ARTICLE 4-3
ANALYSIS OF SPHERICAL SHELLS

4-300 SCOPE

(a) In this article formulas are given for stresses and deformations in spherical shells subjected to internal or external pressure.

(b) Formulas are also given for bending analysis of partial spherical shells under the action of uniformly distributed edge forces and moments.

4-310 NOMENCLATURE AND SIGN CONVENTION

The symbols and sign convention adopted in this article are defined as follows:

(1) p = Uniform pressure, internal or external, psi

(2) M = Meridional bending moment per unit length of circumference, inch-pounds per inch

(3) H = Force per unit length of circumference, perpendicular to center line of sphere, pounds per inch

(4) N = Membrane force, pounds per inch

(5) Q = Radial shearing force per unit of circumference, pounds per inch

(6) S = Stress intensity, psi

(7) R_m = Radius of mid-surface of spherical shell, inches

(8) R = Inside radius, inches

(9) t = Thickness of spherical shell, inches

(10) E = Modulus of elasticity, psi

(11) ν = Poisson's ratio

(12) D = $E\,t^3/12(1-\nu^2)$, flexural rigidity, inch-pounds

(13) β = $[3(1-\nu^2)/R_m^2 t^2]^{1/4}$, 1/in

(14) ϕ = Meridional angle measured from center line of sphere, degrees

(15) ϕ_o = Meridional angle of reference edge where loading is applied, degrees

(16) ϕ_L = Meridional angle of second edge, degrees

(17) α = Meridional angle measured from the reference edge, radians

(18) x = Length of arc for angle α, measured from reference edge of hemisphere, $\pi R_m \alpha/180$, inches

(19) λ = βR_m

(20) Y = Ratio of outside radius to inside radius

(21) Z = Ratio of outside radius to an intermediate radius

(22) U = Ratio of inside radius to an intermediate radius

(23) w = Radial displacement of mid-surface, inches

(24) δ = Lateral displacement of mid-surface, perpendicular to center line of spherical shell, inches

(25) θ = Rotation of mid-surface, radians

(26) o = As a subscript used to denote a quantity at reference edge of sphere

(27) ℓ = As a subscript used to denote meridional direction

(28) t = As a subscript used to denote circumferential direction

(29) $K_1 = 1 - \dfrac{1-2\nu}{2\lambda}\cot(\phi_o - \alpha)$

(30) $K_2 = 1 - \dfrac{1+2\nu}{2\lambda}\cot(\phi_o - \alpha)$

(31) $k_1 = 1 - \dfrac{1-2\nu}{2\lambda}\cot\phi_o$

(32) $k_2 = 1 - \dfrac{1+2\nu}{2\lambda}\cot\phi_o$

(33) $A_o = \sqrt{1 + k_1^2}$

(34) $B(\alpha) = [(1+\nu^2)(K_1 + K_2) - 2K_2]$

(35) $C(\alpha) = \sqrt{\dfrac{\sin \phi_o}{\sin(\phi_o - \alpha)}}$

(36) $F(\alpha) = \sqrt{\sin(\phi_o)\sin(\phi_o - \alpha)}$

(37) γ_o = $\tan^{-1}(-k_1)$

(38) σ_r = Radial stress component, psi

(39) σ_t = Tangential (circumferential) stress component, psi

(40) σ_ℓ = Longitudinal (meridional) stress component, psi

The sign convention is listed below and shown on Fig. 4-310.1 by the positive directions of the pertinent quantities.

(p) Pressure, Positive radially outward

(δ) Lateral Displacement, Perpendicular to ℄ of sphere, positive outward

(θ) Rotation, Positive when accompanied by an increase in the radius or curvature, as caused by a positive moment

$(M), (M_o)$ Moment, Positive when causing tension on the inside surface

$(H), (H_o)$ Force perpendicular to ℄, positive outward

$(N_t), (N_\ell)$ Membrane Force, Positive when causing tension

4-320 PRINCIPAL STRESSES, AND STRESS INTENSITIES RESULTING FROM INTERNAL OR EXTERNAL PRESSURE

In this paragraph formulas are given for principal stresses and stress intensities resulting from uniformly distributed internal or external pressure in complete or partial spherical shells. The effects of discontinuities in geometry and loading are not included and should be evaluated independently. The stresses resulting from all effects must be combined by superposition.

