3E.1.16 Fuel Building Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade

This critical section presents the analysis and structural design methodology and design results of the Fuel Building (FB) Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade. The FB is described in Section 3.8.4.1.2. The dimensions of the FB are shown on Figure 3B-27—Fuel Building Dimensional Section A-A to Figure 3B-29—Fuel Building Dimensional Section C-C.

The FB is a safety-related, Seismic Category I, reinforced concrete structure that is supported by the Nuclear Island (NI) Foundation Basemat structure, as described in Section 3.8.

The FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade includes the East, West, and South Shield Walls of the FB Hardened Shell. The wall buttress at the South wall is included and is considered as a T-Beam section. An isometric view of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade is shown on Figure 3E.1.16-1—Isometric View FB Hardened Shell Walls from Top of Nuclear Island Basemat to Grade. Design details for the following FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade subcomponents are within the scope of this critical section:

- Figure 3E.1.16-2—FB Hardened Shell East Wall 16A.
- Figure 3E.1.16-3—FB Hardened Shell East Wall 16B.
- Figure 3E.1.16-4—FB Hardened Shell South Wall 16C.
- Figure 3E.1.16-5—FB Hardened Shell South Wall 16D.
- Figure 3E.1.16-6—FB Hardened Shell West Wall 16E.
- Figure 3E.1.16-7—FB Hardened Shell West Wall 16F.
- Figure 3E.1.16-8—FB Hardened Shell West Wall 16G.
- Figure 3E.1.16-9—FB Hardened Shell West Wall 16H.

3E.1.16.1 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 to design the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade.

The FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade are modeled using SHELL43 elements. The element size in these wall areas is approximately 5 ft by 5 ft. The shield wall buttress is modeled using Beam44 elements.

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

3E.1.16.2 Load Combinations and Loads

The load combinations applied to the FB The FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade are described in Section 3.8.4.3. The design of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade is achieved using the results obtained from the model pertaining to the E-Series load combinations 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 FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade are shown in Table 3E.1-2 and described in Sections 3.8.4.3.1 and 3E.1. Independent loads not considered in the ANSYS NI static model are shown in Table 3E.1-3.

Missing loads considered in the design include accidental torsion and differential settlement/construction sequence.

The additional loads created from accidental torsion are part of the safe shutdown earthquake load. A separate analysis was performed to estimate the effects of accidental torsional loads. Based on the results of the analysis, additional in-plane shear and axial loads are included in the design of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade.

A separate structural evaluation is performed to determine the effects of differential settlement/construction. The additional design forces and moments from the settlement effects are included in the design. Differential settlement/construction sequence is described in Section 3.8.5.4.2.

3E.1.16.3 Analysis and Design Methods

The methodology used for the structural analysis and design of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade is to determine the reinforcement configuration using forces and moments generated from the finite element ANSYS NI static model. The design of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade is performed using the applicable codes, standards, and specifications described in Section 3.8.4.2.

The FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade 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 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.1.16.4 Critical Section Design

The structural design provides reinforcement to resist element forces and moments for each of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade. The FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade are designed so that each is capable of carrying the applied design loadings provided they are constructed in accordance with the material properties in Section 3E.1 and the section geometry and reinforcing described in this critical section.

The governing design data for the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade are shown in Table 3E.1.16-1—Governing Design Data for FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade. The governing design data for the FB Hardened Shell Buttress is shown in Table 3E.1.16-2—Governing Design Data for FB Hardened Shell Buttress.

A key plan of the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade is shown on Figure 3E.1.16-10—Key Plan FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade. The minimum required area of steel reinforcement for the FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade is shown in Table 3E.1.16-3—Reinforcement for FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade and Table 3E.1.16-4—Reinforcement for FB Hardened Shell Buttress. Table 3E.1.16-3 and Table 3E.1.16-4 also show the area of steel reinforcement in the design based on the reinforcement configurations shown on Figure 3E.1.16-11—Reinforcement Details of FB Hardened Shell East Wall 16A (Section 7-7) through Figure 3E.1.16-20—Reinforcement Details of FB Hardened Shell Buttress.

Use of reinforcement configurations (including bar size, spacing, and clear cover) different from those shown on Figure 3E.1.16-11 through Figure 3E.1.16-20 are acceptable, provided they meet or exceed the minimum required area of steel reinforcement shown in Table 3E.1.16-3 and Table 3E.1.16-4.

Table 3E.1.16-1—Governing Design Data for FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade
Sheet 1 of 2

Locations	LC[1]	SC[1]	Design Condition	Governing Design Data[2][3][4][5]						
				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
FB Hardened Shell East Wall 16A	E_06_04_1X	5AH	Bending + Axial (Horizontal)	*	14	*	95	*	*	*
	E_06_01_1X	5AH	Bending + Axial (Vertical)	334	*	-66	*	*	*	*
	E_06_04_1x	5AH	In-plane Shear (Horizontal)	*	*	-29	*	298	*	*
	E_06_04_1x	5AH	In-plane Shear (Vertical)	*	*	*	4	298	*	*
	E_06_01_1X	5AH	Out-of-plane Shear	*	*	-35	7	*	39	11
FB Hardened Shell East Wall 16B	E_06_32_1X	5AH	Bending + Axial (Horizontal)	*	-260	*	490	*	*	*
	E_06_24_2X	5AH	Bending + Axial (Vertical)	-118	*	167	*	*	*	*
	E_06_24_2X	5AH	In-plane Shear (Horizontal)	*	*	379	*	371	*	*
	E_06_24_1X	5AH	In-plane Shear (Vertical)	*	*	*	-80	333	*	*
	E_06_32_1X	5AH	Out-of-plane Shear	*	*	-561	432	*	3	13
FB Hardened Shell West Wall 16C	E_06_08_2X	1N5AH	Bending + Axial (Horizontal)	*	518	*	37	*	*	*
	E_06_08_2X	5AH	Bending + Axial (Vertical)	464	*	188	*	*	*	*
	E_06_08_2X	1N5AH	In-plane Shear (Horizontal)	*	*	-62	*	228	*	*
	E_06_08_2X	1N5AH	In-plane Shear (Vertical)	*	*	*	14	227	*	*
	E_13_20_3a	5AH	Out-of-plane Shear	*	*	-44	-78	*	144	16

Table 3E.1.16-1—Governing Design Data for FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade
Sheet 2 of 2

