3E.1.3 Reactor Containment Building Dome and Ring Girder

This critical section presents the structural design of the Reactor Containment Building (RCB) Dome and Ring Girder. The description of the RCB is provided in Section 3.8.1.1. The dimensions of the RCB are shown in Figure 3B-12 to Figure 3B-14.

The RCB is a pre-stressed reinforced concrete structure comprised of a cylindrical wall and dome roof. The RCB is a safety-related, Seismic Category I structure, as described in Section 3.8.1. Isometric views of the RCB Dome and Ring Girder critical section are shown on Figure 3E.1.3-1—Isometric View RCB Dome and Ring Girder and Figure 3E.1.3-2—Isometric View RCB Ring Girder, respectively.

Design details for the following subcomponents of the RCB Dome and Ring Girder are within the scope of this critical section:

- Figure 3E.1.3-3—RCB Dome Subcomponent AB.
- Figure 3E.1.3-4—RCB Dome Subcomponent CD.
- Figure 3E.1.3-5—RCB Dome Subcomponent E.
- Figure 3E.1.3-6—RCB Dome Subcomponent F.
- Figure 3E.1.3-7—RCB Dome Subcomponent G.
- Figure 3E.1.3-8—RCB Dome Subcomponent H.

3E.1.3.1 Model

The finite element ANSYS static model of the NI Common Basemat Structures (ANSYS NI static model) described in Sections 3.8.1.4.1 and 3E.1 is used for the design of the RCB Dome and Ring Girder. The RCB Dome is modeled using 8-node brick elements (SOLID45). Multiple layers of the SOLID45 elements are used to model the thickness of the RCB. The element size is approximately 4 ft by 4 ft. To convert the solid stresses into shell-type forces and moments used in the design, “dummy shells” are created over the solid elements. These dummy shells are modeled as SHELL181 elements and have the same properties as the solid elements.

The ring girder is discretized using a combination of SOLID95 (20-node structural solid element), SOLID92 (10-node tetrahedral structural solid element), and SOLID45 elements (8-node brick element). Because the thickness of the ring girder changes rapidly, the dummy shells cannot be used on the ring girder to extract shell like forces and moments. Therefore, a separate analysis is performed to extract the shell like forces and moments from the solid elements.

The nomenclature for the forces and moments results of the ANSYS NI static model is shown on Figure 3E.1-1. Note that the moments obtained from ANSYS results have the opposite sign convention from those obtained from CivilFEM. The sign convention for ANSYS NI static model results is shown on Figure 3E.1-1 and the sign convention for CivilFEM results is shown on Figure 3E.1-2.

3E.1.3.2 Load Combinations and Loads

The load combinations applied to the RCB Dome and Ring Girder are described in Section 3.8.1.3.2. The design of the RCB Dome and Ring Girder is achieved using the results obtained from the model for the A Series Load Combination shown in Table 3E.1-4. This critical section is also designed for the soil analysis cases in Table 3.7.1-6.

Independent loads considered in the ANSYS NI static model for the RCB Dome and Ring Girder are shown in Table 3E.1-2 and described in Sections 3.8.1.3.1 and 3E.1. Independent loads not considered in the ANSYS NI static model are shown in Table 3E.1-3.

The missing loads considered in the design include accidental torsion, thermal loading, and polar crane.

A separate analysis was performed to determine the effects of thermal loading. Based on the results of the thermal loading analysis, a modification factor is applied to the thermal moment to account for concrete cracking. A different modification factor was determined for each time step. The thermal moment modification factors are shown in Table 3E.1.3-1—Thermal Moment Modification Factors for the three time step considerations. The use of the thermal moment modification factors provides the thermal moment that should be used for design.

A separate analysis was performed to determine the effects due to accidental torsion. Based on the results of this analysis, an additional tensile membrane force is included for the wall design as well as an additional tangential shear value. The tangential shear value is given the same sign as the associated tangential shear value from a given load combination.

A separate analysis was performed to determine the effects due to dead, live, and seismic loads from the polar crane. Based on the results, additional membrane, tangential and radial forces, and bending and twisting moments are included in the design.

3E.1.3.3 Analysis and Design Methods

The methodology used for the structural analysis and design of the RCB Dome and Ring Girder is to determine the reinforcement configuration using forces and moments generated from the finite element ANSYS NI static model. The design of the RCB Dome and Ring Girder is performed using the applicable codes, standards, and specifications in Section 3.8.1.2.

In general, the RCB Dome and Ring Girder are designed for the resultant forces and moments determined based on the applied loading and soil conditions. CivilFEM is used to extract forces and moments from the ANSYS NI static model for a given load combination. Once the forces and moments are obtained, the material properties are checked and adjusted as needed, additional loads are added, and the design function of CivilFEM is run to obtain the required reinforcement. If high reinforcement values are obtained in a concentrated area, the areas of steel results are averaged to better reflect the behavior of the reinforced concrete.

3E.1.3.4 Critical Section Design

The structural design provides reinforcement to resist element forces and moments for the RCB Dome and Ring Girder critical section. The RCB Dome and Ring Girder critical section is designed such that each is capable of carrying all applied design loadings provided they are constructed in accordance with the material properties in Section 3E.1 and the section geometry and reinforcing shown within the critical section. A 10% design margin is maintained.

The governing design data for the RCB Dome and Ring Girder are shown in Table 3E.1.3-2—Governing Design Data for RCB Dome and Ring Girder.

A Key Plan of the RCB Dome and Ring Girder is shown on Figure 3E.1.3-9—Key Plan RCB Dome and Ring Girder. The minimum required area of steel reinforcement for the RCB Dome and Ring Girder is shown in Table 3E.1.3-3—Reinforcement Detail for RCB Dome and Ring Girder. Table 3E.1.3-3 also indicates the area of steel reinforcement in the design based on the reinforcement configuration shown on Figure 3E.1.3-10—Reinforcement Details for the RCB Ring Girder through Figure 3E.1.3-13—Reinforcement Details for the RCB Dome Subcomponent GH. Use of reinforcement configurations (including bar size, spacing and clear cover) different from those shown on Figure 3E.1.3-10 through Figure 3E.1.3-13 are acceptable, provided they meet or exceed the minimum required area of steel reinforcement in Table 3E.1.3-3.

Table 3E.1.3-1—Thermal Moment Modification Factors

Section Location	Post-Accident Time (seconds)		
	0.005	**5000**	**86400**
Containment Ring Girder	0.28	0.65	1.01
Containment Dome	0.23	0.66	1.02

Table 3E.1.3-2—Governing Design Data for RCB Dome and Ring Girder
Sheet 1 of 4

Locations	LC(1)	SC(1)	Design Condition	Governing Design Data(2)(3)(4)(5)(7)						
				M_{XU}(6)	M_{YU}(6)	T_X	T_Y	T_{XY}	N_X	N_Y
				k-ft/ft	k-ft/ft	k/ft	k/ft	k/ft	k/ft	k/ft
RCB Dome Subcomponent AB	A_08_04_1a	Generic	Membrane +Bending (Hoop)	-126	*	75	*	*	*	*
	A_08_04_1a	Generic	Membrane +Bending (Meridional)	*	-128	*	75	*	*	*
	N/A	N/A	Tangential Shear (Hoop)	*	*	N/A	N/A	N/A	*	*
	N/A	N/A	Tangential Shear (Meridional)	*	*	N/A	N/A	N/A	*	*
	A_03_01_2xp	Generic	Radial Shear	*	*	-831	-829	*	-2	-2
RCB Dome Subcomponent CD	A_08_04_1a	Generic	Membrane +Bending (Hoop)	-127	*	110	*	*	*	*
	A_08_04_1a	Generic	Membrane +Bending (Meridional)	*	-143	*	101	*	*	*
	N/A	N/A	Tangential Shear (Hoop)	*	*	N/A	N/A	N/A	*	*
	A_08_04_1a	Generic	Tangential Shear (Meridional)	*	*	58	85	28	*	*
	A_03_01_2xp	Generic	Radial Shear	*	*	-832	-888	*	1	7