4-321 Principal Stresses Resulting from Internal Pressure

The principal stresses at any point in the wall of a spherical shell are given by the following formulas:

$$\sigma_1 = \sigma_\ell = p(Z^3 + 2)/2(Y^3 - 1) \quad (1)$$

$$\sigma_2 = \sigma_t = p(Z^3 + 2)/2(Y^3 - 1) \quad (2)$$

$$\sigma_3 = \sigma_r = p(1 - Z^3)/(Y^3 - 1) \quad (3)$$

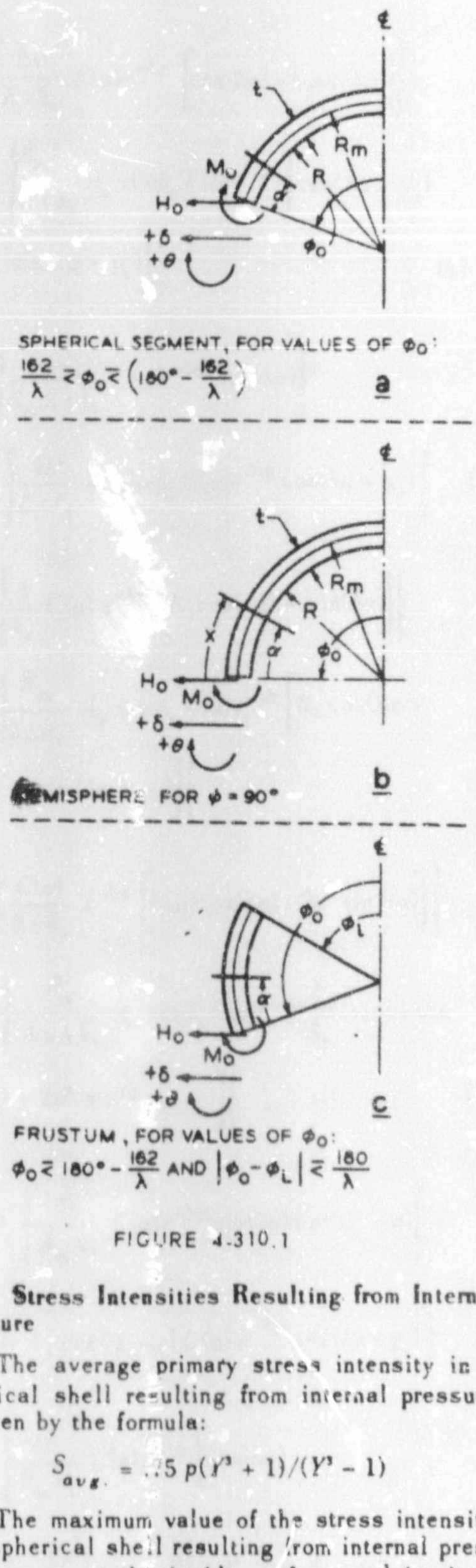

FIGURE 4-310.1

4-322 Stress Intensities Resulting from Internal Pressure

(a) The average primary stress intensity in a spherical shell resulting from internal pressure is given by the formula:

$$S_{avg.} = .75\, p(Y^3 + 1)/(Y^3 - 1)$$

(b) The maximum value of the stress intensity in a spherical shell resulting from internal pressure occurs at the inside surface and is given by the formula:

$$S_{max.} = 1.5\, p(Y^3)/(Y^3 - 1)$$

4-323 Principal Stresses Resulting from External Pressure

The principal stresses at any point in the wall of a spherical shell resulting from external pressure are given by the following formulas:

$$\sigma_1 = \sigma_\ell = -pY^3(U^3 + 2)/2(Y^3 - 1) \qquad (1)$$

$$\sigma_2 = \sigma_t = -pY^3(U^3 + 2)/2(Y^3 - 1) \qquad (2)$$

$$\sigma_3 = \sigma_r = pY^3(U^3 - 1)/(Y^3 - 1) \qquad (3)$$

4-324 Stress Intensities Resulting from External Pressure

(a) The average primary stress intensity in a spherical shell resulting from external pressure is given by the formula:

$$S_{avg.} = .75\, p(Y^3 + 1)/(Y^3 - 1)$$

(b) The maximum value of the stress intensity in a spherical shell resulting from external pressure occurs at the inside surface and is given by the formula:

$$S_{max.} = 1.5\, p(Y^3)/(Y^3 - 1)$$

NOTE: The formulas in Pars. 4-323 and 4-324 may be used only if the applied external pressure is less than the critical pressure which would cause instability of the spherical shell. The value of the critical pressure must be evaluated in accordance with the rules given in Article D-3.

4-330 BENDING ANALYSIS FOR UNIFORMLY DISTRIBUTED EDGE LOADS

(a) The formulas in this paragraph describe the behavior of partial spherical shells of the types shown in Fig. 4-310.1, when subjected to the action of meridional bending moments, M_o (inch pounds per inch of circumference), and forces, H_o (pounds per inch of circumference), uniformly distributed at the reference edge and acting at the mean radius of the shell. The effects of all other loading must be evaluated independently and combined by superposition.

(b) The formulas listed in this paragraph become less accurate and should be used with caution when R_m/t is less than 10 and/or the opening angle limitations shown in Fig. 4-310.1 are exceeded.

4-331 Displacement, Rotation, Moment and Membrane Force in Terms of Loading Conditions at Reference Edge

The displacement, (δ), the rotation, (θ), the bending moments, (M_ℓ), (M_t), and the membrane forces, (N_ℓ), (N_t), at any location of sphere are given in terms of the edge loads, M_o and H_o, by the following formulas:

$$\delta = M_o\left\{\frac{2\lambda^2}{E t k_1} F(\alpha)e^{-\lambda\alpha}\left[\cos(\lambda\alpha) - K_2\sin(\lambda\alpha)\right]\right\} + H_o\left\{\frac{R_m\lambda}{E t k_1} A_o \sin\phi_o F(\alpha)e^{-\lambda\alpha}\left[\cos(\lambda\alpha + \gamma_o) - K_2 \sin(\lambda\alpha + \gamma_o)\right]\right\} \qquad (1)$$

$$\theta = M_o\left\{\frac{4\lambda^2}{R_m E t k_1} C(\alpha)e^{-\lambda\alpha}\cos(\lambda\alpha)\right\} + H_o\left\{\frac{2\lambda^2}{E t k_1} A_o \sin\phi_o C(\alpha)e^{-\lambda\alpha}\cos(\lambda\alpha + \gamma_o)\right\} \qquad (2)$$

$$M_\ell = M_o\left\{\frac{1}{k_1} C(\alpha)\, e^{-\lambda\alpha}\left[K_1\cos(\lambda\alpha) + \sin(\lambda\alpha)\right]\right\} + H_o\left\{\frac{R_m}{2\lambda k_1} A_o \sin\phi_o C(\alpha)e^{-\lambda\alpha}\left[K_1 \cos(\lambda\alpha + \gamma_o) + \sin(\lambda\alpha + \gamma_o)\right]\right\} \qquad (3)$$

$$M_t = M_o\left\{\frac{C(\alpha)}{2 \nu k_1} e^{-\lambda\alpha}\left[B(\alpha)\cos(\lambda\alpha) + 2\nu^2\sin(\lambda\alpha)\right]\right\} + H_o\left\{\frac{R_m}{4\nu\lambda k_1} A_o \sin\phi_o C(\alpha)e^{-\lambda\alpha}\left[B(\alpha)\cos(\lambda\alpha + \gamma_o) + 2\nu^2 \sin(\lambda\alpha + \gamma_o)\right]\right\} \qquad (4)$$

$$N_\ell = -M_o\left\{\frac{2\lambda}{R_m k_1} C(\alpha)e^{-\lambda\alpha}\sin(\lambda\alpha)\cot(\phi_o - \alpha)\right\} - H_o\left\{\frac{1}{k_1} A_o \cot(\phi_o - \alpha)\, C(\alpha)\, e^{-\lambda\alpha}\sin(\lambda\alpha + \gamma_o)\right\} \qquad (5)$$