Locations	LC[1]	SC[1]	Design Condition	Governing Design Data[2][3][4][5]						
				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
FB Hardened Shell West Wall 16D	E_06_32_2X	5AH	Bending + Axial (Horizontal)	*	-310	*	259	*	*	*
	E_06_08_2X	5AH	Bending + Axial (Vertical)	334	*	379	*	*	*	*
	E_06_32_2X	4UM	In-plane Shear (Horizontal)	*	*	-413	*	276	*	*
	E_13_19_3a	5AH	In-plane Shear (Vertical)	*	*	*	-102	241	*	*
	E_06_08_2X	5AH	Out-of-plane Shear	*	*	-301	284	*	124	37
FB Hardened Shell West Wall 16E	E_06_32_1X	5AH	Bending + Axial (Horizontal)	*	-327	*	474	*	*	*
	E_06_24_2X	5AH	Bending + Axial (Vertical)	-288	*	260	*	*	*	*
	E_06_32_2X	5AH	In-plane Shear (Horizontal)	*	*	-327	*	201	*	*
	E_06_24_2X	5AH	In-plane Shear (Vertical)	*	*	*	162	336	*	*
	E_06_24_2X	5AH	Out-of-plane Shear	*	*	-216	455	*	47	71
FB Hardened Shell South Wall 16F	E_06_32_1X	4UM	Bending + Axial (Horizontal)	*	-133	*	194	*	*	*
	E_06_21_2X	5AH	Bending + Axial (Vertical)	-214	*	106	*	*	*	*
	E_06_32_1X	4UM	In-plane Shear (Horizontal)	*	*	-453	*	252	*	*
	E_06_03_1x	1N5AH	In-plane Shear (Vertical)	*	*	*	183	288	*	*
	E_06_21_2X	5AH	Out-of-plane Shear	*	*	153	-43	*	131	10
FB Hardened Shell South Wall 16G	E_06_32_1X	4UM	Bending + Axial (Horizontal)	*	-505	*	166	*	*	*
	E_06_24_2X	5AH	Bending + Axial (Vertical)	-317	*	72	*	*	*	*
	E_06_32_1X	4UM	In-plane Shear (Horizontal)	*	*	-328	*	419	*	*
	E_06_24_1X	5AH	In-plane Shear (Vertical)	*	*	*	-151	435	*	*
	E_06_24_1X	5AH	Out-of-plane Shear	*	*	-235	174	*	18	114

Notes:

1. LC is the governing load combination, SC is the governing soil analysis case.
2. (–) indicates compression, (+) indicates tension.
3. CivilFEM forces and moments (averaged).
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 bending moment about the y-axis. M_Y is bending moment about the x-axis. M_{XY} is twisting moment. 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_Y. See Section 3E.1.1 for additional details.

Table 3E.1.16-2—Governing Design Data for FB Hardened Shell Buttress

Locations	LC(1)	SC(1)	Design Condition	Governing Design Data(2)(3)(4)(5)					
				P_X (kips)	V_Y (kips)	V_Z (kips)	M_Y (k-ft/ft)	M_Z (k-ft/ft)	T_X (k-ft)
Buttress 16H	E_09_07_1a_beams	1N5AH	Axial	344	*	*	*	*	*
	E_06_08_2x_beams	1N5AH	Axial	-3366	*	*	*	*	*
	E_06_08_2x_beams	1N5AH	Shear	*	1313	*	*	*	*
	E_06_08_2x_beams	1N5AH	Shear	*	*	2482	*	*	*
	E_09_07_1a_beams	1N5AH	Bending	*	*	*	7632	495	*
	E_06_08_2x_beams	1N5AH	Torsion	*	*	*	*	*	9630

Notes:

1. LC is the governing load combination, SC is the governing soil analysis case.
2. (–) indicates compression, (+) indicates tension.
3. CivilFEM forces and moments (unaveraged).
4. P_Z is axial along the x-axis, V_Y is shear along the y-axis, V_Z is shear about the z-axis, M_Y is bending moment about the y-axis, M_Z is bending moment about the z-axis, T_X is torsion about the x-axis.
5. (*) Not applicable for indicated reinforcement.

Table 3E.1.16-3—Reinforcement for FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade
Sheet 1 of 2

Locations	Reinforcing Direction	Thickness	Reinforcing Condition	Required $A_{S\text{-}req}$ (in^2/ft) (3)	Reinforcement Pattern (1,2)	Provided $A_{S\text{-}pro}$ (in^2/ft) (4)	Reinforcement Ratio (i.e., $A_{S\text{-}pro}/A_{S\text{-}req}$)
FB Hardened Shell East Wall 16A	Horizontal	4 ft 4 in	Axial + Bending & In-plane Shear	*[4.19*	3# 11s @ 12 in	4.68	1.12
	Vertical		Axial + Bending & In-plane Shear	*3.10*	3# 11 s @ 12 in	4.68	1.51
	Stirrup		Out-of-plane Shear	*0.00*	#6 @ 12 in	0.44	N/A
FB Hardened Shell East Wall 16B	Horizontal	5 ft 0 in	Axial + Bending & In-plane Shear	*9.31*	3# 11 s @ 6 in	9.36	1.01
	Vertical		Axial + Bending & In-plane Shear	*5.12*	3# 11 s @ 6 in	9.36	1.83
	Stirrup		Out-of-plane Shear	*0.02*	# 6 @ 12 in	0.44	22.0
FB Hardened Shell West Wall 16C	Horizontal	5 ft 11 in	Axial + Bending & In-plane Shear	*3.94*	3# 10 s @ 6 in	7.62	1.19
	Vertical		Axial + Bending & In-plane Shear	*5.05*	3# 10 s@ 6 in	7.62	1.51
	Stirrup		Out-of-plane Shear	*0.16*	#6 @12 in	0.44	2.75
FB Hardened Shell West Wall 16D	Horizontal	5 ft 11 in	Axial + Bending & In-plane Shear	*6.30*	3# 10 s@ 6 in	7.62	1.21
	Vertical		Axial + Bending & In-plane Shear	*7.14*	3# 10 s @ 6 in	7.62	1.07
	Stirrup		Out-of-plane Shear	*0.37*	# 6 @ 12 in	0.44	1.19

Table 3E.1.16-3—Reinforcement for FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade
Sheet 2 of 2