**Table 3E.1.3-2—Governing Design Data for RCB Dome and Ring Girder
Sheet 2 of 4**

Locations	LC(1)	SC(1)	Design Condition	Governing Design Data(2)(3)(4)(5)(7)						
				M_{XU}(6)	M_{YU}(6)	T_X	T_Y	T_{XY}	N_X	N_Y
				k-ft/ft	k-ft/ft	k/ft	k/ft	k/ft	k/ft	k/ft
RCB Dome Subcomponent E	A_08_08_1a	Generic	Membrane +Bending (Hoop)	-116	*	173	*	*	*	*
	A_08_08_1a	Generic	Membrane +Bending (Meridional)	*	-114	*	219	*	*	*
	A_08_08_1a	Generic	Tangential Shear (Hoop)	*	*	89	25	56	*	*
	A_08_08_1a	Generic	Tangential Shear (Meridional)	*	*	9	112	43	*	*
	A_03_01_2xp	Generic	Radial Shear	*	*	-810	-915	*	-3	7
RCB Dome Subcomponent F	A_08_08_1a	Generic	Membrane +Bending (Hoop)	-145	*	150	*	*	*	*
	A_08_08_1a	Generic	Membrane +Bending (Meridional)	*	-158	*	178	*	*	*
	A_08_08_1a	Generic	Tangential Shear (Hoop)	*	*	101	21	92	*	*
	A_08_08_1a	Generic	Tangential Shear (Meridional)	*	*	-71	87	91	*	*
	A_02_01_1x	Generic	Radial Shear	*	*	-666	-905	*	5	5

Table 3E.1.3-2—Governing Design Data for RCB Dome and Ring Girder
Sheet 3 of 4

Locations	LC(1)	SC(1)	Design Condition	Governing Design Data(2)(3)(4)(5)(7)						
				M_{XU}(6)	M_{YU}(6)	T_X	T_Y	T_{XY}	N_X	N_Y
				k-ft/ft	k-ft/ft	k/ft	k/ft	k/ft	k/ft	k/ft
RCB Dome Subcomponent G	A_08_07_2a	Generic	Membrane +Bending (Hoop)	-456	*	153	*	*	*	*
	A_08_07_2a	Generic	Membrane +Bending (Meridional)	*	-444	*	163	*	*	*
	A_08_08_1a	Generic	Tangential Shear (Hoop)	*	*	119	-47	117	*	*
	A_08_08_1a	Generic	Tangential Shear (Meridional)	*	*	-203	159	140	*	*
	A_03_01_1xp	Generic	Radial Shear	*	*	-314	-963	*	4	-30
RCB Dome Subcomponent H	A_08_08_2a	Generic	Membrane +Bending (Hoop)	-470	*	87	*	*	*	*
	A_08_08_2a	Generic	Membrane +Bending (Meridional)	*	-440	*	171	*	*	*
	A_08_08_1a	Generic	Tangential Shear (Hoop)	*	*	136	100	151	*	*
	A_08_08_1a	Generic	Tangential Shear (Meridional)	*	*	-371	150	263	*	*
	A_03_01_2xp	Generic	Radial Shear	*	*	-443	-583	*	-7	-62

Table 3E.1.3-2—Governing Design Data for RCB Dome and Ring Girder
Sheet 4 of 4

Locations	LC(1)	SC(1)	Design Condition	Governing Design Data(2)(3)(4)(5)(7)						
				M_{XU}(6)	M_{YU}(6)	T_X	T_Y	T_{XY}	N_X	N_Y
				k-ft/ft	k-ft/ft	k/ft	k/ft	k/ft	k/ft	k/ft
RCB Ring Girder	A_15_01_3a	5AH	Membrane +Bending (Hoop)	*	-2201	*	63	*	*	*
	A_15_08_2a	5AH	Membrane +Bending (Meridional)	-2340	*	-389	*	*	*	*
	A_15_08_2a	5AH	Tangential Shear (Hoop)	*	*	-272	-151	377	*	*
	A_15_08_2a	5AH	Tangential Shear (Meridional)	*	*	-242	-154	343	*	*
	A_03_08_p	Generic	Radial Shear	*	*	-1039	-574	*	-160	121

Notes:

1. LC is the governing load combination, and SC is the governing soil analysis case.
2. (–) is compression, and (+) is tension.
3. CivilFEM forces and moments.
4. T_X is axial in the x-direction. T_Y is axial in the y-direction. T_{XY} is in-plane shear. N_X is out-of-plane shear through the x-axis. N_Y is out-of-plane shear through the y-axis.
5. (*) Not applicable for indicated reinforcement.
6. M_X is absolute summed with M_{XY} to obtain M_{XU}, the same is done for M_Y and M_{XY} to obtain M_{YU}. See Section 3E.1.1 for additional details.
7. N/A indicates that no reinforcing was required, therefore no forces or moments are provided.

Table 3E.1.3-3—Reinforcement Detail for RCB Dome and Ring Girder
Sheet 1 of 4

Locations	Reinforcing Direction	Thickness	Condition	Required $A_{S\text{-}req}$ (in^2/ft)(2)	Reinforcement Pattern	Provided $A_{S\text{-}pro}$ (in^2/ft)(2)	Reinforcement Ratio (i.e. $A_{S\text{-}pro}/A_{S\text{-}req}$)(1)
RCB Dome Subcomponent AB	Meridional – Inside Face	3 ft ¼ in	Tangential Shear, Membrane + Bending	*[1.44*	#14s @ 12 in	2.25	1.56
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*1.44*	#14's @ 6"	4.50	3.12
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*1.44*	#10s @ 6 in	2.54	1.77
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*1.44*	#14s @ 6 in	4.50	3.14
	Stirrup		Radial Shear	*0.040*	#4 bars @ 12 in	0.20	5.00
RCB Dome Subcomponent CD	Meridional – Inside Face	3 ft ¼ in	Tangential Shear, Membrane + Bending	*1.78*	#14s @ 12 in	2.25	1.26
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*1.78*	#1's @ 6 in	4.50	2.53
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*1.76*	#10s @ 6 in	2.54	1.44
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*1.76*	#14s @ 6 in	4.50	2.56
	Stirrup		Radial Shear	*0.08*	#4 bars @ 12 in	0.20	2.67

Table 3E.1.3-3—Reinforcement Detail for RCB Dome and Ring Girder
Sheet 2 of 4

Locations	Reinforcing Direction	Thickness	Condition	Required $A_{S\text{-}req}$ $(in^2/ft)^{(2)}$	Reinforcement Pattern	Provided $A_{S\text{-}pro}$ $(in^2/ft)^{(2)}$	Reinforcement Ratio (i.e. $A_{S\text{-}pro}/A_{S\text{-}req})^{(1)}$
RCB Dome Subcomponent E	Meridional – Inside Face	3 ft ¼ in	Tangential Shear, Membrane + Bending	*2.887*	2 layers #10s @ 6 in	5.08	1.39
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*2.89*	#14s @ 6 in	4.50	1.55
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*2.46*	#14s @ 6 in	4.50	1.83
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*2.46*	#14s @ 6"	4.50	1.83
	Stirrup		Radial Shear	*0.092*	#4 bars @ 12 in	0.20	2.17
RCB Dome Subcomponent F RCB Ring Girder	Meridional – Inside Face	3 ft ¼ in	Tangential Shear, Membrane + Bending	*3.25*	2 layers #10s @ 6 in	5.08	1.56
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*3.25*	#14s @ 6 in	4.50	1.38
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*2.82*	#14s @ 6 in	4.50	1.60
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*2.82*	#14s @ 6 in	4.50	1.60
	Stirrup		Radial Shear	*0.10*	#4 bars @ 12 in	0.20	2.00