$$N_t = M_o\left\{\frac{2\lambda^2}{R_m k_1} C(\alpha)e^{-\lambda\alpha}\left[\cos(\lambda\alpha) - \left(\frac{K_1 + K_2}{2}\right)\sin(\lambda\alpha)\right]\right\} + H_o\left\{\frac{\lambda}{k_1} A_o \sin\phi_o C(\alpha)e^{-\lambda\alpha}\left[\cos(\lambda\alpha + \gamma_o) - \left(\frac{K_1 + K_2}{2}\right)\sin(\lambda\alpha + \gamma_o)\right]\right\} \qquad (6)$$

4-332 Displacement and Rotation of Reference Edge in Terms of Loading Conditions at Reference Edge

(a) At the reference edge $\alpha = 0$, and $\phi = \phi_c$. The formulas for the displacement and rotation (Par. 4-331) simplify to those given below:

$$\delta_o = M_o \frac{2\lambda^2 \sin\phi_o}{E t k_1} + H_o \frac{R_m \lambda \sin^2\phi_o}{E t}\left(\frac{1}{k_1} + k_2\right) \quad (1)$$

$$\theta_o = M_o \frac{4\lambda^3}{R_m E t k_1} + H_o \frac{2\lambda^2 \sin\phi_o}{E t k_1} \quad (2)$$

(b) In the case where the shell under consideration is a full hemisphere the formulas given in (1) and (2) above reduce to those given below:

$$\delta_o = M_o \frac{2\lambda^2}{E t} + H_o \frac{2R_m\lambda}{E t} \quad (1)$$

$$\theta_o = M_o \frac{4\lambda^3}{R_m E t} + H_o \frac{2\lambda^2}{E t} \quad (2)$$

4-333 Principal Stresses in Spherical Shells Resulting from Edge Loads

The principal stresses at the inside and outside surfaces of a spherical shell at any location, resulting from edge loads, M_o and H_o, are given by the following formulas:

$$\sigma_1 = \sigma_\ell(\alpha) = \frac{N_\ell}{t} \pm \frac{6M_\ell}{t^2} \quad (1)$$

$$\sigma_2 = \sigma_t(\alpha) = \frac{N_t}{t} \pm \frac{6M_t}{t^2} \quad (2)$$

$$\sigma_3 = \sigma_r(\alpha) = 0 \quad (3)$$

In these formulas where terms are preceded by a double sign, ±, the upper sign refers to the inside surface of the shell and the lower sign refers to the outside surface.

4-340 Alternate Bending Analysis of a Hemispherical Shell Subjected to Uniformly Distributed Edge Loads

If a less exacting but more expedient analysis of hemispherical shells is required, formulas derived for cylindrical shells may be used in a modified form. The formulas listed in this paragraph describe the behavior of a hemispherical shell as approximated by a cylindrical shell of the same radius and thickness when subjected to the action of uniformly distributed edge loads, M_o and H_o, at $\alpha = 0$, $x = 0$, and $\phi_o = 90°$.

4-341 Displacement Rotation, Moment and Shear Forces in Terms of Loading Conditions at Edge

$$\delta_o = H_o/2\beta^3 D + M_o/2\beta^2 D \quad (1)$$

$$\theta_o = H_o/2\beta^2 D + M_o/\beta D \quad (2)$$

$$\delta(x) = \frac{H_o \sin^2\phi}{2\beta^3 D} f_1(\beta x) + \frac{M_o \sin\phi}{2\beta^2 D} f_2(\beta x) \quad (3)$$

$$\theta(x) = \frac{H_o \sin\phi}{2\beta^2 D} f_2(\beta x) + \frac{M_o}{\beta D} f_1(\beta x) \quad (4)$$

$$M(x) = \frac{H_o \sin\phi}{\beta} f_4(\beta x) + M_o f_3(\beta x) \quad (5)$$

$$Q(x) = H_o \sin\phi\, f_2(\beta x) - 2\beta M_o f_4(\beta x) \quad (6)$$

Where

f_1, f_2, f_3 and f_4 are defined in Article 4-2, Analysis of Cylindrical Shells, and