Locations	Reinforcing Direction	Thickness	Reinforcing Condition	Required $A_{S\text{-}req}$ (in^2/ft) (3)	Reinforcement Pattern (1,2)	Provided $A_{S\text{-}pro}$ (in^2/ft) (4)	Reinforcement Ratio (i.e., $A_{S\text{-}pro}/A_{S\text{-}req}$)
FB Hardened Shell West Wall 16E	Horizontal	5 ft 11 in	Axial + Bending & In-plane Shear	*8.66*	3# 11 s @ 6 in	9.36	1.08
	Vertical		Axial + Bending & In-plane Shear	*5.26*	3# 11 s @ 6 in	9.36	1.78
	Stirrup		Out-of-plane Shear	*0.19*	#6 @ 12 in	0.44	2.32
FB Hardened Shell South Wall 16F	Horizontal	5 ft 2 1/4 in	Axial + Bending & In-plane Shear	*4.50*	2# 11 s @ 6 in	6.24	1.39
	Vertical		Axial + Bending & In-plane Shear	*4.67*	2#10 s @ 6 in	5.08	1.09
	Stirrup		Out-of-plane Shear	*0.29*	#6 @ 12 in	0.44	1.52
FB Hardened Shell South Wall 16G	Horizontal	5 ft 10 7/8 in	Axial + Bending & In-plane Shear	*8.47*	3# 11 s @ 6 in	9.36	1.11
	Vertical		Axial + Bending & In-plane Shear	*6.62*	3# 10 s @ 6 in	7.62	1.15
	Stirrup		Out-of-plane Shear	*0.19]**	#6 @ 12 in	0.44	2.44

Notes:

1. EF is each face.
2. EW is each way.
3. $A_{S\text{-}req}$ is required reinforcement.
4. $A_{S\text{-}pro}$ is provided reinforcement.

Table 3E.1.16-4—Reinforcement for FB Hardened Shell Buttress

Location	Reinforcing Direction	Width	Reinforcing Condition	*[Required $A_{S\text{-}req}$ (1)*	Provided $A_{S\text{-}pro}$ (2)	Reinforcement Ratio ($A_{S\text{-}pro}/A_{S\text{-}req}$)
Buttress 16H East-West Faces	Longitudinal	111 in.	Axial + Bending	*79.6 in^2*	79.6 in^2	1.00
	Shear		Shear	*1.02 in^2/ft*	1.58 in^2/ft	1.55
Buttress 16H Inside/Outside Face	Longitudinal	182 in.	Axial + Bending	*140.4 in^2*	140.4 in^2	1.00
	Tie		Shear	*0.12 in^2/ft*	0.79 in^2/ft	6.58
Total Section	Closed Stirrup	111 in. x 182 in.	Torsion	*0.87 in^2/ft*	1.58 in^2/ft	1.82
	Longitudinal			*56.7 in^2]**	60 in^2	1.06

Notes:

1. $A_{S\text{-}req}$ is required reinforcement.
2. $A_{S\text{-}pro}$ is provided reinforcement.

Figure 3E.1.16-1—Isometric View FB Hardened Shell Walls from Top of Nuclear Island Basemat to Grade