Table 3E.1.3-3—Reinforcement Detail for RCB Dome and Ring Girder
Sheet 3 of 4

Locations	Reinforcing Direction	Thickness	Condition	Required $A_{S\text{-}req}$ (in^2/ft)[2]	Reinforcement Pattern	Provided $A_{S\text{-}pro}$ (in^2/ft)[2]	Reinforcement Ratio (i.e. $A_{S\text{-}pro}/A_{S\text{-}req}$)[1]
RCB Dome Subcomponent G	Meridional – Inside Face	3 ft ¼ in	Tangential Shear, Membrane + Bending	*6.18*	2 layers (2) #9s @ 6 in bundled	8.00	1.29
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*6.18*	2 layers (2) #9s @ 6 in bundled	8.00	1.29
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*5.77*	2 layers (2) #9s @ 6 in bundled	8.00	1.39
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*5.77*	2 layers (2) #9s @ 6 in bundled	8.00	1.39
	Stirrup		Radial Shear	*0.16*	#4 bars @ 6 in	0.40	2. 50
RCB Dome Subcomponent H	Meridional – Inside Face	3 ft ¼ in	Tangential Shear, Membrane + Bending	*7.26*	2 layers (2) #9s @ 6 in bundled	8.00	1.10
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*7.26*	2 layers (2) #9s @ 6 in bundled	8.00	1.10
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*5.18*	2 layers (2) #9s @ 6 in bundled	8.00	1.55
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*5.18*	2 layers (2) #9s @ 6 in bundled	8.00	1.55
	Stirrup		Radial Shear	*0.34*	#4 bars @ 6 in	0.40	1.18

Table 3E.1.3-3—Reinforcement Detail for RCB Dome and Ring Girder Sheet 4 of 4

Locations	Reinforcing Direction	Thickness	Condition	Required $A_{S\text{-}req}$ (in^2/ft)(2)	Reinforcement Pattern	Provided $A_{S\text{-}pro}$ (in^2/ft)(2)	Reinforcement Ratio (i.e. $A_{S\text{-}pro}/A_{S\text{-}req}$)(1)
RCB Ring Girder	Meridional – Inside Face	Approx. 45.65 in-110.76 in (Varies)	Tangential Shear, Membrane + Bending	*10.76*	2 layers (2) #11s @ 6 in bundled	12.48	1.16
	Meridional – Outside Face		Tangential Shear, Membrane + Bending	*10.76*	2 layers (2) #11s @ 6 in bundled	12.48	1.16
	Hoop – Inside Face		Tangential Shear, Membrane + Bending	*10.535*	2 layers (2) #11s @ 6 in bundled	12.48	1.18
	Hoop – Outside Face		Tangential Shear, Membrane + Bending	*10.54*	2 layers (2) #11s @ 6 in bundled	12.48	1.18
	Stirrup		Radial Shear	*0.58]**	#6 bars @ 6 in	0.88	1.51

Notes:

1. The 10% design margin is maintained.
2. $A_{S\text{-}req}$ is required reinforcement. $A_{S\text{-}pro}$ is provided reinforcement