$$x = \alpha R_m = \frac{\pi R_m}{180°}(90° - \phi)$$

4-342 Principal Stresses in a Hemispherical Shell Due to Edge Loads

The principal stresses in a hemispherical shell due to edge loads, (M_o) and (H_o), at the inside and outside surfaces of a hemispherical shell at any meridional location, are given by the formulas:

$$\sigma_1 = \sigma_\ell(x) = \pm 6M(x)/t^2 \quad (1)$$

$$\sigma_2 = \sigma_t(x) = E\,\delta(x)/R_m \pm \nu 6M(x)/t^2 \quad (2)$$

$$\sigma_3 = \sigma_r = 0 \quad (3)$$

In these formulas where terms are preceeded by a double sign, ±, the upper sign refers to the inside surface of the hemisphere and the lower sign refers to the outside surface.

APPENDIX G. FLOW DIAGRAMS OF THE COMPUTER MODELS.

1. Basic Truncated Hemisphere (first principles)
2. Basic FEM Hemisphere Model.

G.1 BASIC ISOTROPIC MODEL

Figure 11 depicts the flow diagram of the first principles computer program. The method of operation of the program is as follows :

All dimensions are in millimeters, pressures in Newtons/millimeter^2 and angles in degrees. A value for the edge moment would be in Newton•millimeters.

1) DATA INPUT :

Enter in - Pipe cut-out diameter, hemisphere diameter and the average wall thickness
- Internal pressure, Modulus of Elasticity and Poissons ratio of the material of construction of the hemisphere
- The increment angle which is the angle at which each section of the element is to be analysed for stress decay

```
                    FIRST PRICIPLES COMPUTER MODEL
                 ------------------------------------

+-------------------------------------------+
|DATA INPUT:                                |
| PIPE CUTOUT DIAMETER - B  (mm)            |        +----------------+
| HEMISPHERE DIAMETER  - D  (mm)            |        |CALCULATION OF  |
| INTERNAL PRESSURE    - P  (bars)          +------->+THE EDGE MOMENT |
| AVERAGE WALL THICKNESS    (mm)            |        | Mo - plate     |
| INCREMENT ANGLE (α)       (degrees)       |        +----------------+
| MODULUS OF ELASTICITY     (N/mm^2)        |
| POISSONS RATIO                            |
+-----------------+-------------------------+
                  v
       +----------+------------+    +------------------------------+
       |STARTING PHI VALUE     +--->+ TRUNCATED ELEMENT CALC.      |
       |        φ = ?          |    | SCREEN OUTPUT                |
       +----------+------------+    +------------------------------+
                  v
+-----------------+----------+    +----------------+
|DATA INPUT OF THE ELEMENT   |    | STORE/RETRIEVE |
|THICKNESSES AND THE         +--->+   DATA         |
|INCLUDED ANGLES             |    |                |
+-------------+--------------+    +----------------+
              v
  +> FOR i = 1 TO NUMBER OF ELEMENTS
  |     +----------------------+
  |     |ANALYSIS OF ELEMENT   |
  |     +----------+-----------+
  |     +----------v-----------------+
  |     | PRE CALCULATIONS OF THE    |
  |     | ELEMENT VARIABLE VALUES    |
  |     +----------------------------+
  |+> FOR j = 1 TO INCLUDED ANGLE/INCREMENT ANGLE
  ||
  ||     +-------------------------+ +-----------------------------+
  ||     | CALCULATION OF THE      | | CALCULATION OF STRESS DUE   |
  ||     | BENDING MOMENTS AND     +>+ TO INTERNAL PRESSURE AND    |
  ||     | THE MEMBRANE FORCES.    | | EDGE MOMENTS STRESSES       |
  ||     +-----------+-------------+ +-----------------------------+
  ||     +-----------v---------------+  +------------------------------+
  ||     | SUM PRESSURE AND EDGE     +->+ PRINT STRESS VALUES FOUND    |
  ||     | MOMENT STRESSES           |  | AT INCREMENT ANGLE o         |
  ||     +---------------------------+  +--------------+---------------+
  ||                             +<--------------------+
  ||           NEXT INCREMENT ANGLE ON THE ELEMENT i
  |+------------------------------------
  |          Mo = MERIDIONAL MOMENT VALUE ON ELEMENT i
  |                                |
  |                      NEXT ELEMENT i
  +--------------------------------+


                      ------END PROGRAM------
```

Figure 11. Flow chart of the first principles computer model

2) SCREEN display will ensue requesting an edge moment, Mo, value. This value may be calculated using the pipe-cut diameter and the internal pressure value in which case the ENTER key should be depressed.