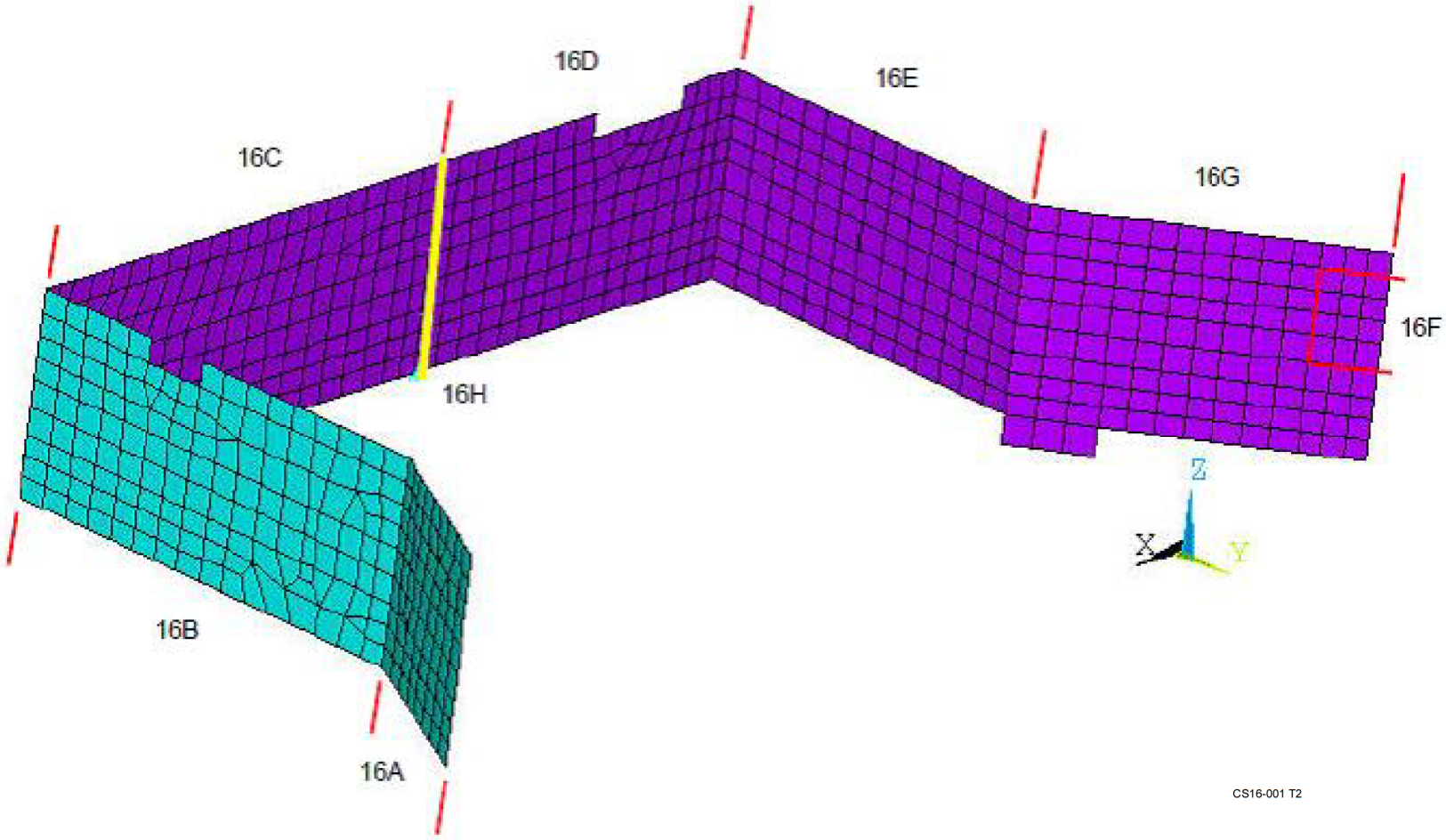

Figure 3E.1.16-2—FB Hardened Shell East Wall 16A

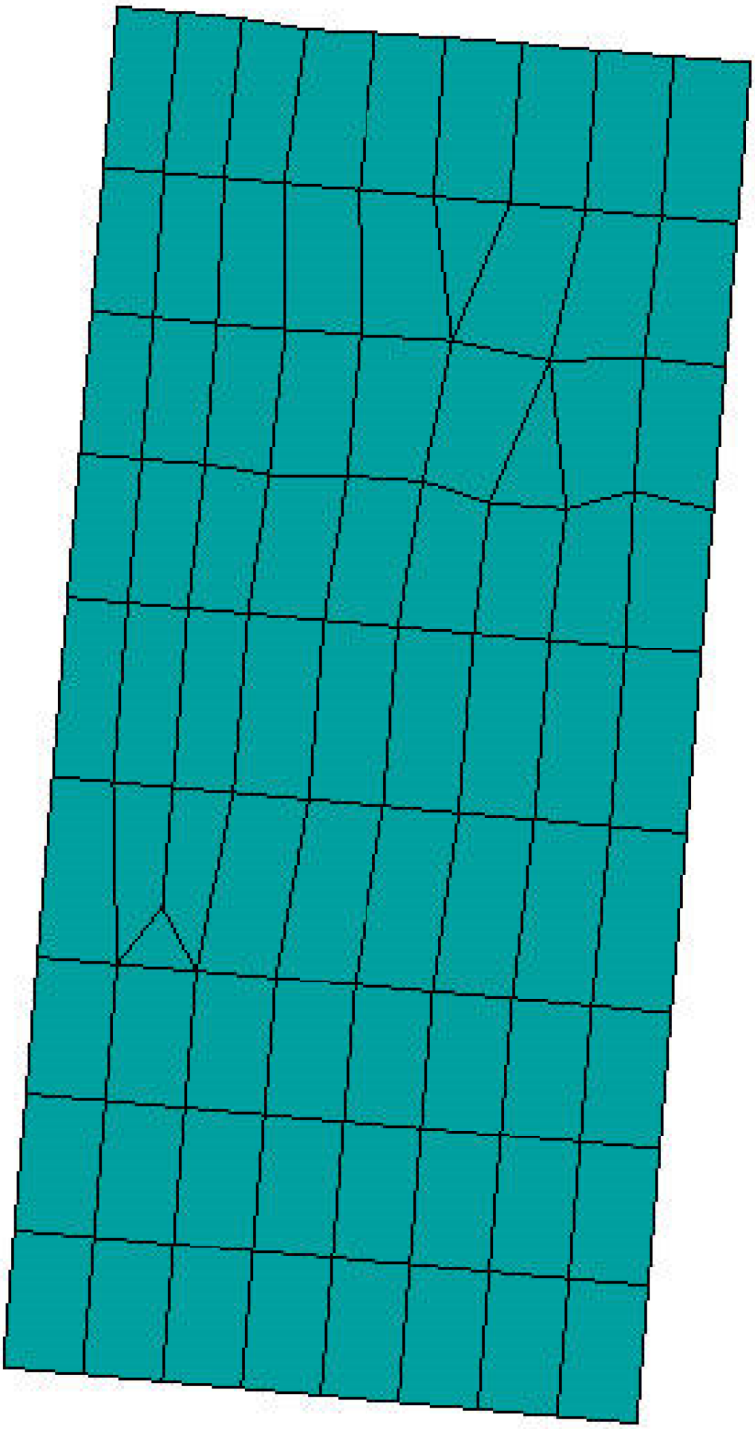

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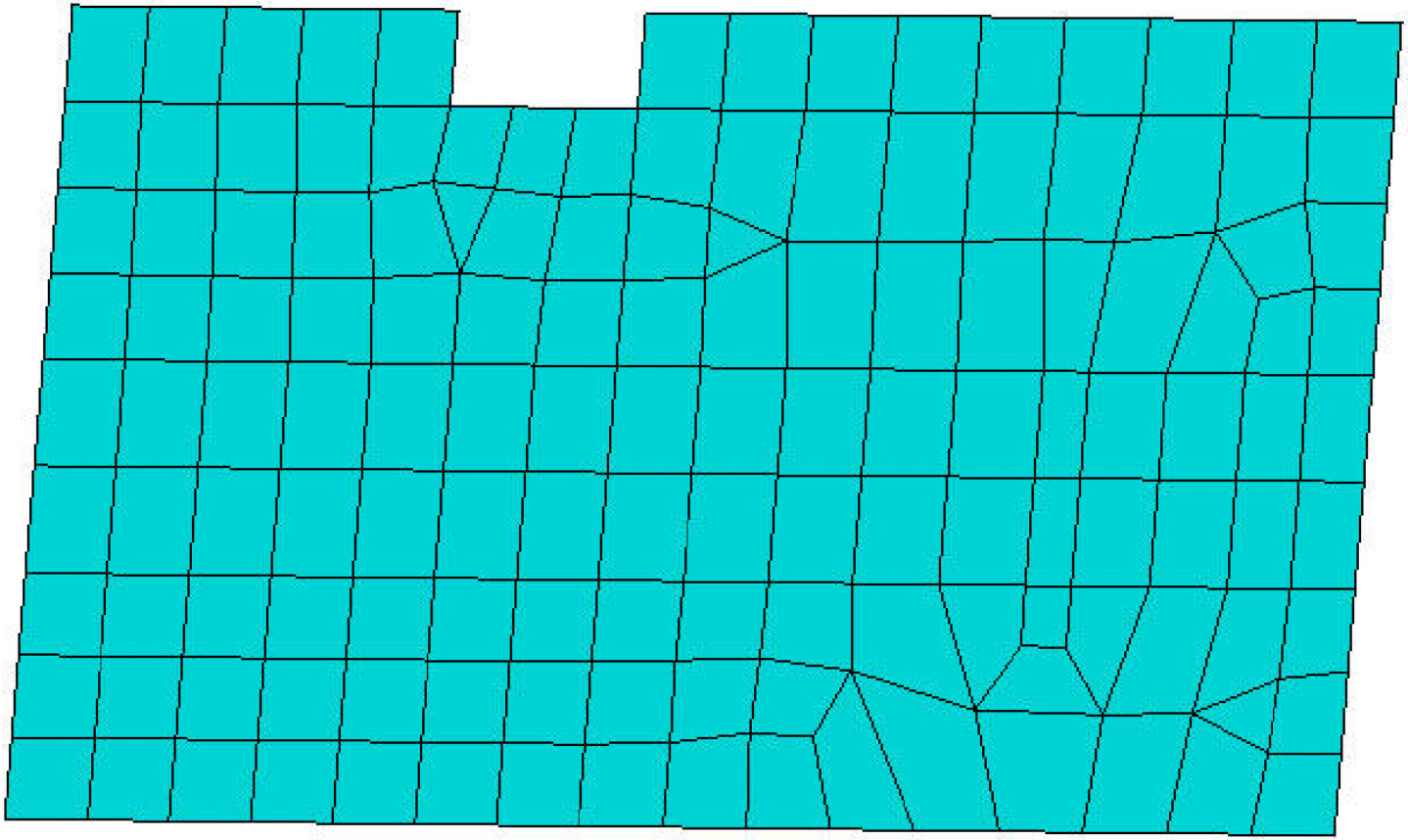
Figure 3E.1.16-3—FB Hardened Shell East Wall 16B



