Sengupta, Abhijit

From: Dyksterhouse, Don [don.dyksterhouse@pgnmail.com]
Sent: Friday, January 08, 2010 8:17 AM
To: Thomas, George
Cc: Dyksterhouse, Don; Lake, Louis
Subject: Approved calculations
Attachments: 0102-0135-jlh-2 Radial Pressure at Tendons r0_signed.pdf; Approved January 6 0102-0135-01 effective elastic modulus r0.pdf

George,

Please find attached the two approved MPR calculations. Please note that the numbers will change as we place the calculations in the Progress Energy document control system.

0102-0135-jlh-2 Radial Pressure at Hoop Tendons – pages 15
0102-0135-01 Reinforcement Ratio and Effective Modulus of Elasticity – pages 13

P/113

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CALCULATION TITLE PAGE

Client: Progress Energy	Page 1 of 15
Project: CR3 Containment Calculations	Task No. 0102-0906-0135
Title: Radial Pressure at Hoop Tendons	Calculation No. 0102-0135-jlh-2

Preparer / Date	Checker / Date	Reviewer & Approver / Date	Rev. No.
J. L. Hibbard 11-11-2009	Kevin Gantz 11-11-2009	Edward Bird 11-11-2009	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked, and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

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RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page: 2
0102-0135-jlh-2	J. L. Hibbard	Kevin Gotz	

Revision	Affected Pages	Description
0	All	Initial Issue

Note: *The revision number found on each individual page of the calculation carries the revision level of the calculation in effect at the time that page was last revised.*

Table of Contents

1.0 PURPOSE

This calculation determines the radial pressure in the Crystal River 3 containment at the location of the hoop tendons. The radial pressure is determined for two values of the concrete elastic modulus, a nominal value based on the ACI correlation and the minimum value from CR3 design basis calculations. The radial pressure is also determined for three area cases. This is the area that is assumed to carry the radial load. The first is the base case with no area reduction. The second removes the area of the horizontal tendon. The third removes the area of the horizontal and vertical tendons.

2.0 SUMMARY

The radial pressure at the location of the hoop tendons is provided in Table T_s.

T_s =

"Area" "Reduction"	"Nominal" "Modulus"	"Minimum" "Modulus"
"No Area Removed"	28.2	27.1
"Horizontal Conduit"	38.8	37.3
"Horizontal & Vertical Conduit"	45.6	43.8

$$E_c = \begin{pmatrix} 4.29 \times 10^6 \\ 2.5 \times 10^6 \end{pmatrix} psi$$

Notes:

1. The radial pressure value does not account for stress intensification at the tendon conduits.

3.0 BACKGROUND

A project is underway at Progress Energy's Crystal River Unit 3 site to replace the steam generators. As part of that project, an opening has been cut into the concrete containment above the equipment hatch. As this opening was being cut, cracking in the concrete wall was identified. The crack is around the full periphery of the opening and is in the cylindrical plane of the wall. The cracking is located at the radius of the circumferential tensioning tendons, and is indicative of a delaminated condition.

4.0 ASSUMPTIONS

4.1 Unverified Assumptions

There are no unverified assumptions.

4.2 Other Assumptions

1. It is assumed that the tension in a tendon is $T = 1635 \cdot kip$ based on Reference 2, p. 15. This is the tendon tension at lockoff.

2. It is assumed that there is negligible change in thickness of the concrete due to the radial pressure from the tendons. This is a reasonable assumption since the radial strain is negligible.

5.0 CALCULATION

5.1 Data

Containment

$r_i := 65 \cdot ft + 0.375 \cdot in \qquad r_i = 65.03\,ft$ — Concrete containment inside radius; Ref. 1.1

$r_o := r_i + 3.5 \cdot ft \qquad r_o = 68.53\,ft$ — Containment outside radius; Ref. 1.1

$\sigma := 5000 \cdot psi$ — Containment concrete minimum strength; Ref. 2, p. 2
A scoping calculation shows the interface pressure is not sensitive to this input

