3E.3.3 Essential Service Water Building Fan Deck Slab at Elevation 63 ft

This critical section presents the analysis and structural design methodology and design of the Essential Service Water Building (ESWB) Fan Deck Slab at Elevation 63 ft (Slab63). The ESWB Slab63 is shown on Figure 3B-75—Essential Service Water Building Dimensional Section A-A and Figure 3B-76—Essential Service Water Building Dimensional Section B-B.

This critical section designs ESWB Slab63, selected via the supplementary selection methodology as described in Section 3E to verify an evaluation of an "essentially complete" design. The ESWB is a safety-related, Seismic Category I structure. Specifically, this critical section designs the following portions of the ESWS shown on Figure 3E.3.3-1—ESWB Slab 63 Flexural and North-South Shear Design Regions (FEM) and Figure 3E.3.3-2—ESWB Slab 63 East-West Shear Design Regions (FEM):

- Slab63 - North-South Region 1, between Z-coordinates 21 ft and 36 ft and coordinates 69 ft and 84 ft.
- Slab63 - North-South Region 2, between Z-coordinates 36 ft and 69 ft.

ESWS Slab63 is divided into two subsections for flexure and shear design in the north-south direction, with Region 1 and Region 2 shown on Figure 3E.3.3-1. The five subsections for shear design in the east-west direction, Region 1 through Region 5, are shown on Figure 3E.3.3-2. These subsections facilitate an economical reinforcement design and manage analysis results more easily. Each region is scanned separately for the maximum axial force, shear, and bending moment demands.

In the design of ESWS Slab63, GTSTRUDL finite element forces averaged at the nodes are used. Averaging methodology for bending moment and axial force resultants are based on a section length of three times the thickness following ACI 349-01. Averaging the results of four or three neighboring joints generally satisfies this requirement for the entire critical section. Section cuts that give the maximum design moment (M_{U-YY} and M_{U-XX}), design axial force (N_{XX} and N_{YY}), and maximum eccentricity (M/N) for ESWS Slab63 are selected for each region as shown on Figure 3E.3.3-3—ESWB Slab 63 Axial Force (Tension) and Bending Moment Critical Design Cuts (FEM). For in-plane and out-of-plane shear, longer cuts covering the entire possible length and height of the wall are used. Section cuts are selected based on demand to capacity ratios considering the axial tension acting simultaneously on the cut as shown on Figure 3E.3.3-4—ESWB Slab 63 In-Plane and Out-of-Plane Shear Critical Design Cuts (FEM).

3E.3.3.1 Model

The global GTSTRUDL finite element model (FEM) described in Sections 3.7.2.3.2 and 3.8.4.4.4 is used in the design of the ESWS Slab63. Most of the concrete plates in the superstructure of the ESWB qualify for a stress analysis with thin plates; therefore, GTSTRUDL SBHQ6 element is used to mesh the superstructure. The basemat of the ESWB static model is meshed using eight-node, three-dimensional solid GTSTRUDL IPSLIM elements to accurately capture its behavior. The element size is approximately 3 ft by 3 ft at subgrade elevations and 6 ft by 6 ft at higher elevations with variations in aspect ratios to accommodate openings.

The finite element planar reference system for the GTSTRUDL finite element analysis output is shown on Figure 3E.3.3-5—GTSTRUDL Finite Element Planar Reference Frame Systems (Plate Bending) and Figure 3E.3.3-6—GTSTRUDL Finite Element Planar Reference Frame Systems (Plane Stress/Strain). The positive direction of the finite element bending moments M_{XX}, M_{YY}, and M_{XY} and out-of plane shear forces V_{XX} and V_{YY} are shown on Figure 3E.3.3-5. The positive direction of the finite element in-plane forces N_{XX}, N_{YY}, and N_{XY} are the same as the positive orientation of the plane stresses S_{XX}, S_{YY}, and S_{XY} shown on Figure 3E.3.3-6.

3E.3.3.2 Load Combinations and Loads

The applicable loads applied to the ESWB Slab63 are described in Sections 3.8.4.3.1 and 3.8.5.3. The applicable loading combinations are described in Sections 3.8.4.3.2 and 3.8.5.3. This critical section is also designed for the soil analysis cases shown in Table 3.7.1-9.

The design of ESWS Slab63 is achieved using the results obtained from the model for the load combinations which are shown in Table 3E.3.3-1—Governing Design Data for ESWB Slab63.

No additional missing loads are considered in the design of ESWS Slab63.

3E.3.3.3 Analysis and Design Methods

The methodology used for the structural analysis and design of ESWS Slab63 is to determine the reinforcement configuration using forces and moments generated from the finite element GTSTRUDL model. The design of the ESWS Slab63 is performed using hand calculations utilizing the applicable codes, standards, and specifications described in Sections 3.8.4.2 and 3.8.5.2.

ESWS Slab63 is designed for the resultant forces and moments determined based on the applied loading and soil conditions. The data shown in Table 3E.3.3-1 are obtained by sorting results extracted from the finite element GTSTRUDL model.

Section cuts are used to determine the forces and moments throughout ESWS Slab63. Section cut locations are determined through a review of enveloping distributions of forces and moments described in Section 3E.3.3.1. The section cut locations are shown on Figure 3E.3.3-3 and Figure 3E.3.3-4. The sign convention describing the nomenclature for north-south and east-west cuts applicable to this critical section is shown on Figure 3E.3.3-5 and Figure 3E.3.3-6.