CS16-003 T2

Figure 3E.1.16-4—FB Hardened Shell South Wall 16C

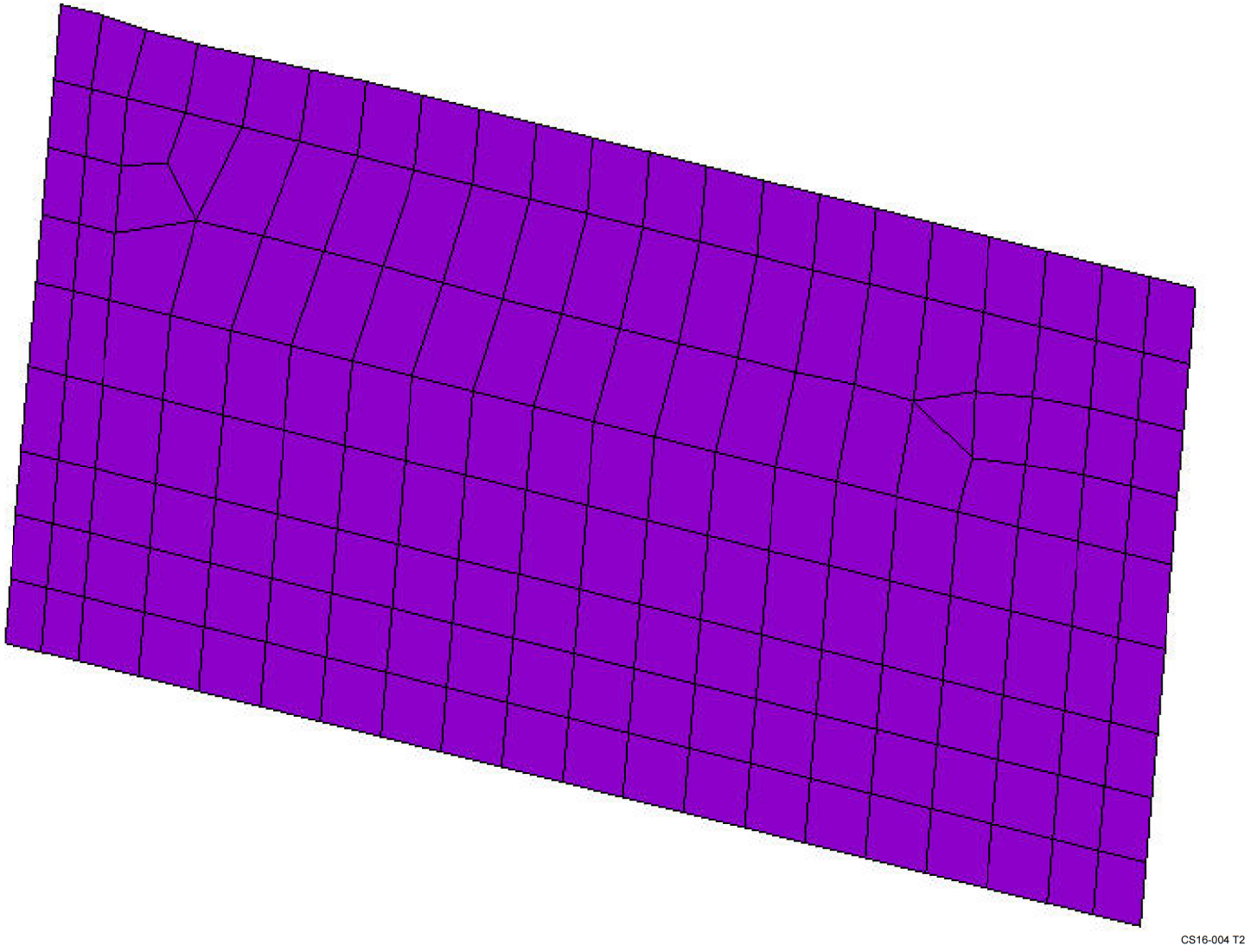


Figure 3E.1.16-5—FB Hardened Shell South Wall 16D

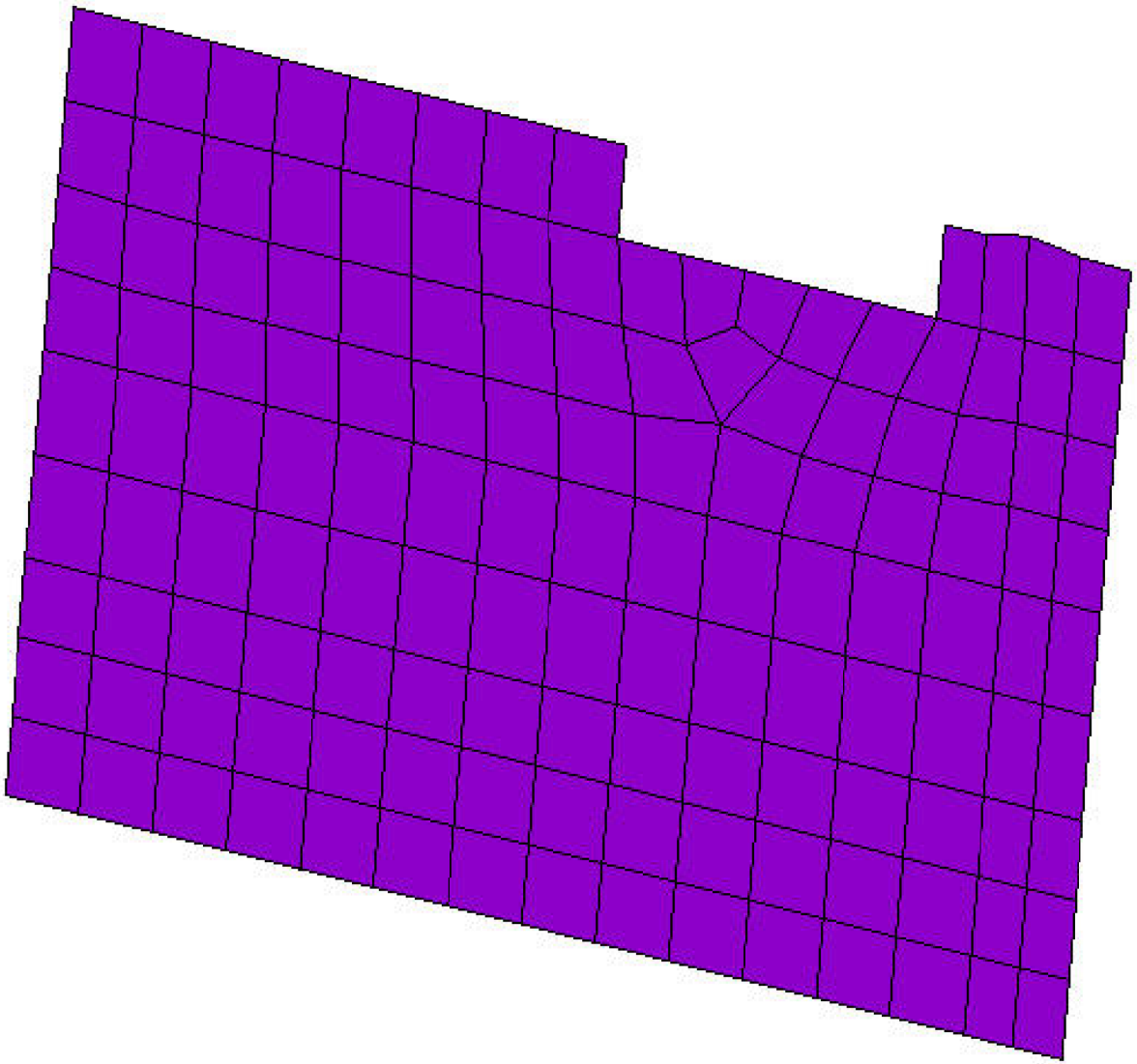