Figure 3E.1.3-1—Isometric View RCB Dome and Ring Girder

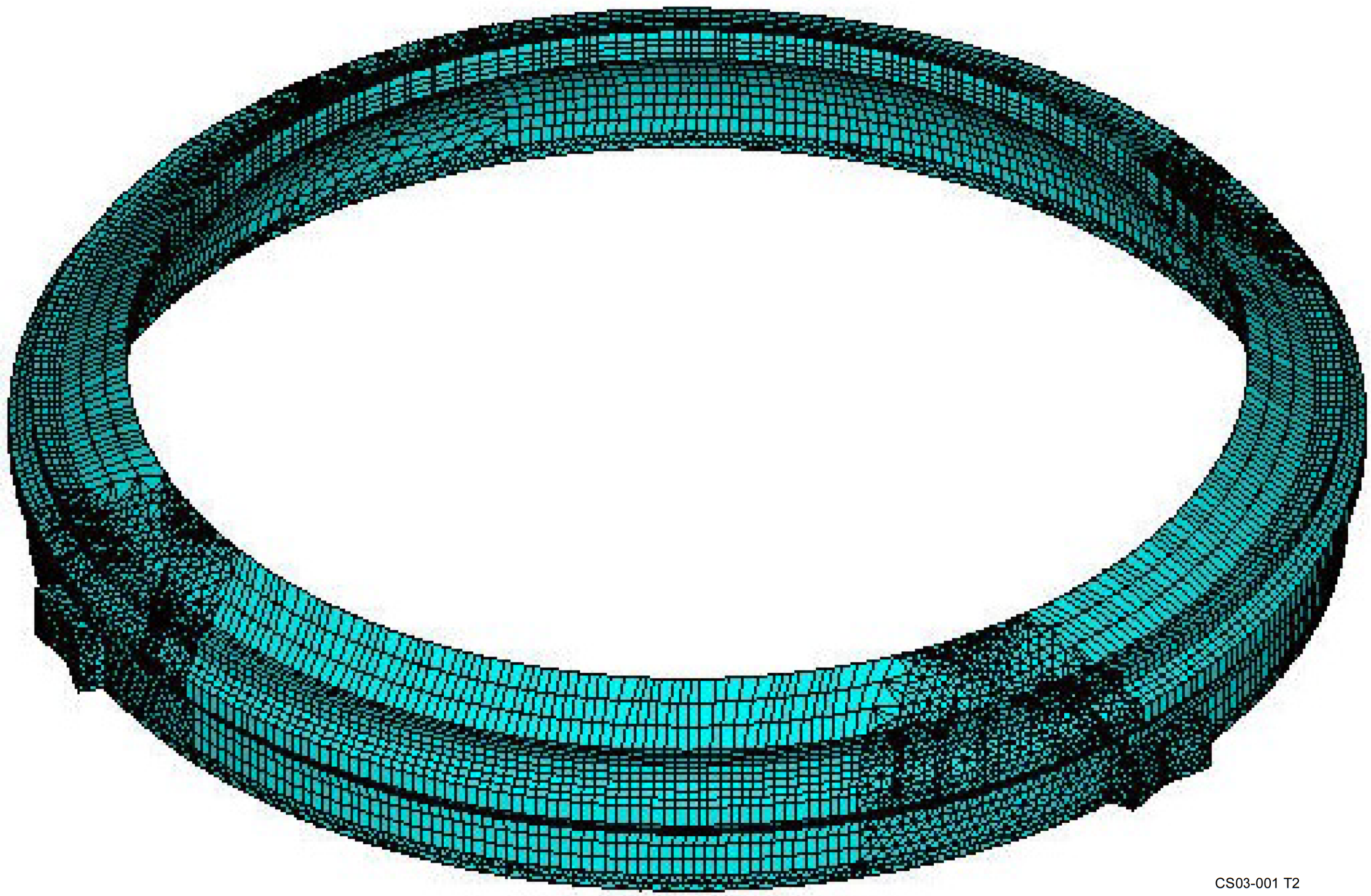

Figure 3E.1.3-2—Isometric View RCB Ring Girder

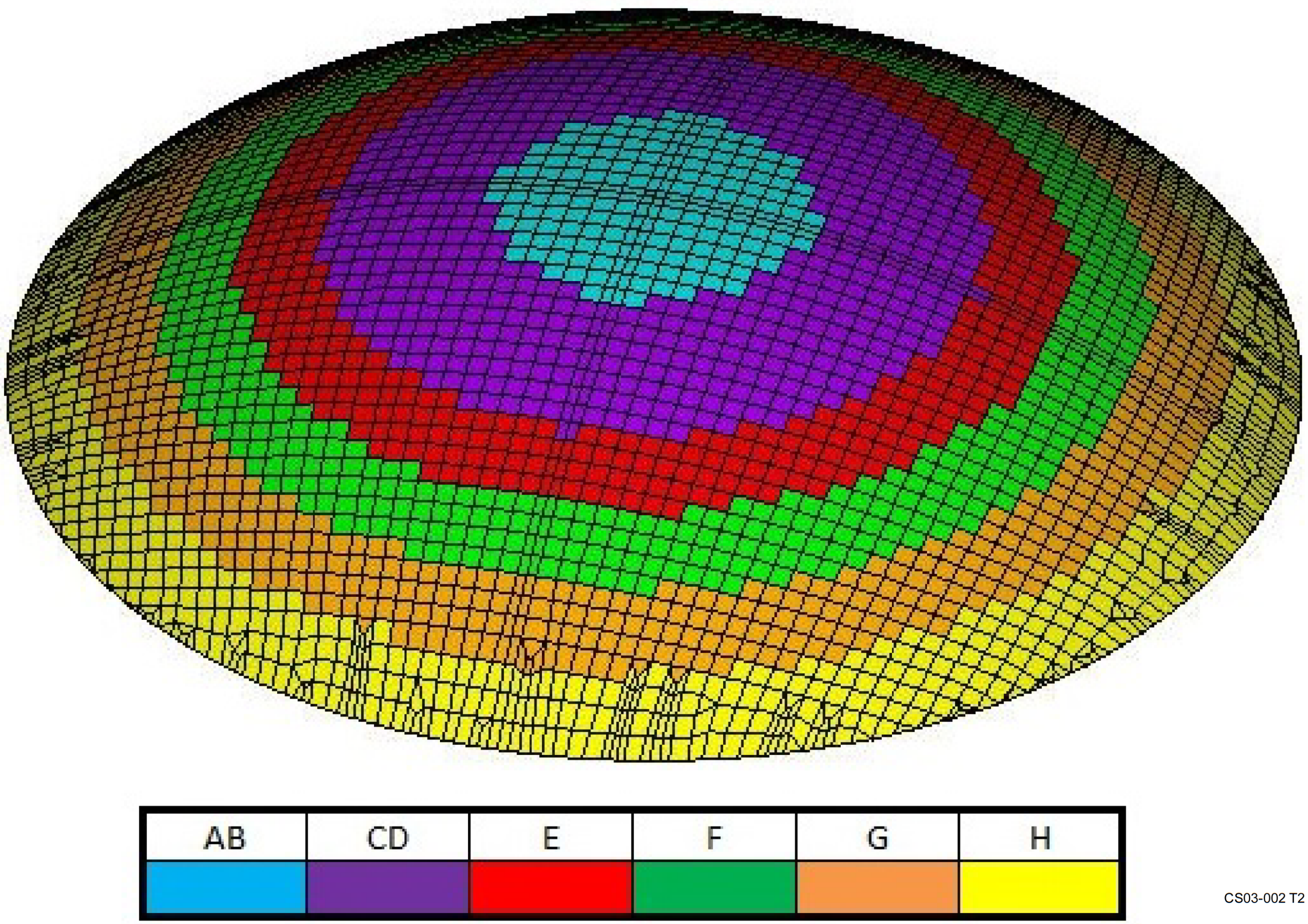

Figure 3E.1.3-3—RCB Dome Subcomponent AB