$W := 150 \cdot \frac{lb}{ft^3}$ — Containment concrete density; Ref. 2, p. 3

$$E_{c_1} := 33 \cdot psi \cdot \left(\frac{W}{lb \div ft^3}\right)^{1.5} \cdot \sqrt{\frac{\sigma}{psi}}$$

$$E_{c_2} := 2.5 \cdot 10^6 \cdot psi$$

Nominal and low values of elastic modulus for concrete; Ref. 4, p. 51 and Ref. 5, Page 1.01.7/6, Note 4

$$E_c = \begin{pmatrix} 4.287 \times 10^6 \\ 2.5 \times 10^6 \end{pmatrix} psi$$

Tendons

$T \equiv 1635 \cdot kip$ — Hoop tendon tension at lockoff; Assumption 4.2.1

$r_{HT} := 812.375 \cdot in \qquad r_{HT} = 67.7\,ft$ — Hoop tendon radius at conduit centerline; Ref. 2, p. 15

$$y_t := \frac{(210 \cdot ft + 6.75 \cdot in) - (181 \cdot ft + 8.75 \cdot in)}{18}$$

$$y_t = 19.22 \cdot in$$

Average vertical spacing of hoop tendons at the approximate elevation of the access opening for the steam generator replacement; Ref. 1.2

$r_{VT} := 807.375 \cdot in$ $\quad r_{VT} = 67.28\,ft$ — Vertical tendon radius at conduit centerline; Ref. 2, p. 15

$$x_t := \frac{\left[\left(161 + \frac{15}{60}\right) - \left(138 + \frac{45}{60}\right)\right] \cdot deg \cdot r_{VT}}{9}$$

Average horizontal spacing of vertical tendons at the approximate location of the access opening for the steam generator replacement; Ref. 1.2

$x_t = 35.23 \cdot in$

$d_c := 5.25 \cdot in$ — Tendon conduit outside diameter; Ref. 2, p. 4

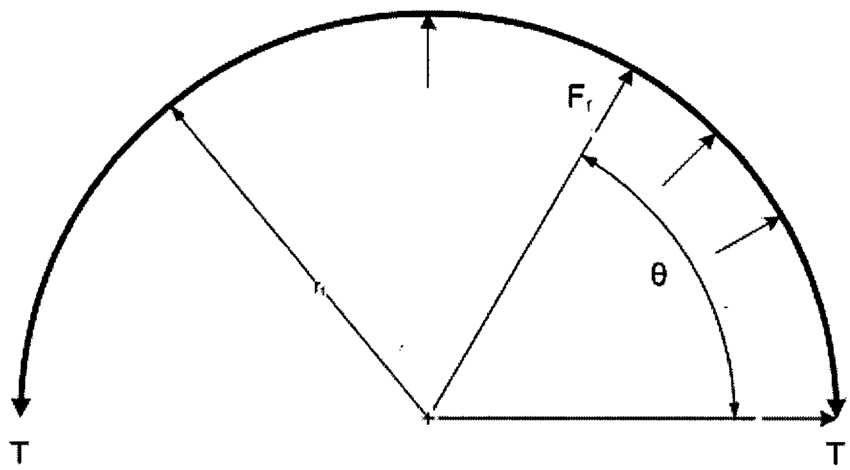
Containment Liner

$E_s := 29 \cdot 10^6 \cdot psi$ — Elastic modulus for steel; Ref. 3, Table 38, steel for bridges and buildings

$t_l := 0.375 \cdot in$ — Containment liner thickness; Ref. 1.1

5.2 Radial Pressure from Hoop Tendon

The figure below is a free body diagram for a hoop tendon.



Hypothetical Hoop Tendon Free Body Diagram

A force balance in the up/down direction as shown by the figure gives:

$$0 = -2 \cdot T + 2 \cdot \int_0^{\frac{\pi}{2}} F_r \cdot \sin(\theta) \cdot r_t \, d\theta$$

Solve for the radial force per unit circumferential length of the tendon on the containment. Use the radius to the inner most point of the conduit as the effective radius for the hoop tendon.

$$r_t := r_{HT} - \frac{d_c}{2} \qquad r_t = 809.75 \cdot in$$

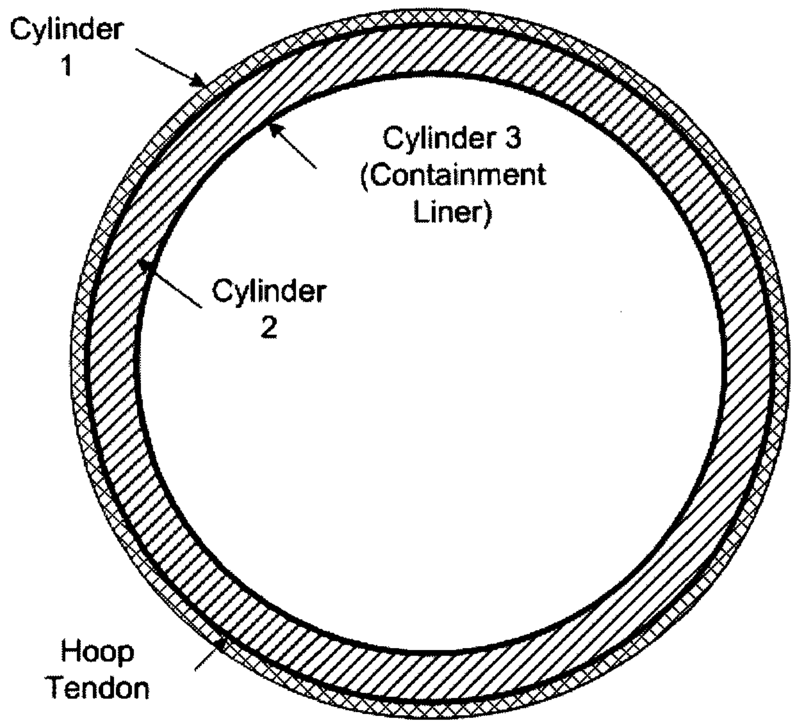
$$F_r := \frac{T}{r_t} \qquad F_r = 24230 \cdot \frac{lbf}{ft}$$