Figure 3E.1.16-6—FB Hardened Shell West Wall 16E

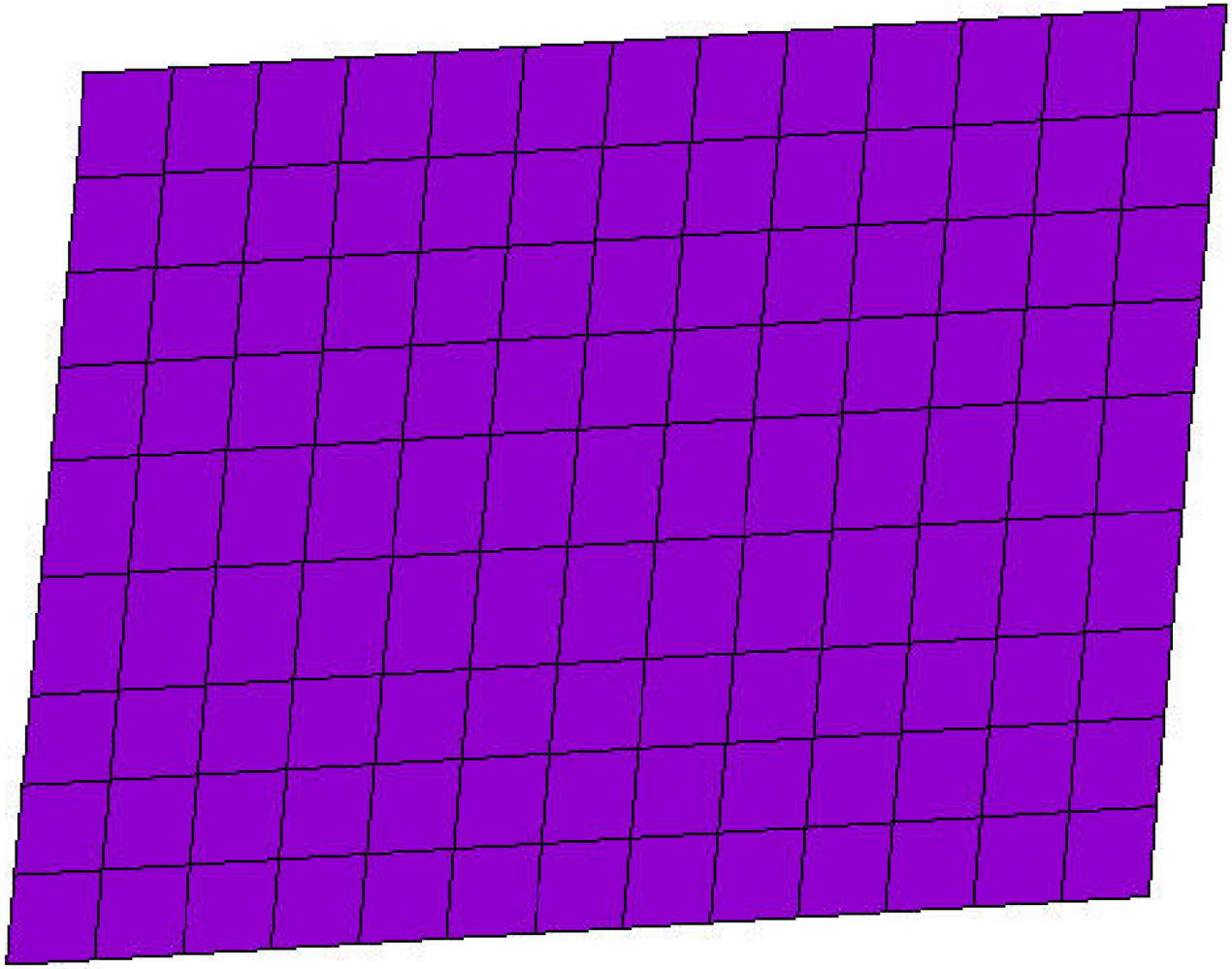


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Figure 3E.1.16-7—FB Hardened Shell West Wall 16F