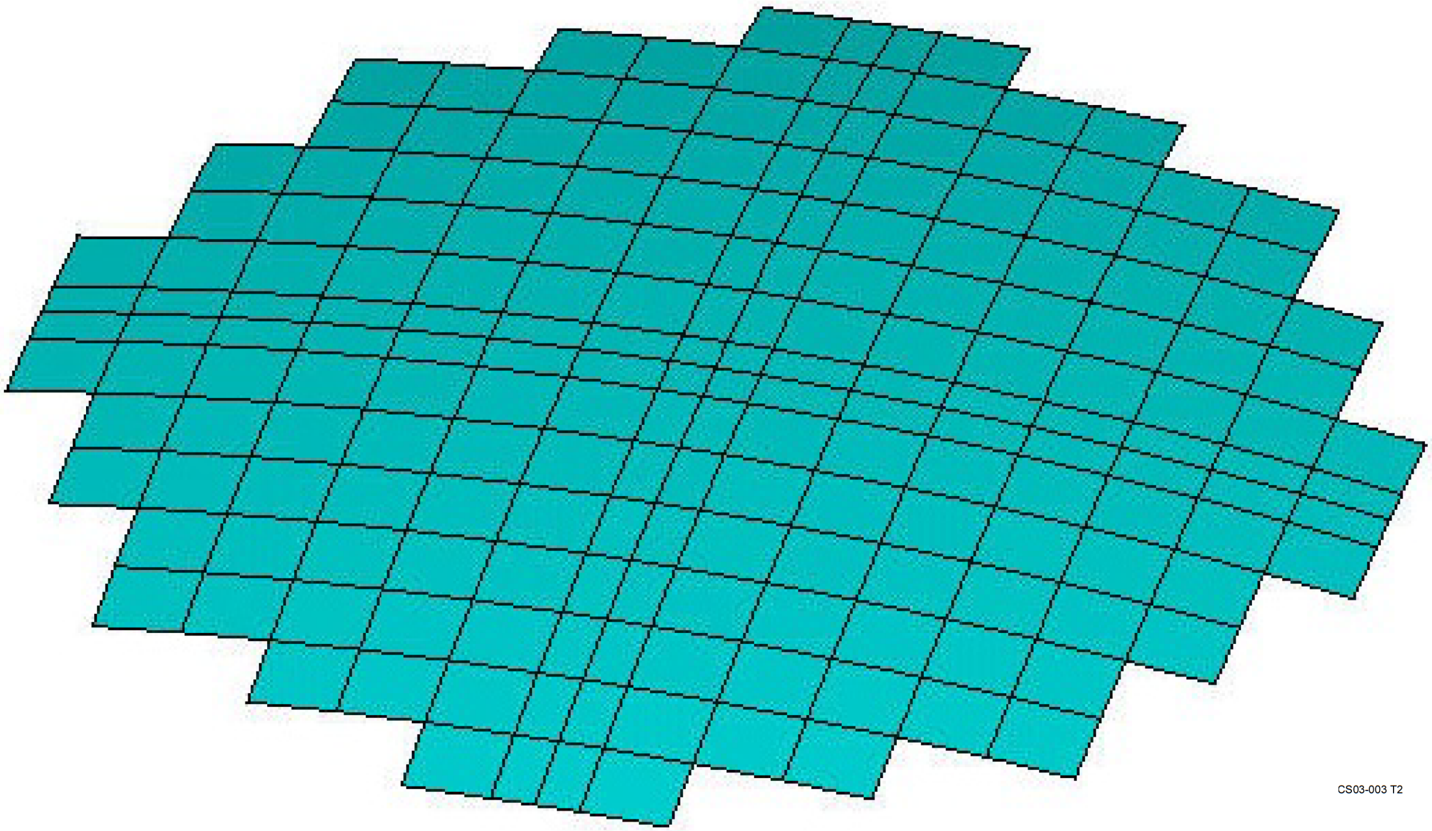

Figure 3E.1.3-4—RCB Dome Subcomponent CD

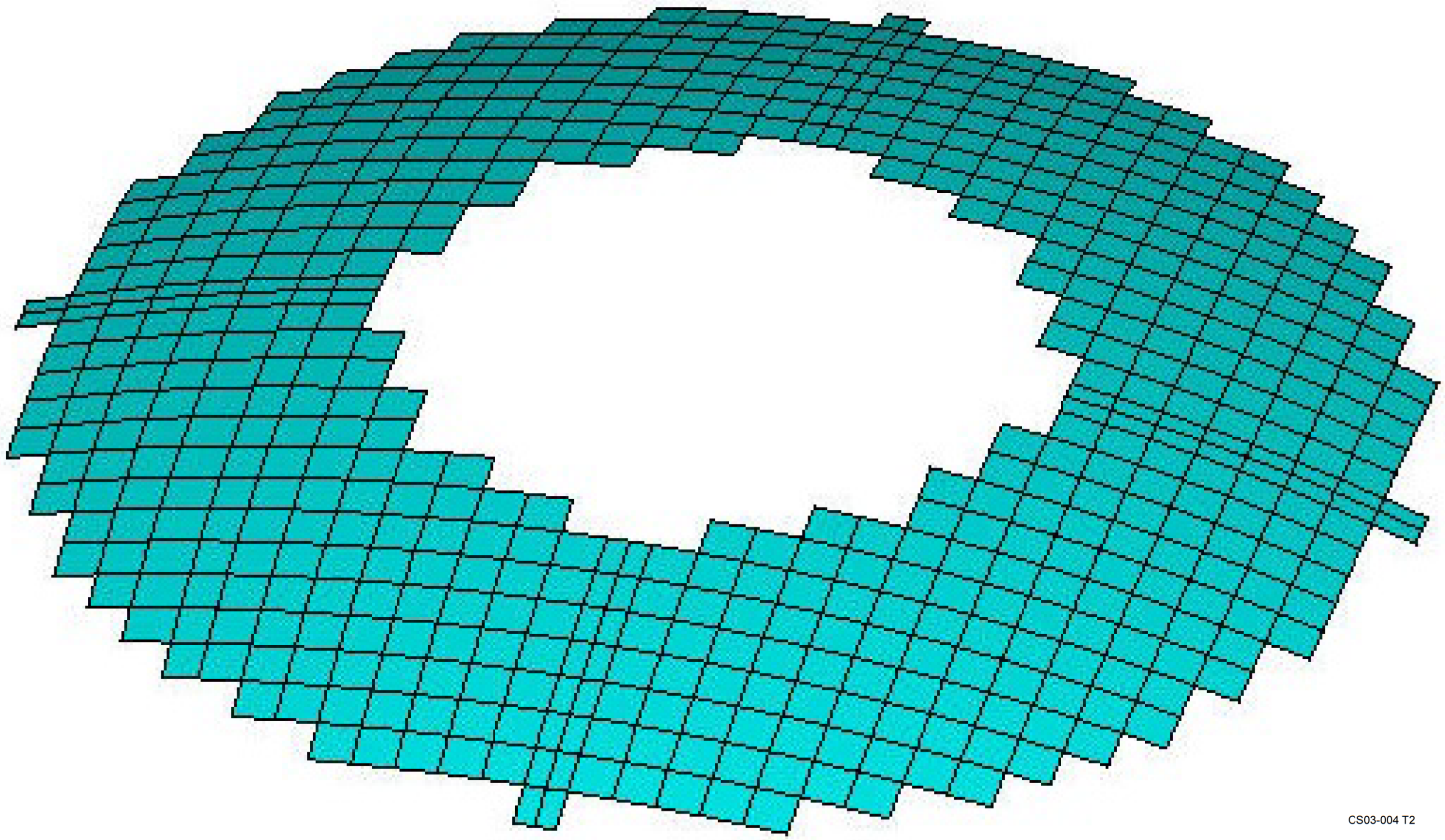

Figure 3E.1.3-5—RCB Dome Subcomponent E

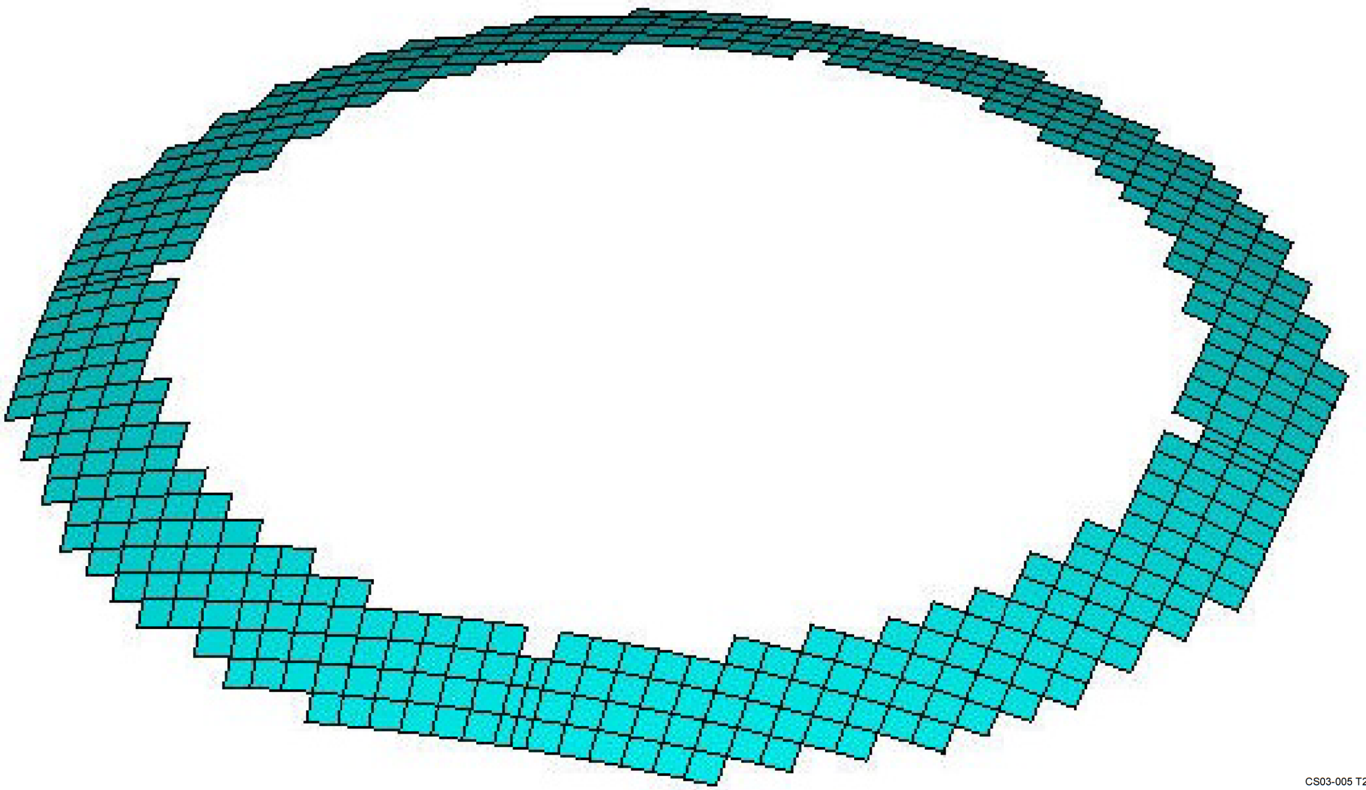

Figure 3E.1.3-6—RCB Dome Subcomponent F