3) REQUEST for a starting Phi value. This angle is measured from the hemisphere base flange to the junction of the nozzle and its compensation overlay.

4) SCREEN OUTPUT is provided of the truncated element limits for the initial phi value data value.
At this stage the program determines the initial values required for the stress calculation equations.

5) INPUT - Data of the element thicknesses and the included angle of each element.

6) The stress values are determined for each element at the particular increment angles. This loop is completed until the stress distribution within the element is completed. The next element is then considered in a similar way.

7) A printout ensues of the stresses found at each increment level of all the elements.

8) ABOUT THE PRINTOUT
The symbols used in the printout ha[illegible]owing meaning:

- x,t - Hoop direction
- y,l - Meridional direction
- in,ot - inside and outside respectively
- M - Unit bending moment
- N - Unit force
- S - Stress due to pressure
- SM - Stress due to the edge moment

All stress values consider either the outside wall surface or the inside wall surface.

The totals provide the values of the sum of the bending and the plane stress values. It must be noted that the M1 value is zero for each new element considered for alpha equal to zero.

G.2 BASIC FEM HEMISPHERE MODEL

Figure 12 depicts the flow diagram for the Basic program of the FEM program. Its operation is as follows.

All dimensions are in millimeters and the pressures and stresses in Newtons/millimeter^2.

1) DATA INPUT

Enter in

- Number of elements and suppressed displacements.
- Strength properties of the material of construction of the hemisphere , the Modulus of Elasticity and the Poissons Ratio.
- Axial Pressure value (zero for this case)
- Lateral pressure value (Internal pressure value)

```
                BASIC ISOTROPIC FINITE ELEMENT METHOD
                -------------------------------------

 INPUT DATA
  NO. OF ELEMENTS
  NO. OF SUPPRESSED DISPLACEMENTS
  ELASTIC MODULUS  (N/mm^2)
  POISSONS RATIO
  LATERAL PRESSURE (N/mm^2)
                 |
                 v
 POSITIONS OF THE SUPPRESSED DISPLACEMENTS  -->  PRINTOUT OF
 ELEMENT NODE DATA (X,R,T,PRI) - (mm,N/mm^2)     INPUT DATA
                              |
                              v
 LOOP FOR EACH ELEMENT
  COMPUTATION :
   COORDINATE PARAMETERS
   B AND D MATRICES
   PRESSURE EFFECTS ON THE LOAD VECTOR
   ELEMENTAL LOAD AND STIFFNESS MATRIX
   TRANSFORMATION OF THE K AND Q MATRIX INTO GLOBAL AXES
   THE STIFFNESS MATRIX SYSTEM
   SET UP THE SIMULTANEOUS EQUATIONS
                              |
                              v
           SOLVING THE SIMULTANEOUS EQUATIONS
                              |
                              v
              DATA OUTPUT :
               U W O DISPLACEMENTS FOR EACH NODE
               STRESSES FOR EACH ELEMENT

                   ------END OF PROGRAM------
```

Figure 12. Flow chart of the FEM computer model.

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2) The positions of the suppressed displacements :

- These values are calculated so -
For each node there are three possible directions in which it may be suppressed. These being the W_i^o , U_i^o and θ_i^o directions. For a node i, to be suppressed in a particular direction the respective suppressed displacement value may be calulated as follows.

U_i^o : 3 * i - 2
W_i^o : 3 * i - 1
θ_i^o : 3 * i

3) DATA INPUT of the position of each node with respect to a particular reference axis and the thickness and applied pressure on each element

The meridional radius of curvature for each element is also entered.

4) PRINTOUT of the input data ensues.

At this stage the program develops the set of simultaneous equations for determining the stresses at each node site.