The radial pressure on the containment created by all of the hoop tendons is P_r, which is equal to F_r (radial force per unit circumferential length for a single hoop tendon) divided by the average vertical spacing between hoop tendons.

$$P_r := \frac{F_r}{y_t} \qquad P_r = 105 \, psi$$

5.3 Radial Pressure in Concrete

This section determines the radial pressure in the concrete at the radius of the inner most surface of the hoop tendon conduit. The figure below shows three cylinders, one for the containment concrete at a larger radius than the tendon, a second for the concrete at a smaller radius than the tendon, and a third for the containment liner.



Plan View of Containment

Loads acting on the three cylinders are as follows:

- Cylinder 1. The radial interface pressure between Cylinders 1 and 2 exerts a radial inward pressure on Cylinder 1.
- Cylinder 2. The radial interface pressure between Cylinders 1 and 2 exerts a radial outward pressure on Cylinder 2. The tendon exerts a radial inward pressure on Cylinder 2. The radial interface pressure between Cylinder 2 and the containment liner exerts a radial outward pressure on Cylinder 2.
- Cylinder 3. The radial interface pressure between Cylinder 2 and the containment liner exerts a radial inward pressure on Cylinder 3.

The net internal pressures acting on Cylinders 1, 2, and 3 as a function of the interface pressures are:

$$P_1(P_{1.2}) := -P_{1.2}$$

$$P_2(P_{1.2}, P_{2.3}) := -P_r + P_{1.2} + P_{2.3}$$

$$P_3(P_{2.3}) := -P_{2.3}$$

where	P_1	=	net internal pressure on cylinder 1
	P_2	=	net internal pressure on cylinder 2
	P_3	=	net internal pressure on cylinder 3
	P_r	=	radial pressure from hoop tendons
	$P_{1.2}$	=	interface radial pressure between cylinders 1 and 2
	$P_{2.3}$	=	interface radial pressure between cylinders 2 and 3

The radial displacements of the three cylinders are equal (Assumption 4.2.2).

$$\Delta r_1 = \Delta r_2 = \Delta r_3$$

Define a function to calculate radial displacement in a thin wall cylinder for an internal pressure (Ref. 3, Equations 2.2.4 and 2.4.2 with σ_1=0):

$$\Delta r(r, P, t, E) := \frac{P \cdot r^2}{E \cdot t}$$

The parameters r and t for the three cylinders are:

$r_1 := r_t$	$r_1 = 67.48\,ft$	$t_1 := r_o - r_t$	$t_1 = 1.05\,ft$
$r_2 := r_i$	$r_2 = 65.03\,ft$	$t_2 := r_t - r_i$	$t_2 = 2.45\,ft$
$r_3 := r_i - t_l$	$r_3 = 65\,ft$	$t_3 := t_l$	$t_3 = 0.0312\,ft$

The radial displacements of the three cylinders as a function of the interface pressures are:

$$\Delta r_1(P_{1.2}, E_c) := \Delta r(r_1, P_1(P_{1.2}), t_1, E_c)$$

$$\Delta r_2(P_{1.2}, P_{2.3}, E_c) := \Delta r(r_2, P_2(P_{1.2}, P_{2.3}), t_2, E_c)$$

$$\Delta r_3(P_{2.3}) := \Delta r(r_3, P_3(P_{2.3}), t_3, E_s)$$

Set the displacements equal to solve for the interface pressures. The initial guesses for the interface pressures are:

$P_{1.2} := 10 \cdot psi$ $\qquad$ $P_{2.3} := 10 \cdot psi$

Given

$$\Delta r_1(P_{1.2}, E_c) = \Delta r_2(P_{1.2}, P_{2.3}, E_c)$$

$$\Delta r_2(P_{1.2}, P_{2.3}, E_c) = \Delta r_3(P_{2.3})$$

$$P_{int}(E_c) := Find(P_{1.2}, P_{2.3})$$

Case 1—Nominal Modulus of Elasticity

$i := 1$

$E_{c_i} = 4.29 \times 10^6\ psi$

$$\begin{pmatrix} P_{1.2_i} \\ P_{2.3_i} \end{pmatrix} := P_{int}(E_{c_i}) \qquad \begin{pmatrix} P_{1.2_i} \\ P_{2.3_i} \end{pmatrix} = \begin{pmatrix} 28.22 \\ 6.11 \end{pmatrix} psi$$

Verify that the displacements are equal.

$$\Delta r_1(P_{1.2_i}, E_{c_i}) = -0.342 \cdot in$$

$$\Delta r_2(P_{1.2_i}, P_{2.3_i}, E_{c_i}) = -0.342 \cdot in$$

$$\Delta r_3(P_{2.3_i}) = -0.342 \cdot in$$

Case 2—Minimum Modulus of Elasticity

$i := 2$

$E_{c_i} = 2.5 \times 10^6\, psi$

$\begin{pmatrix} P_{1.2_i} \\ P_{2.3_i} \end{pmatrix} := P_{int}\left(E_{c_i}\right)$ $\qquad$ $\begin{pmatrix} P_{1.2_i} \\ P_{2.3_i} \end{pmatrix} = \begin{pmatrix} 27.1 \\ 10.06 \end{pmatrix} psi$

Verify that the displacements are equal.

$\Delta r_1\left(P_{1.2_i}, E_{c_i}\right) = -0.563 \cdot in$

$\Delta r_2\left(P_{1.2_i}, P_{2.3_i}, E_{c_i}\right) = -0.563 \cdot in$

$\Delta r_3\left(P_{2.3_i}\right) = -0.563 \cdot in$

5.4 Radial Pressure at Reduced Area

The pressure $P_{1.2}$ is the general membrane stress at the location of the inner most radius of the hoop conduit. Calculate the local membrane stress at a reduced area. The variable, A_{ratio}, is the ratio of the reduced area to the area used for the calculation in Section 5.3.

$$P_m(A_{ratio}) := \frac{1}{A_{ratio}}$$

Consider two cases of reduced area in addition to the nominal case with no area reduction. One case is subtracting the area of the hoop conduit. The second case is subtracting the area of the hoop conduit and the vertical conduit.

$$A_{ratio} := \begin{bmatrix} 1 \\ \frac{y_t - d_c}{y_t} \\ \frac{(y_t - d_c)\cdot(x_t - d_c)}{y_t \cdot x_t} \end{bmatrix} \qquad A_{ratio} = \begin{pmatrix} 1 \\ 0.73 \\ 0.62 \end{pmatrix}$$

The pressure multipliers for these two areas are:

$$P_{mult} := \overrightarrow{P_m(A_{ratio})} \qquad P_{mult} = \begin{pmatrix} 1 \\ 1.38 \\ 1.62 \end{pmatrix}$$

The $P_{1.2}$ interface pressures at the reduced areas are:

Case 1—Nominal Modulus of Elasticity

$$i := 1$$

$$P_{1.2'_i} := P_{1.2_i} \cdot P_{mult} \qquad P_{1.2'_i} = \begin{pmatrix} 28.22 \\ 38.83 \\ 45.63 \end{pmatrix} psi$$

Case 2—Minimum Modulus of Elasticity

$i := 2$

$P_{1.2'_i} := P_{1.2_i} \cdot P_{mult}$

$$P_{1.2'_i} = \begin{pmatrix} 27.1 \\ 37.28 \\ 43.81 \end{pmatrix} psi$$

6.0 REFERENCES

1. Crystal River Unit 3 Drawings:

1.1 Drawing No. SC-421-031, "Reactor Building Exterior Wall Concrete Outline," Revision 4.
1.2 Drawing No. 421-347, "Reactor Building Temporary Access Opening for SGR Vertical & Horizontal Tendon Positions," Revision 0.