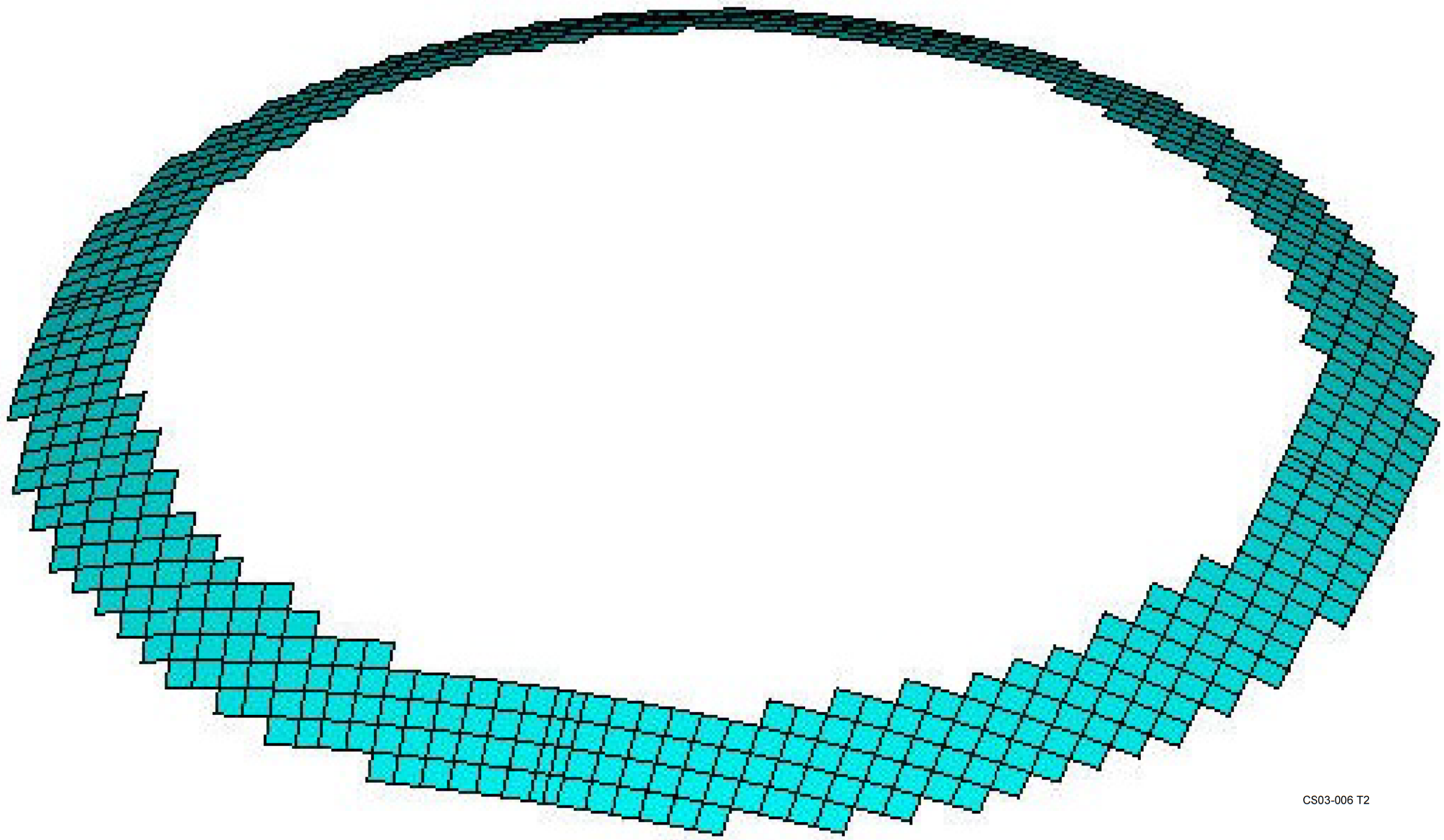

Figure 3E.1.3-7—RCB Dome Subcomponent G

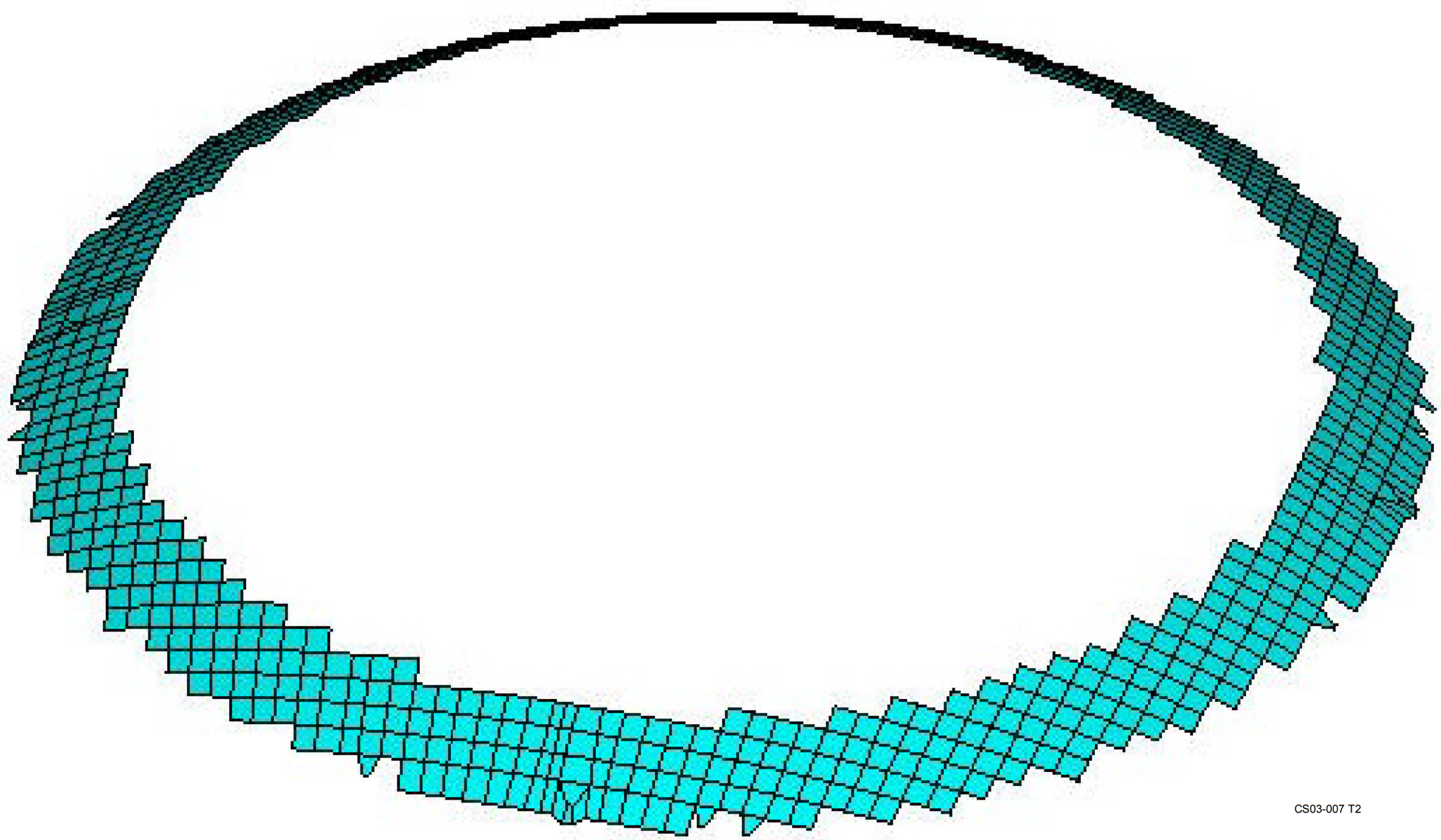

Figure 3E.1.3-8—RCB Dome Subcomponent H

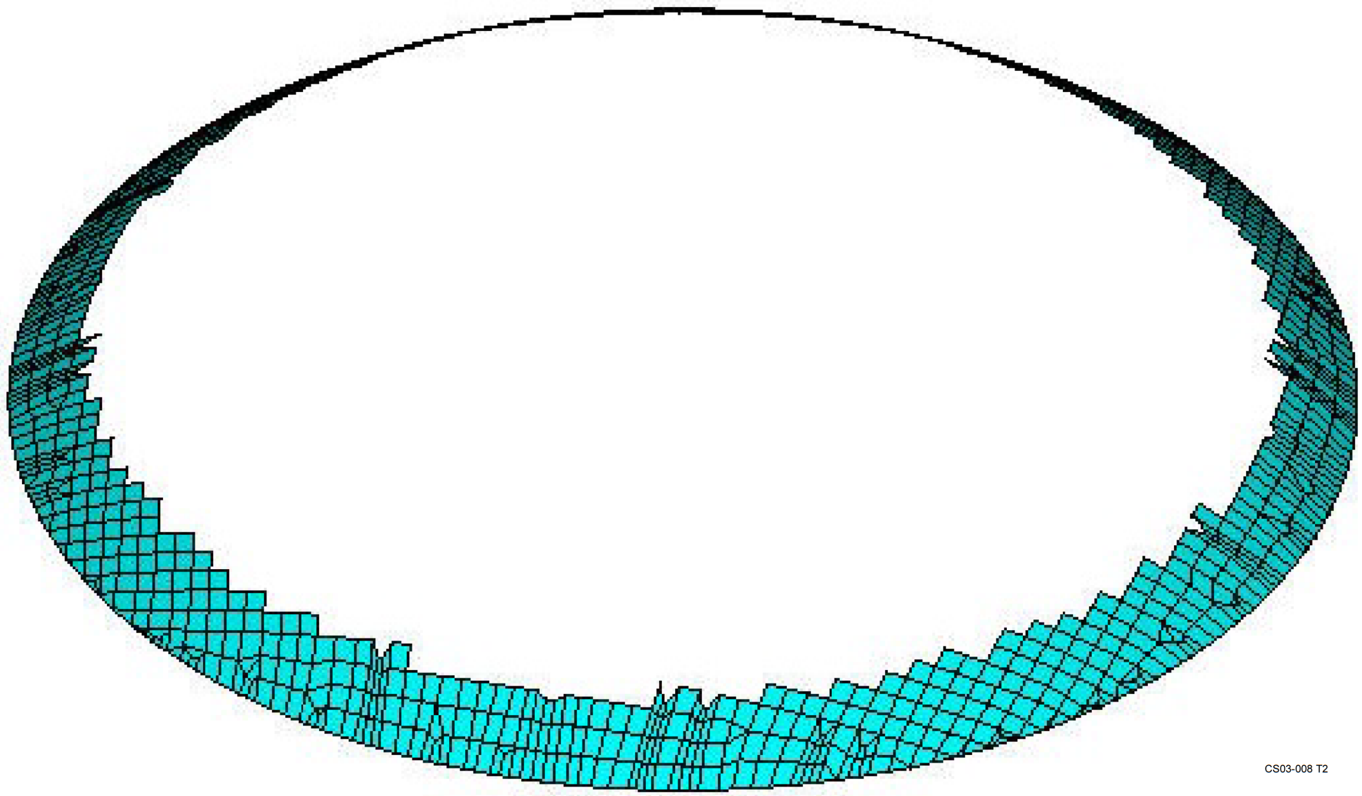