5) ABOUT THE PRINTOUT

The symbols used have the following meaning.

I - Node number
X,R - Reference axes coordinates of the node.
T - Element thickness
PR - Internal pressure value
E NO - Element Number
POS - Position on the element +1 and -1
MERIDIN, MERIDEX - Meridional stresses internally and externally respectively.
HOOPIN, HOOPEX - Hoop stresses internally and externally respectively.

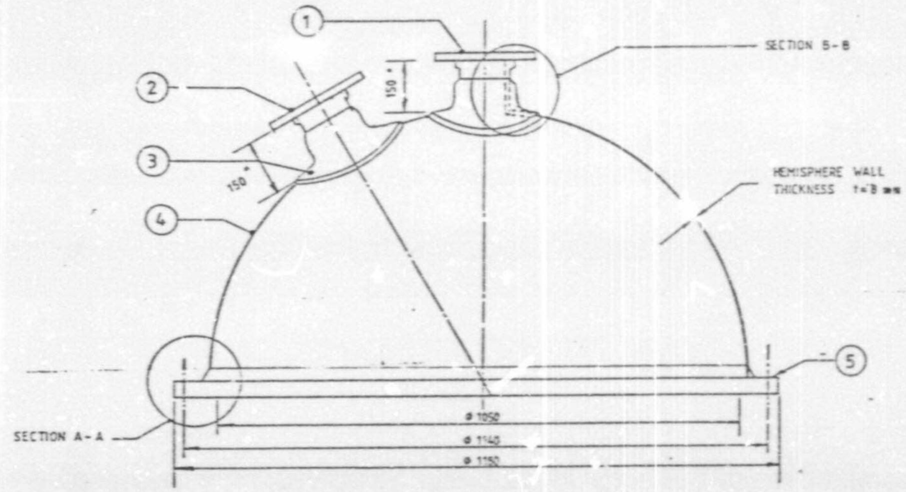
The printout of the stresses occurs once the simultaneous equations are solved.