2. Progress Energy, "Design Basis Document for the Containment," Revision 6.

3. J. F. Harvey, "Pressure Vessel Design: Nuclear and Chemical Applications," D. Van Nostrand Company, 1963.

4. ACI 318-63, "Building Code Requirements for Reinforced Concrete."

5. CR3 Reactor Building Shell Calc's, 4203-00-212, 1:01.4 to 1:01.11, Material Design, Book 2 of 5.

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CALCULATION TITLE PAGE

Client: Progress Energy	Page 1 of 13
Project: CR3 Containment Calculations	Task No. 0102-0906-0135
Title: Reinforcement Ratio and Effective Modulus of Elasticity	Calculation No. 0102-0135-01

Preparer / Date	Checker / Date	Reviewer & Approver / Date	Rev. No.
J. L. Hibbard 1-6-2010	Chris Bagley 1-6-2010	P. Butler 1-6-2010	0

QUALITY ASSURANCE DOCUMENT

This document has been prepared, checked, and reviewed/approved in accordance with the Quality Assurance requirements of 10CFR50 Appendix B, as specified in the MPR Quality Assurance Manual.

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RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page: 2
0102-0135-01	J. L. Hibbard	C W Bagley	

Revision	Affected Pages	Description
0	All	Initial Issue

Note: *The revision number found on each individual page of the calculation carries the revision level of the calculation in effect at the time that page was last revised.*

Table of Contents

1.0 PURPOSE

This calculation determines the reinforcement ratio and the equivalent modulus of elasticity in selected concrete sections for the Crystal River Unit 3 containment. These results will be used in subsequent calculations supporting the repair of the containment to make informed decisions on how to address rebar in constructing finite element models of the containment. The selected sections are the containment locations of interest in the finite element model with potential for high stress.

2.0 SUMMARY

The reinforcement ratio and the equivalent modulus of elasticity of selected concrete sections are summarized in Table T_s. The equivalent modulus of elasticity is calculated with an area weighted average of the concrete and steel moduli of elasticities. This modulus of elasticity can be used to calculate the displacement of concrete sections in pure tension or compression. This modulus of elasticity will not provide accurate calculations of displacements for bending, because the reinforcing steel is not uniformly distributed in the concrete sections.

T_s =

"Section"	"Location"	"Rebar"	"Elevation"	"Reinf."	"Equiv."	"Modulus"
""	""	"Orientation"	"(ft)"	"Ratio"	"Modulus"	"Increase"
""	""	""	""	"%"	"E6 psi"	"%"
1	"Buttress"	"vertical"	"93 to 103"	1.2	4.95	5.9
2	"Ring Girder"	"hoop"	"250 to 256"	0.3	4.76	1.8
3	"Ring Girder"	"vertical"	"250 to 256"	1.5	5.03	7.6
4	"Containment"	"vertical"	"230 to 250"	1.7	5.08	8.6
5	"Containment"	"vert & horiz"	"103 to 250"	0.2	4.71	0.8
6	"Containment"	"vertical"	"93 to 103"	2.1	5.18	10.9
7	"Under Eq. Hatch"	"vertical"	"~103"	2.2	5.21	11.4
8	"SGR Plug"	"hoop"	"196"	0.8	4.88	4.3
9	"Equipment Hatch"	"hoop"	"116"	2.7	5.32	13.8

Notes:
1. The reinforcement ratio is an approximation based on the total rebar area (tension and compression areas) divided by the concrete section area.
2. The equivalent modulus accounts for the steel and concrete.
3. The modulus increase is the increase in the equivalent modulus compared to the concrete modulus of $E_c = 4.675 \times 10^6$ psi (calculated on p. 9).

3.0 BACKGROUND

A project is underway at Progress Energy's Crystal River Unit 3 site to replace the steam generators. As part of that project, an opening has been cut into the concrete containment above the equipment hatch. As this opening was being cut, cracking in the concrete containment wall was identified. The crack is around the full periphery of the opening and is in the plane of the wall. The cracking is located at the radius of the circumferential tensioning tendons, and is indicative of a delaminated condition.

4.0 ASSUMPTIONS

4.1 Unverified Assumptions

None.

4.2 Other Assumptions

None.

5.0 CALCULATION

5.1 Design Input

Data for the calculation is input into arrays that contain entries, each of which corresponds to the section number in the table below. For the elevation of the SGR plug, see Reference 2.8.

