NPIV=N,
C DET SHOULD BE THE DETERMINANT OF A,PIV WILL BE THE NTH PIVOT,AND LPR
C AND LPC LIST ALL PIVOT POSITIONS.
C
C DO INITIALIZATIONS
C
    1 IERR=0
      DET=1.
      DO 2 I=1,N
      LPR(I)=I
    2 LPC(I)=I
C
C BEGIN ELIMINATION PROCESS
C
      DO 18 NP=1,N
      NPIV=NP
C
C SELECT PIVOT
C
      PIV=0.
      DO 4 K=NP,N
      I=LPR(K)
      DO 4 L=NP,N
      J=LPC(L)
      IF( DABS(A(I,J))-DABS(PIV) ) 4,3,3
    3 KPIV=K
      LPIV=L
      IPIV=I
      JPIV=J
      PIV=A(I,J)
    4 CONTINUE
C
C UPDATE DETERMINANT AND PIVOT ROW AND COLUMN LISTS
C
      DET=DET*PIV
      ITEMP=LPR(NP)
      LPR(NP)=LPR(KPIV)
      LPR(KPIV)=ITEMP
      ITEMP=LPC(NP)
      LPC(NP)=LPC(LPIV)
      LPC(LPIV)=ITEMP
C
C EXIT IF PIVOT TOO SMALL
C
      IF( EPS-DABS(PIV) ) 8,7,7
```

```
    7 IERR= 2
      RETURN
C
C MODIFY PIVOT ROW OF A AND B (ELEMENTS IN PRESENT OR PREVIOUS PIVOT
C     COLUMNS OF A ARE SKIPPED)
C
    8 IF(NP-N)9,11,9
    9 NNP=NP+1
      DO 10 L=NNP,N
      J=LPC(L)
   10 A(IPIV,J)=-A(IPIV,J)/PIV
   11 DO 12 J=1,M
   12 B(IPIV,J)=-B(IPIV,J)/PIV
C
C MODIFY NON-PIVOT ROWS OF A AND B (ELEMENTS IN PRESENT OR PREVIOUS
C     PIVOT ROWS OR COLUMNS ARE SKIPPED)
C
      IF(NP-N)13,18,13
   13 DO 17 K=NNP,N
      I=LPR(K)
      TEMP=A(I,JPIV)
      IF(TEMP)14,17,14
   14 DO 15 L=NNP,N
      J=LPC(L)
   15 A(I,J)=A(I,J)+A(IPIV,J)*TEMP
      DO 16 J=1,M
   16 B(I,J)=B(I,J)+B(IPIV,J)*TEMP
   17 CONTINUE
   18 CONTINUE
C
C END  ELIMINATION PROCESS
C
C DO BACK SUBSTITUTIONS
C
      DO 23 J=1,M
      DO 21 K=2,N
      KK=N-K+1
      I=LPR(KK)
      DO 21 L=2,K
      LL=N-L+2
      II=LPR(LL)
      JJ=LPC(LL)
   21 B(I,J)=B(I,J)+B(II,J)*A(I,JJ)
   23 CONTINUE
C
C UNSCRAMBLE ROWS OF SOLUTION MATRIX AND ADJUST SIGN OF DETERMINANT
C
      DO 24 I=1,N
      L=LPR(I)
   24 LTEMP(L)=LPC(I)
      DO 28 I=1,N
   25 K=LTEMP(I)
      IF(I-K)26,28,26
   26 DET=-DET
      DO 27 J=1,M
      TEMP=B(I,J)
      B(I,J)=B(K,J)
   27 B(K,J)=TEMP
      LTEMP(I)=LTEMP(K)
      LTEMP(K)=K
      GO TO 25
   28 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE COMBIN
      IMPLICIT REAL*8 (A-H,O-Z)                                        COMBIN
      DIMENSION S(6,18) , SC(18)
      DATA SC/18*0.0/                                                  COMBIN
      COMMON ITYPE,IBONI,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,G0,TH,YM,FLA   4
     1AB,QFHR(4),AL,DELTA,XMO,XMCA,QFHGF,QPHGP,QTHGP,BP,GOP,THP,YFP,EFP,FLA   5
     2DELTAP,GOUT,GIN,ROG,SLSO,SLSI,SCSO,SCSI,SILO,SLLI,SCLO,SCLI,STH,
     3  STF,SRH,SRF,ZG,ZC,QFHG,Y0,Y1,T1,THETA,SCRT,SGF,SGT,SCR,SCT,SAT,
     4 W2, W1, S, MA, IT, XM1, XM2, XM2P, IT2
C
      IC = 0
      IF(MATE.LE.2) IT=ITYPE
      GO TO( 1,2,3 ),IT                                                COMBIN