Figure 3E.1.3-9—Key Plan RCB Dome and Ring Girder

Figure 3E.1.3-10—Reinforcement Details for the RCB Ring Girder

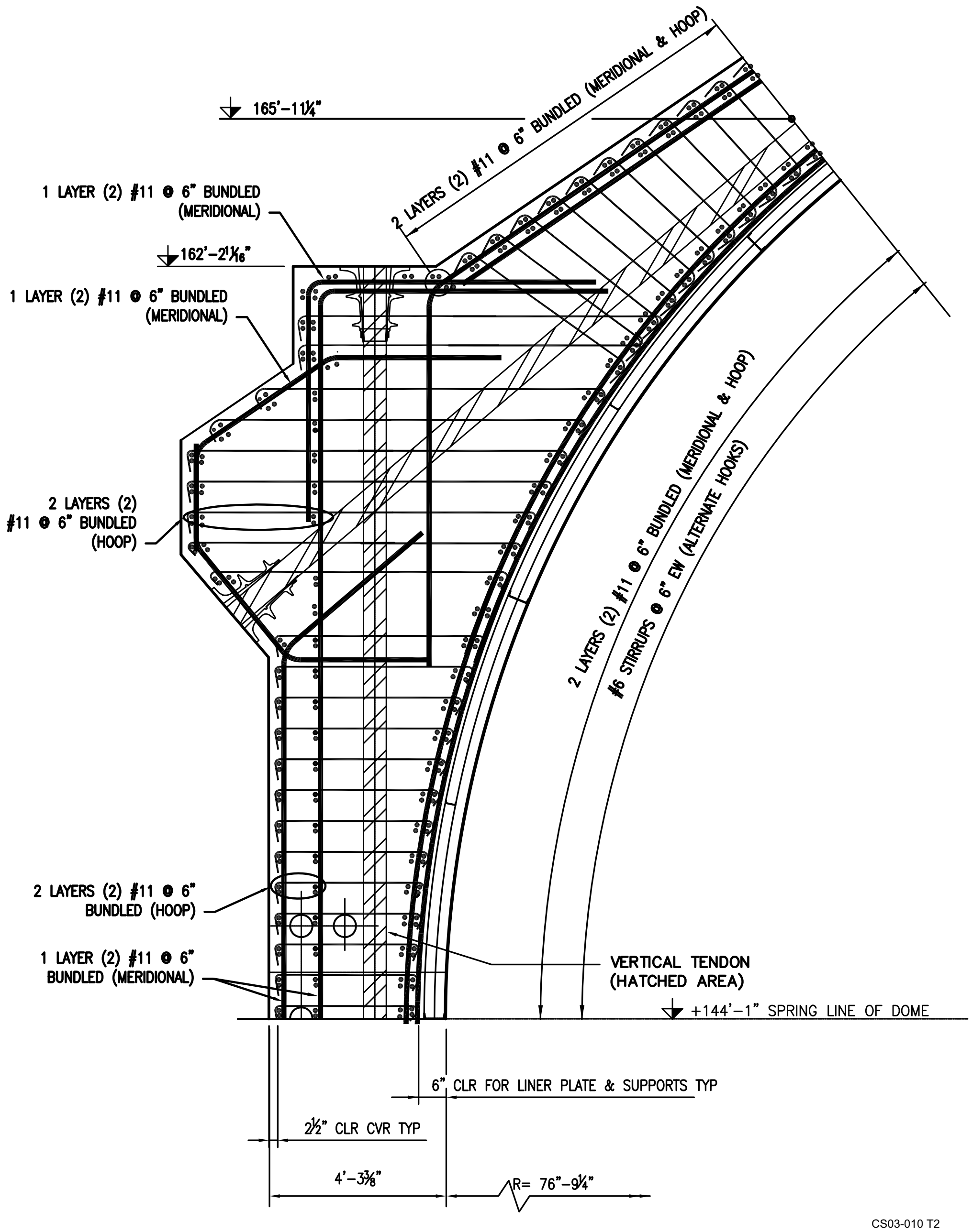

Figure 3E.1.3-11—Reinforcement Details for the RCB Dome Subcomponent AB and CD