$T_d :=$

"Section"	"Location"	"Rebar"	"Elevation"
""	""	"Orientation"	"(ft)"
""	""	""	""
1	"Buttress"	"vertical"	"93 to 103"
2	"Ring Girder"	"hoop"	"250 to 256"
3	"Ring Girder"	"vertical"	"250 to 256"
4	"Containment"	"vertical"	"230 to 250"
5	"Containment"	"vert & horiz"	"103 to 250"
6	"Containment"	"vertical"	"93 to 103"
7	"Under Eq. Hatch"	"vertical"	"~103"
8	"SGR Plug"	"hoop"	"196"
9	"Equipment Hatch"	"hoop"	"116"

Standard rebar diameters from Reference 3, Table 12.3.1 are:

$od_{rebar} :=$

Rebar No.	Rebar Dia. (in.)
3	0.375
4	0.5
5	0.625
6	0.75
7	0.875
8	1
9	1.128
10	1.27
11	1.41
14	1.693
18	2.257

Define a function to return rebar diameter.

$$d_r(n) := vlookup(n, od_{rebar}, 2)_1 \cdot in$$

For example,

$$d_r(18) = 2.257 \cdot in$$

$t_{cont} \equiv 42 \cdot in$ — Containment wall thickness; Ref. 2.1

$t_b \equiv t_{cont} + (2 \cdot ft + 4 \cdot in)$ — $t_b = 70 \cdot in$ — Buttress thickness; Ref. 2.1

$t_{rg} \equiv t_{cont} + (2 \cdot ft + 4 \cdot in)$ — $t_{rg} = 70 \cdot in$ — Ring girder thickness at approximately the 250 ft elevation; Ref. 2.1

$R_{o.c} \equiv 65 \cdot ft + 0.375 \cdot in + 42 \cdot in$ — $R_{o.c} = 68.53\, ft$ — Outside radius of containment; Ref. 2.1

$R_{o.rg} \equiv R_{o.c} + (2 \cdot ft + 4 \cdot in)$ — $R_{o.rg} = 70.86\, ft$ — Outside radius of ring girder; Ref. 2.1

$$t_c := \begin{pmatrix} 70 \\ 70 \\ 70 \\ 42 \\ 42 \\ 42 \\ 42 \\ 42 \\ 83.625 \end{pmatrix} in \qquad loc = \begin{pmatrix} \text{"Buttress"} \\ \text{"Ring Girder"} \\ \text{"Ring Girder"} \\ \text{"Containment"} \\ \text{"Containment"} \\ \text{"Containment"} \\ \text{"Under Eq. Hatch"} \\ \text{"SGR Plug"} \\ \text{"Equipment Hatch"} \end{pmatrix}$$

Concrete thickness
-Ref. 2.1
-Ref. 2.1; conservative thickness
-Ref. 2.1; conservative thickness
-Ref. 2.1
-Ref. 2.1
-Ref. 2.1; conservative thickness for Elev. = 93 ft
-Ref. 2.1; conservative thickness for Elev. = 93 ft
-Ref. 2.1
-Ref. 2.6

$$b := \begin{bmatrix} 12 \cdot ft \\ (255 \cdot ft + 10.5 \cdot in) - (250 \cdot ft) \\ 30 \cdot deg \cdot R_{o.rg} \\ (11 + 15 \div 60) \cdot deg \cdot R_{o.c} \\ 12 \cdot in \\ 48 \cdot in \\ 144 \cdot in \\ 132 \cdot in \\ 103.5 \cdot in \end{bmatrix}$$

Width of section considered; this is an arbitrary dimension, but references are provided to show the dimension
-Ref. 2.1
-Ref. 2.1
-Ref. 2.3, 0° to 330°
-Ref. 2.2, Section 2-2, 11°-15' section
-Ref. 2.2, Section 3-3 and Ref. 2.7
-Ref. 2.2, this width was chosen to give an integer number of rebar for each layer
-Ref. 2.2, this width was chosen to give an integer number of rebar for each layer
-Ref. 5; this width was chosen to give an integer number of rebar for each layer
-Ref. 2.6.

$$b = \begin{pmatrix} 144 \\ 70.5 \\ 445.26 \\ 161.47 \\ 12 \\ 48 \\ 144 \\ 132 \\ 103.5 \end{pmatrix} \cdot in \qquad loc = \begin{pmatrix} \text{"Buttress"} \\ \text{"Ring Girder"} \\ \text{"Ring Girder"} \\ \text{"Containment"} \\ \text{"Containment"} \\ \text{"Containment"} \\ \text{"Under Eq. Hatch"} \\ \text{"SGR Plug"} \\ \text{"Equipment Hatch"} \end{pmatrix}$$

There are several layers of rebar through the depth of the sections. The data for the layers are input with 1 by x arrays below, with x being the number of layers. For example, the first entry in the array below is a 1 x 3 array with the three entries corresponding to the three layers of rebar in the buttress (one layer of #11 at the OD face and two layers of #18 near the ID face).