    1 IC = IC + 1
      IF(IC.GT.2) GO TO 99
      IF(MATE.GT.1) PRINT 49
      PRINT 50
      NN = 18
      DO 4 MA = 1,3
      GO TO( 5,6,7 ),MA                                                COMBIN
    5 PRINT 53
      GO TO 8
    6 PRINT 54
      GO TO 8
    7 PRINT 55
    8 GO TO( 12,13 ),IC                                                COMBIN
   12 PRINT 60, (S (MA, I), I=1,NN)
      GO TO 4
   13 PRINT 60, (S (MA+3,I), I=1,NN)
    4 CONTINUE
      IF(MATE.EQ.1) GO TO 99
      DO 9 I=1,NN
      GO TO( 10,11 ),IC                                                COMBIN
   10 SC(I) = S(1,I)*XM2P/XM1+S(2,I) + S(3,I)
      GO TO 9
   11 SC(I) = S(4,I)*XM2/XM1+ S(5,I) + S(6,I)
    9 CONTINUE
      GO TO( 40,41 ),IC                                                COMBIN
   40 PRINT 56, XM2P
      GO TO 42
   41 PRINT 56, XM2
   42 PRINT 60, (SC(I),    I=1,NN)
      IF(MATE.EQ.2) GO TO 99
      IF(IT.EQ.IT2) GO TO 1
      IF(MATE.EQ.4) GO TO 2
      IF(MATE.EQ.6) GO TO 99
    2 IC = IC + 1
      IF(IC.GT.2) GO TO 99
      IF(MATE.GT.1) PRINT 49
      PRINT 51
      NN = 13
      DO14 MA = 1,3
      GO TO( 15,16, 17 ),MA                                            COMBIN
   15 PRINT 53
      GO TO 18
   16 PRINT 54
      GO TO 18
   17 PRINT 55
   18 GO TO( 22,23 ),IC                                                COMBIN
   22 PRINT 61, (S (MA, I), I=1,NN)
      GO TO14
   23 PRINT 61, (S (MA+3,I), I=1,NN)
   14 CONTINUE
      IF(MATE.EQ.1) GO TO 99
      DO19 I=1,NN
      GO TO( 20,21 ),IC                                                COMBIN
   20 SC(I) = S(1,I)*XM2P/XM1+S(2,I) + S(3,I)
      GO TO19
   21 SC(I) = S(4,I)*XM2/XM1+ S(5,I) + S(6,I)
   19 CONTINUE
      GO TO( 43,44 ),IC                                                COMBIN
```

```
43 PRINT 56, XM2P
   GO TO 45
44 PRINT 56, XM2
45 PRINT 61, (SC(I),     I=1,NN)
   IF(MATE.EQ.2) GO TO 99
   IF(IT.EQ.IT2) GO TO 2
   IF(MATE.EQ.4) GO TO 1
   IF(MATE.EQ.6) GO TO 99
 3 IC = IC + 1
   IF(MATE.GT.1) PRINT 49
   PRINT 52
   NN = 7
   DO 24 MA=1,2
   GO TO( 25,26 ),MA                                                  COMBIN
25 PRINT 57
   GO TO 28
26 PRINT 54
28 PRINT 62, (S (MA,I), I=1,NN)
24 CONTINUE
   IF(MATE.EQ.1) GO TO 99
   DO 29 I=1,NN
   SC(I) = S(1,I)*W2/W1 + S(2,I)
29 CONTINUE
   PRINT 56 , W2
   PRINT 62, (SC(I), I=1,NN)
   GO TO( 1,2 ),ITYPE                                                 COMBIN
99 PRINT 49
   RETURN
49 FORMAT (1H1)
50 FORMAT (/50H             TAPERED HUB FLANGE                  /)
51 FORMAT (/50H             STRAIGHT HUB FLANGE                 /)
52 FORMAT (/50H             BLIND FLANGE                        /)
53 FORMAT(50H      CALCULATIONS FOR MOMENT LOADING             //)
54 FORMAT(50H      CALCULATIONS FOR PRESSURE LOADING           //)