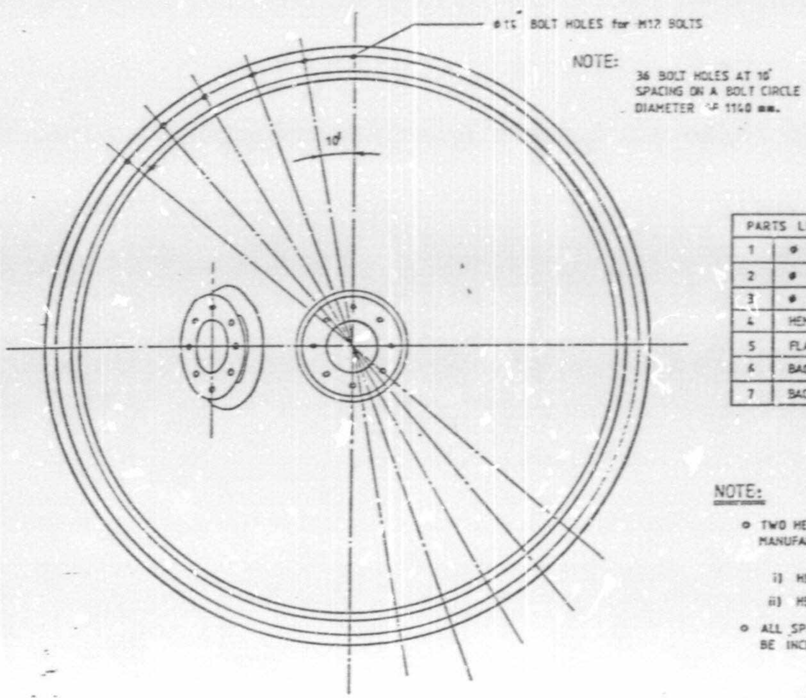
APPENDIX H. DRAWINGS OF THE TESTING RIG

Working Drawing Specification

APPENDIX H. DRAWINGS OF THE TESTING RIG

Working Drawing Specification





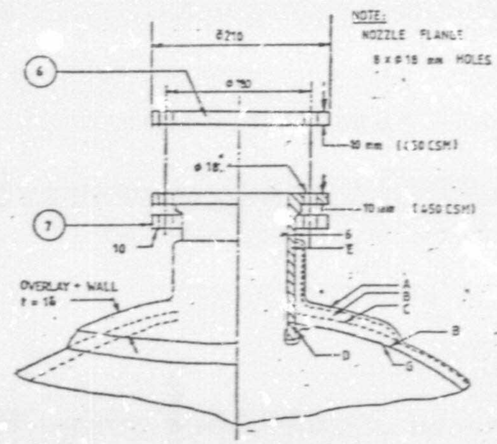
NOTE:
36 BOLT HOLES AT 10° SPACING ON A BOLT CIRCLE DIAMETER OF 1140 mm.

SPECIFICATIONS
DESIGN PRESSURE : 2 bars DESIGN TEMPERATURE : 50° C
CONTENTS : WATER
DIMENSIONS: HEMISPHERE: Diameter : 1500 mm Thickness : 8 mm Area : 1,73 m² FLANGE: Diameter (ins) : 1050 mm Bolt Circle : 1140 mm Diameter (out) : 1180 mm Thickness : 30 mm NOZZLES: Diameter (ins) : 100 mm Thickness : 6 mm Length (out) : 150 mm* Length (ins) : 50 mm* NOZZLE OVERLAYS (minimum) Diameter : 250 mm Thickness : 8 mm

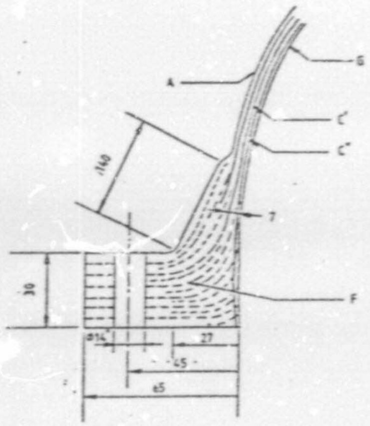
PARTS LIST		No off	Material
1	ø 100 mm NOZZLE and FLANGE	2	GRP
2	ø 100 mm NOZZLE and FLANGE	1	GRP
3	ø 230 mm OVERLAY	3	GRP
4	HEMISPHERE	2	GRP
5	FLANGE	2	GRP
6	BACKING PLATE	3	GRP
7	BACKING RING	3	SMC*

NOTE:

- TWO HEMISPHERES ARE TO BE MANUFACTURED.
  - i) HEMISPHERE + NOZZLE 1 [through wall type]*
  - ii) HEMISPHERE + NOZZLE 1 and 2 [through wall type]*
- ALL SPECIFIED OVERLAYS AND FLANGES ARE TO BE INCLUDED.



SECTION B-B ø100 NOZZLE



SECTION A-A HEMISPHERE BASE FLANGE.

STRUCTURE OF THE LAMINATES	
A	"C"/ 300 CSM / 450 CSM
B	450 CSM* 450 WR* } x Y 450 CSM
	FOR: * Hemisphere Y = 1 * ø 100 Nozzle Overlays Y = 3 *[2]
C	450 CSM *[x2]
D	"C"/ 300 CSM
E	"C"/ 300 CSM 450 CSM 5x "C" (outside)
F	450 CSM [30x]
G	450 CSM 2x 300 CSM "C" GLASS (inside)
C'	450 WR
C"	450 CSM

"C" C GLASS SURFACE TISSUE
* CHANGES BY MANUFACTURER.

MATERIALS:

RESIN: DERAKANE 470-36

GLASS: "C" GLASS SURFACE TISSUE
300 CSM
450 CSM
450 WR

RESIN / GLASS % By weight

C GLASS SURFACE	90 %
CSM	33 %
WR	50 %

NOT TO SCALE	UNIVERSITY OF THE WITWATERSRAND REINFORCED PLASTIC / COMPOSITE MATERIALS FACILITY.
dimensions: mm date: 10/11/86 drawn by: JHC	HEMISPHERE and "AXISYMMETRICALLY" PLACED NOZZLE WORKING DRAWING - EXPERIMENTATION ON THE STRESS CONCENTRATIONS AROUND A NOZZLE

APPENDIX I. REFERENCES

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