$$od_r := \begin{bmatrix} (d_r(11) \;\; d_r(18) \;\; d_r(18)) \\ (d_r(9) \;\; d_r(9) \;\; d_r(9) \;\; d_r(9)) \\ (d_r(9) \;\; d_r(9) \;\; d_r(11) \;\; d_r(11) \;\; d_r(18)) \\ (d_r(18) \;\; d_r(18)) \\ (d_r(8)) \\ (d_r(11) \;\; d_r(18) \;\; d_r(18)) \\ (d_r(11) \;\; d_r(18) \;\; d_r(18)) \\ (d_r(8) \;\; d_r(11) \;\; d_r(11)) \\ (d_r(11) \;\; d_r(18) \;\; d_r(18) \;\; d_r(11) \;\; d_r(11) \;\; d_r(18) \;\; d_r(11)) \end{bmatrix}$$

Rebar diameter
-Ref. 2.2, Section 1-1 and Ref. 2.5, Section 1-1
-Ref. 2.3, Section 1-1
-Ref. 2.3, Section 1-1
-Ref. 2.2, Section 3-3
-Ref. 2.2, Section 3-3 and Ref. 2.7
-Ref. 2.2, Section 3-3 and Ref. 2.5, Section 1-1
-Ref. 2.2, Section 3-3, Ref. 2.5, Section 1-1, and Ref. 2.4
-Ref. 5
-Ref. 2.6

$$od_r = \begin{bmatrix} (1.41 \;\; 2.257 \;\; 2.257) \\ (1.128 \;\; 1.128 \;\; 1.128 \;\; 1.128) \\ (1.128 \;\; 1.128 \;\; 1.41 \;\; 1.41 \;\; 2.257) \\ (2.257 \;\; 2.257) \\ (1) \\ (1.41 \;\; 2.257 \;\; 2.257) \\ (1.41 \;\; 2.257 \;\; 2.257) \\ (1 \;\; 1.41 \;\; 1.41) \\ (1.41 \;\; 2.257 \;\; 2.257 \;\; 1.41 \;\; 1.41 \;\; 2.257 \;\; 1.41) \end{bmatrix} \cdot in \qquad loc = \begin{pmatrix} \text{"Buttress"} \\ \text{"Ring Girder"} \\ \text{"Ring Girder"} \\ \text{"Containment"} \\ \text{"Containment"} \\ \text{"Containment"} \\ \text{"Under Eq. Hatch"} \\ \text{"SGR Plug"} \\ \text{"Equipment Hatch"} \end{pmatrix}$$

$$n_r := \begin{bmatrix} (12\ \ 8\ \ 16) \\ (5\ \ 2\ \ 2\ \ 8) \\ (59\ \ 59\ \ 33\ \ 33\ \ 59) \\ (11\ \ 17) \\ (1) \\ (4\ \ 3\ \ 6) \\ (16\ \ 9\ \ 18) \\ (11\ \ 12\ \ 12) \\ (12\ \ 19\ \ 11\ \ 10\ \ 11\ \ 10\ \ 11) \end{bmatrix}$$

Number of rebar in section width, b
-Ref. 2.2, Section 1-1
-Ref. 2.3, Section 1-1 (there are four rebar in the angle section of which two are credited and assumed to align with the above rebar for ease of calculation)
-Ref. 2.3, 0° to 330° with spacing at mid-bay used over buttress for Layer 1
-Ref. 2.2, Section 2-2
-Ref. 2.2, Section 3-3 and Ref. 2.7
-Ref. 2.2, Section 1-1
-Ref. 2.2, Section 1-1, Ref. 2.5, Section 1-1, and Ref. 2.4
-Ref. 5
-Ref. 2.6

Misc.

$E_s := 29 \cdot 10^6 \cdot psi$ — Steel modulus of elasticity; Ref. 1, Section 1100

$f_{c'} := 6720 \cdot psi$ — Concrete minimum compressive strength; Ref. 4, Results Summary, Class 5000 concrete

$\rho_c := 144 \cdot \frac{lb}{ft^3}$ — Concrete density; Ref. 7

$E_c := 33 \cdot psi \cdot \left(\frac{\rho_c}{lb \div ft^3} \right)^{1.5} \cdot \sqrt{\frac{f_{c'}}{psi}}$ — Elastic modulus for concrete; Ref. 1, Section 1102