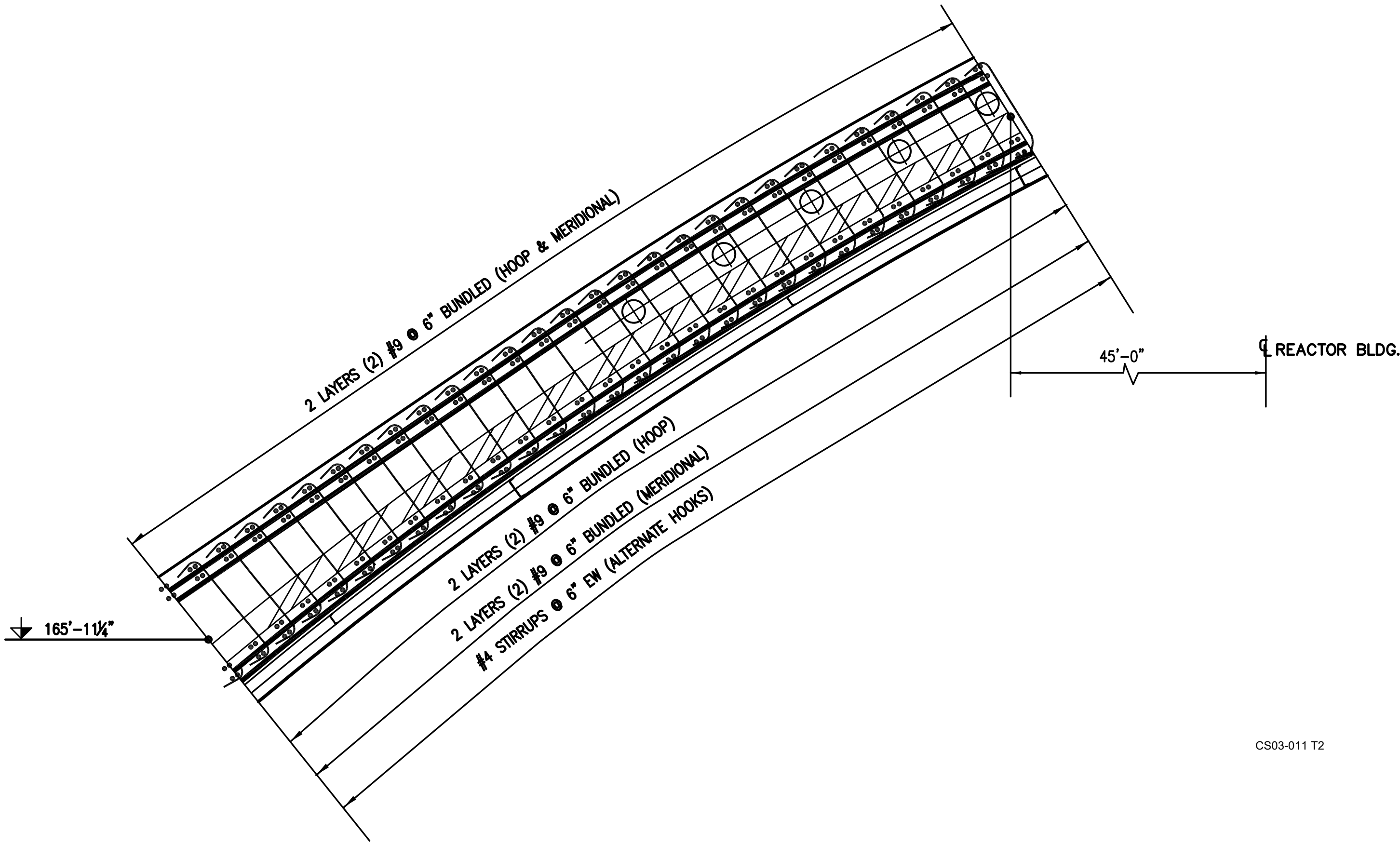

Figure 3E.1.3-12—Reinforcement Details for the RCB Dome Subcomponent EF

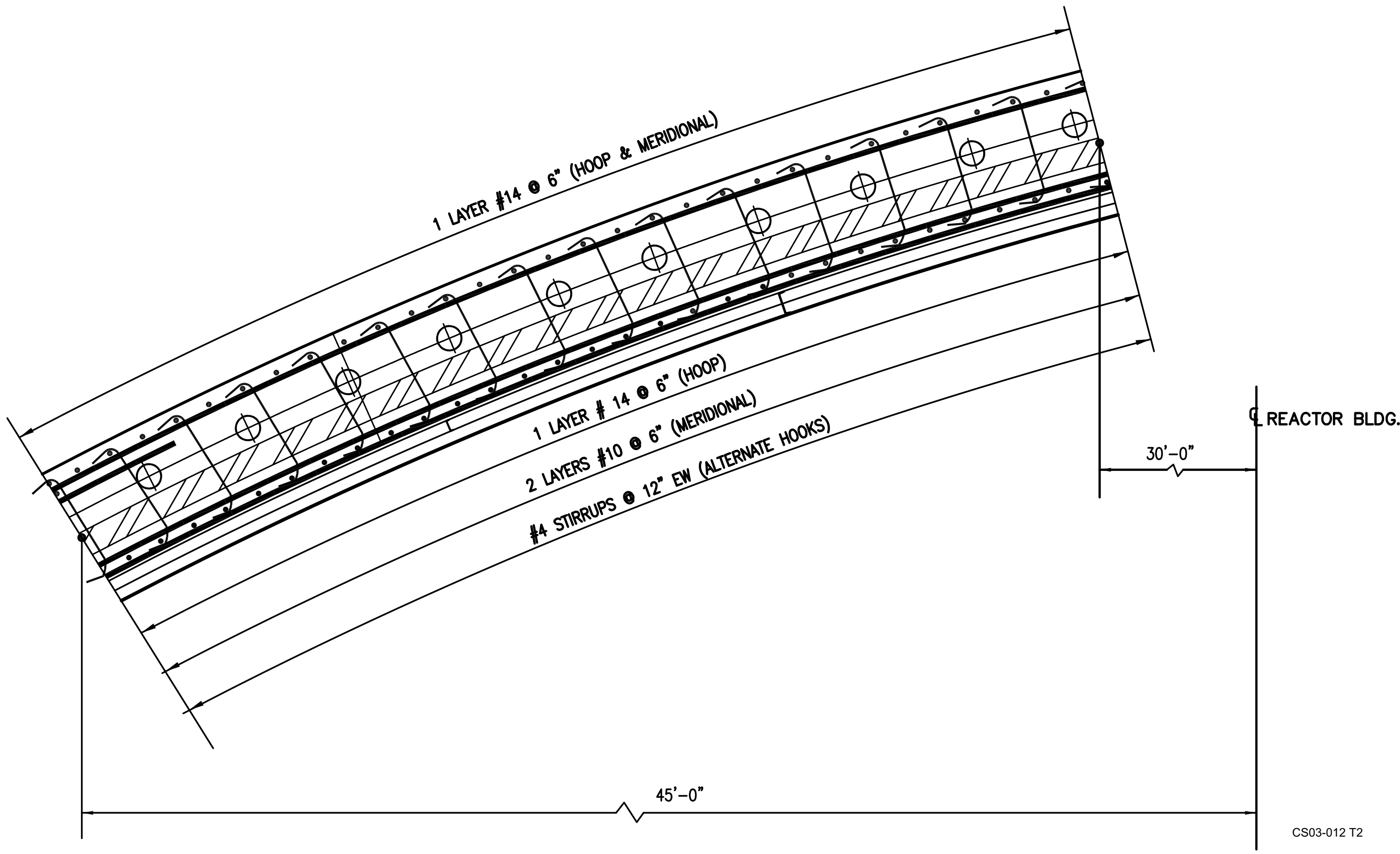

Figure 3E.1.3-13—Reinforcement Details for the RCB Dome Subcomponent GH