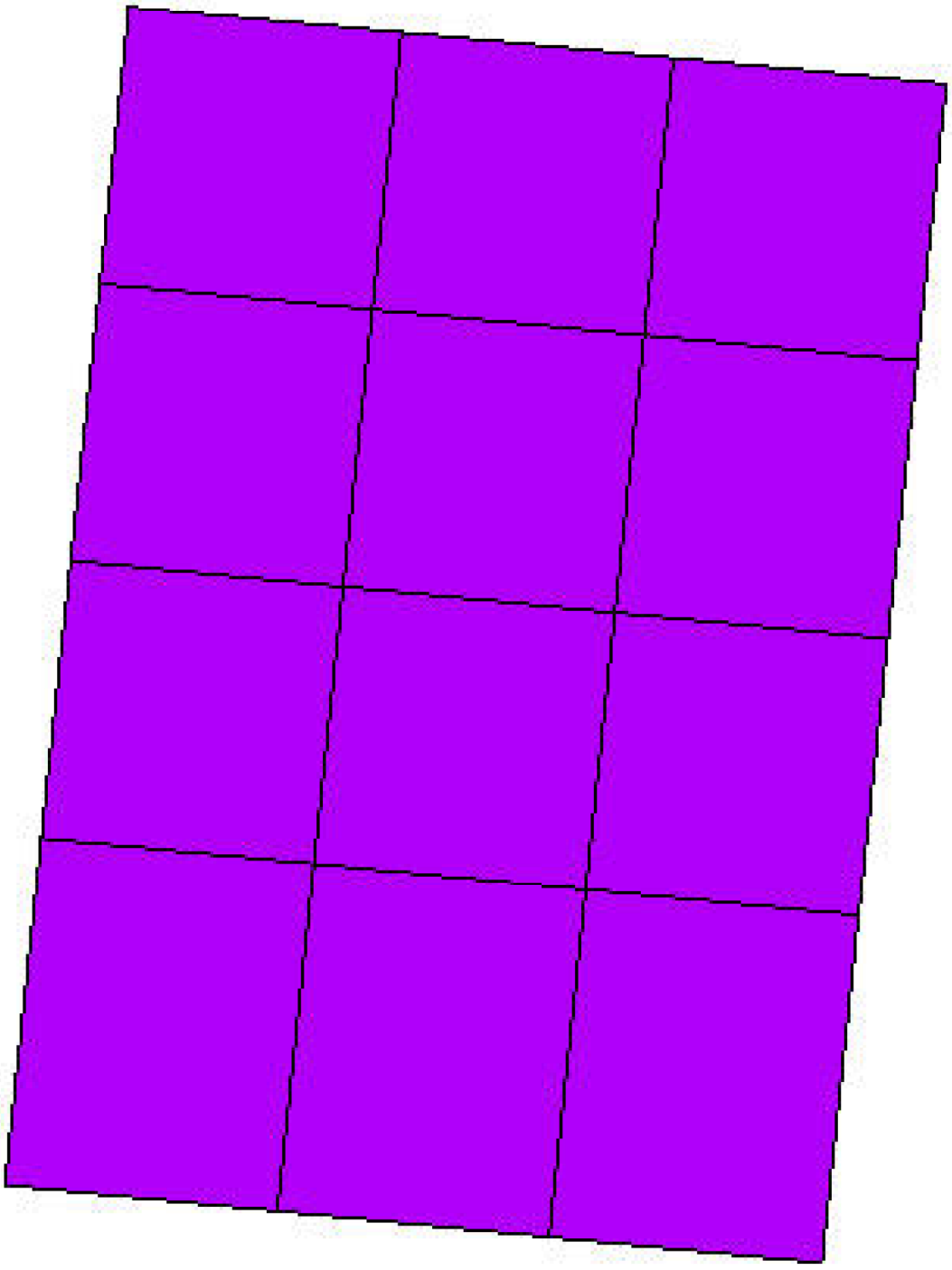

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Figure 3E.1.16-8—FB Hardened Shell West Wall 16G