$E_c = 4.675 \times 10^6\, psi$

5.2 Reinforcement Ratio and Effective Modulus of Elasticity

The area of rebar in each layer is:

$$A_{s1_i} := \overrightarrow{\left[n_{r_i} \cdot \frac{\pi}{4} \cdot \left(od_{r_i}\right)^2\right]}$$

$$A_{s1} = \begin{bmatrix} (18.74 \quad 32.01 \quad 64.01) \\ (5 \quad 2 \quad 2 \quad 7.99) \\ (58.96 \quad 58.96 \quad 51.53 \quad 51.53 \quad 236.05) \\ (44.01 \quad 68.01) \\ (0.79) \\ (6.25 \quad 12 \quad 24.01) \\ (24.98 \quad 36.01 \quad 72.02) \\ (8.64 \quad 18.74 \quad 18.74) \\ (18.74 \quad 76.02 \quad 44.01 \quad 15.61 \quad 17.18 \quad 40.01 \quad 17.18) \end{bmatrix} \cdot in^2$$

The area of rebar at each section is:

$$A_{s_i} := \sum A_{s1_i}$$

$$A_s = \begin{pmatrix} 114.76 \\ 16.99 \\ 457.03 \\ 112.02 \\ 0.79 \\ 42.25 \\ 133.01 \\ 46.11 \\ 228.74 \end{pmatrix} \cdot in^2$$

The concrete area of each section is:

$$A_c := \overrightarrow{(t_c \cdot b - A_s)} \qquad A_c = \begin{pmatrix} 9965 \\ 4918 \\ 30711 \\ 6670 \\ 503 \\ 1974 \\ 5915 \\ 5498 \\ 8426 \end{pmatrix} \cdot in^2$$

The reinforcement ratio is approximated with:

$$\rho := \frac{\overrightarrow{A_s}}{A_c} \qquad \rho = \begin{pmatrix} 1.15 \\ 0.35 \\ 1.49 \\ 1.68 \\ 0.16 \\ 2.14 \\ 2.25 \\ 0.84 \\ 2.71 \end{pmatrix} \cdot \%$$

This is an approximation of the reinforcement ratio,which is defined as (Reference 6, Section 4-1):

$$\rho = \frac{A_s}{b \cdot d}$$

where	A_s	=	reinforcement area at tension face of beam
	b	=	width of the compression face
	d	=	distance from extreme compression fiber to centroid of tension reinforcement

The area weighted equivalent modulus of elasticity is:

$$E_{equiv} := \overrightarrow{\frac{E_c \cdot A_c + E_s \cdot A_s}{A_c + A_s}} \qquad E_{equiv} = \begin{pmatrix} 4.95 \\ 4.76 \\ 5.03 \\ 5.08 \\ 4.71 \\ 5.18 \\ 5.21 \\ 4.88 \\ 5.32 \end{pmatrix} \cdot 10^6 \cdot psi$$

The percentage increase in the concrete modulus of elasticity accounting for the steel is:

$$P_{modulus} := \frac{E_{equiv} - E_c}{E_c} \qquad P_{modulus} = \begin{pmatrix} 5.92 \\ 1.79 \\ 7.63 \\ 8.6 \\ 0.81 \\ 10.91 \\ 11.44 \\ 4.33 \\ 13.75 \end{pmatrix} \cdot \%$$

6.0 REFERENCES

1. ACI 318-63, "Building Code Requirements for Reinforced Concrete."

2. Progress Energy Drawings:

2.1 No. SC-421-031, "Reactor Building Exterior Wall Concrete Outline," Revision 4.
2.2 No. SC-421-036, "Reactor Building External Wall Sections and Details," Revision 10.
2.3 No. SC-421-301, "Reactor Building Ring Girder Plan & Sections," Revision 8.
2.4 No. SC-421-039, "Reactor Building Exterior Wall Equipment Access Opening, Reinforcement Placing," Revision 5.
2.5 No. SC-421-006, "Reactor Building Foundation Mat Anchor Bolt and Dowels," Revision 4.
2.6 No. SC-421-040, "Reactor Building Exterior Wall - Equipment Access Opening Reinforcement Placing Details," Revision 3.
2.7 No. SC-421-032, "Reactor Building Stretch-out of Exterior Wall Buttress #2, #3, #4, & #5," Revision 8.
2.8 No. 421-347, Reactor Building Temporary Access Opening for SGR Vertical & Horizontal Tendon Positions," Revision 0.

3. E. Avallone & T. Baumeister, "Marks' Standard Handbook for Mechanical Engineers," McGraw-Hill Book Company, 9th Edition.

4. Florida Power Corporation Document Identification No. S-00-0047, As-built Concrete Strength for Class 1 Structures, Revision 0.

5. Email from Mr. J. Holliday (PE) to Mr. J. Hibbard (MPR), 1-6-2010, 12:52 PM, Subject: Design Input for Calculation 0102-0135-01.

6. J. Wight and J. MacGregor, Reinforced Concrete Mechanics and Design, Pearson Education, Inc., 5th Edition.

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