55 FORMAT(50H      CALCULATIONS FOR TEMPERATURE LOADING        //)
56 FORMAT( 86H     CALCULATIONS FOR COMBINED LOADING,M2 OR M2P FOR ITY
  1PE=1 OR 2,  W2 FOR ITYPE=3,   =       1PE12.4 //)
57 FORMAT(50H      CALCULATIONS FOR BOLT LOADING               //)
60 FORMAT (7H  SLSO=1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=E1TAP     900
  12.4//7H  SLLO=E12.4,7H  SLLI=E12.4,7H  SCLO=E12.4,7H  SCLI=E12.4//TAP     902
  27H   STH=E12.4,7H   STF=E12.4,7H   SRH=E12.4,7H   SRF=E12.4//5H  ZTAP     904
  3G=E12.4,5H  ZC=E12.4,7H  QFHG=E12.4,5H  YO=E12.4,5H  Y1=E12.4,8H  TAP     906
  4THETA=E12.4/)                                                    TAP     908
61 FORMAT (7H  SLSO=1PE12.4,7H  SLSI=E12.4,7H  SCSO=E12.4,7H  SCSI=E1STH     422
  12.4//7H   STH=E12.4,7H   STF=E12.4,7H   SRH=E12.4,7H   SRF=E12.4//STH     424
  25H  ZG=E12.4,5H  ZC=E12.4,7H  QFHG=E12.4,5H  YO=E12.4,8H  THETA=E1STH     426
  32.4/)                                                            STH     428
62 FORMAT (7H  SORT=1PE12.4,7H   SGR=E12.4,7H   SGT=E12.4,7H   SCR=E1BLI     362
  12.4,7H   SCT=E12.4,7H   SAT=E12.4//9H       ZC=E12.4//)          BLI     364
   END
```

```
    SUBROUTINE STORE
    IMPLICIT REAL*8 (A-H,O-Z)                                         STORE
    DIMENSION S(6,18), SC(18)
    COMMON ITYPE,IBONI,ICODE,MATE,XA,XB,G,C,PRESS,XGS,XOP,G1,GO,TH,YM,FLA     4
   1AB,QFHR(4),AL,DELTA,XMO,XMOA,QFHGP,QFHGI,QTHGP,BP,GOP,THP,YFP,EFP,FLA     5
   2DELTAP,GOUT,GIN,RCG,SLSO,SLSI,SCSO,SCSI,SILO,SLLI,SCLO,SCLI,STH,
   3  STF,SRH,SRF,ZG,ZC,QFHG,YO,Y1,T1,THETA,SCRT,SGR,SGT,SCR,SCT,SAT,
   4 W2, W1, S, MA, IT, XM1, XM2, XM2P
C
```

```
      GO TO( 4,4,4,5,4,5 ),MATE                                    STORE
    5 MA = MA + 3
    4 GO TO( 1,2,3 ),ITYPE                                         STORE
    1 S(MA,1 ) = SLSC
      S(MA,2 ) = SLSI
      S(MA,3 ) = SCSO
      S(MA,4 ) = SCSI
      S(MA,5 ) = SLLO
      S(MA,6 ) = SLII
      S(MA,7 ) = SCLO
      S(MA,8 ) = SCII
      S(MA,9 ) = STH
      S(MA,10) = STF
      S(MA,11) = SRH
      S(MA,12) = SRF
      S(MA,13) = ZG
      S(MA,14) = ZC
      S(MA,15) = QFHG
      S(MA,16) = YO
      S(MA,17) = Y1
      S(MA,18) = I1
      GO TO 50
    2 S(MA,1 ) = SLSC
      S(MA,2 ) = SLSI
      S(MA,3 ) = SCSC
      S(MA,4 ) = SCSI
      S(MA,5 ) = STH
      S(MA,6 ) = STF
      S(MA,7 ) = SRH
      S(MA,8 ) = SRF
      S(MA,9 ) = ZG
      S(MA,10) = ZC
      S(MA,11) = QFHG
      S(MA,12) = YO
      S(MA,13) = THETA
      GO TO 50
    3 S(MA,1 ) = SCRT
      S(MA,2 ) = SGR
      S(MA,3 ) = SGT
      S(MA,4 ) = SCR
      S(MA,5 ) = SCT
      S(MA,6 ) = SAT
      S(MA,7 ) = ZC
   50 RETURN
      END
```

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