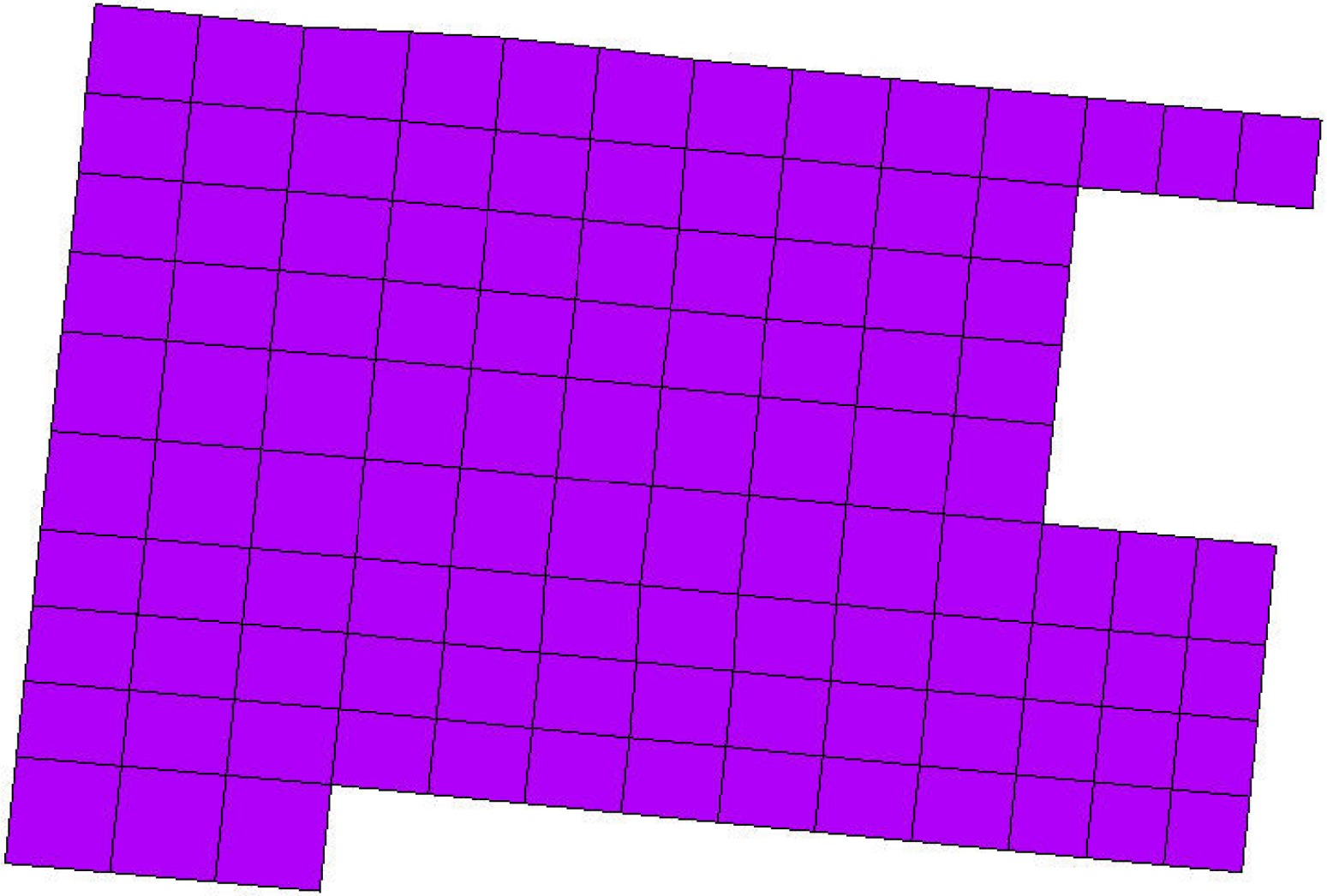

Figure 3E.1.16-9—FB Hardened Shell West Wall 16H

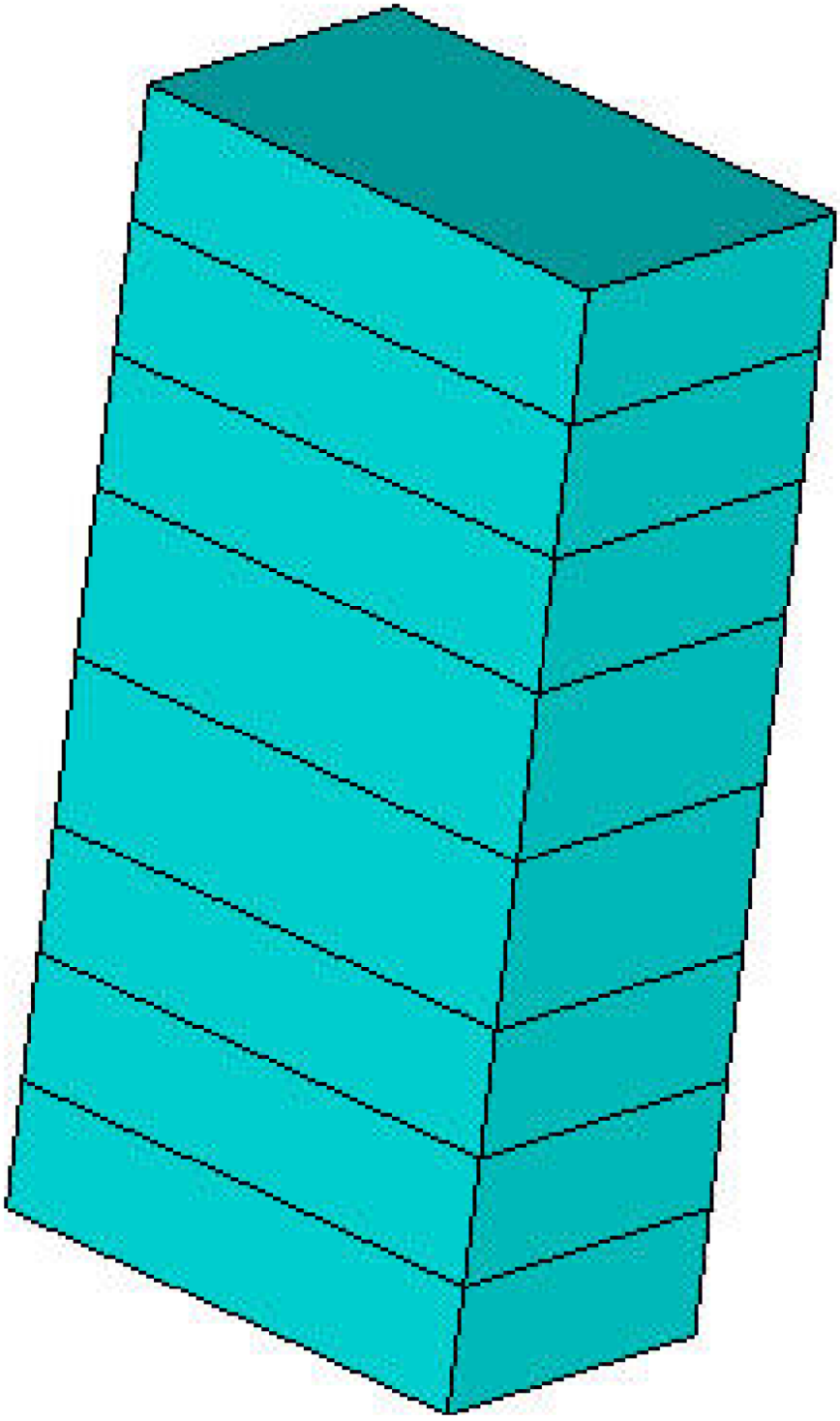

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Figure 3E.1.16-10—Key Plan FB Hardened Shell Walls from Top of the Nuclear Island Basemat to Grade

Figure 3E.1.16-11—Reinforcement Details of FB Hardened Shell East Wall 16A (Section 7-7)

Figure 3E.1.16-12—Reinforcement Details of FB Hardened Shell East Wall 16B (Section 6-6)

Figure 3E.1.16-13—Reinforcement Details of FB Hardened Shell South Wall 16C (Section 5-5)

Figure 3E.1.16-14—Reinforcement Details of FB Hardened Shell South Wall 16D (Section 4-4)

Figure 3E.1.16-15—Reinforcement Details of FB Hardened Shell West Wall 16E (Section 3-3)

Figure 3E.1.16-16—Reinforcement Details of FB Hardened Shell West Wall 16F (Section 1-1)

Figure 3E.1.16-17—Reinforcement Details of FB Hardened Shell West Wall 16G (Section 2-2)

Figure 3E.1.16-18—Reinforcement Details of FB Hardened Shell Wall-to-Wall Joints - Full Moment Connection (Southeast Corner)

Figure 3E.1.16-19—Reinforcement Details of FB Hardened Shell Wall-to-Wall Joints - Full Moment Connection (Southwest Corner)

Figure 3E.1.16-20—Reinforcement Details of FB Hardened Shell Buttress