Each ESWS Slab63 region is first designed for flexure because of maximum out-of-plane bending moments $M_{U\text{-}YY}$ and $M_{U\text{-}XX}$. $M_{U\text{-}XX}$ is used to determine the north-south reinforcement, while $M_{U\text{-}YY}$ is used to determine the east-west reinforcement based on the ESWS Slab63 coordinates and surface normal. The flexural design in each direction is checked by examining the axial force and bending moment interaction. The axial force-bending moment demand pairs (N_{XX} and $M_{U\text{-}XX}$ and N_{YY} and $M_{U\text{-}YY}$) are plotted on a beam-column capacity interaction (N-M) diagram of the wall section, where the ultimate capacity limits for the cross section are developed for a trial reinforcement bar size and spacing selected for the inside and outside faces of the walls. A set of curves on the interaction diagrams defines the ultimate capacity boundary limits for axial tension or compression in combination with positive (hogging) or negative (sagging) moments. If there are any demand pair points that lie outside of the capacity curve boundaries, the reinforcement design is revised until the points are inside the failure surface.

In the second step, the region is designed for out-of-plane shear, in-plane shear, and shear friction in the north-south direction. The shear design is based on section cuts through the diaphragm in either the north-south or east-west directions. The averaged shear demand at the nodes is summed along the cut length. The concrete shear capacity for both out-of-plane and in-plane shear is a function of the simultaneous axial load demand, and net axial tension on the cross section reduces the concrete shear capacity significantly. The north-south cut that produces the highest shear demand to concrete shear capacity ratio is considered the most critical section cut for the region. The shear demand and concrete capacity at this cut are used for the design of the entire region.

The required longitudinal and transverse reinforcement area to satisfy the portion of shear demand that exceeds the concrete shear capacity is calculated for the gross area of the section. The total required shear reinforcement areas will be divided by a factor of two to account for each face, and will be added to the flexural reinforcement. The design for shear in east-west direction is done considering the five east-west regions. The out-of-pane shear, in-plane shear, and friction design for an east-west region is done considering the north-south flexural and in-plane shear reinforcement information, and the maximum reinforcement obtained is assigned to the entire east-west region.

The final arrangement of the wall reinforcement is performed by combining the flexure and shear reinforcement and selecting one bar size and spacing. ESWS Slab63 reinforcement is shown in Table 3E.3.3-2—Reinforcement Detail for ESWB Slab63.

3E.3.3.4 Critical Section Design

The structural design provides reinforcement to resist element forces and moments for the ESWB Slab63.

The governing design data for ESWS Slab63 are shown in Table 3E.3.3-1.

The minimum required area of steel reinforcement for ESWS Slab63 is shown in Table 3E.3.3-2. Table 3E.3.3-2 also shows the area of steel reinforcement in the design based on the reinforcement configuration shown on Figure 3E.3.3-7—ESWB Slab 63 Reinforcement. Use of reinforcement configurations, including bar size, spacing, and clear cover, different from those shown on Figure 3E.3.3-7 are acceptable, provided they meet or exceed the minimum required area of steel reinforcement shown in Table 3E.3.3-2.

Reinforcement for a circumferential beam of seven-foot width is provided around both 33-foot diameter circular openings in the ESWB Fan Deck Slab. This beam develops the regions of slab adjacent to the opening where the main orthogonal pattern of slab reinforcement is interrupted, and the bars must be hooked at the ends and terminated around the perimeter of the opening. The circumferential beam provides supplementary reinforcement to compensate for the partially-developed orthogonal bars around the opening where the hooked bars must be developed in order to carry full tension or compression loads.

The edge of the ESWB fan deck slab is loaded by a circular wall that supports the ESWB fans, generating flexural stress at the edge of the opening. For flexural reinforcement, #10s at six inches spacing (top and bottom) are provided to match the capacity provided by the orthogonal reinforcement.

Table 3E.3.3-1—Governing Design Data for ESWB Slab63
Sheet 1 of 4

Locations	LC(1)	SC(1)	Condition	Governing Design Data(3)(4) (6)						
				M_{U-XX}(2)	M_{U-YY}(2)	N_{XX}(5)	N_{YY}(5)	N_{XY}(5)	V_{XX}(5)	V_{YY}(5)
				k-ft/ft	k-ft/ft	k/ft or k	k/ft or k	k/ft or k	k/ft or k	k/ft or k
Slab 63 - 1	5059 - D + L + H + F + Fb + E'+ SET	Envelope	North-South - Bending & Axial	31	*	82	*	*	*	*
	7513 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - Bending & Axial	*	32	*	44	*	*	*
	5359 - D + L + H + F + Fb + E' + SET	Envelope	North-South - Bending & Axial	114	*	18	*	*	*	*
	5313 - D + L + H + F + Fb + E'	Envelope	East-West - Bending & Axial	*	91	*	18	*	*	*
	1107 - 1.4(D + F + Fb) + 1.7(L + H) + SET	Envelope	North-South - Bending & Axial	-43	*	1	*	*	*	*
	6251 - 0.9(D + H + F + Fb)+ L + E' + SET	Envelope	East-West - Bending & Axial	*	52	*	0	*	*	*
	7214 - 0.9(D + H + F + Fb)+ E'	Envelope	North-South - Bending & Axial	-83	*	-82	*	*	*	*
	5060 - D + L + H + F + Fb + E' + SET	Envelope	East-West - Bending & Axial	*	-24	*	-67	*	*	*
	5364 - D + L + H + F + Fb + E' + SET	Envelope	North-South - Bending & Axial	-90	*	-81	*	*	*	*
	5006 - D + L + H + F + Fb + E'	Envelope	East-West - Bending & Axial	*	-58	*	-32	*	*	*
	1007 - 1.4(D + F + Fb) + 1.7(L + H)	Envelope	North-South - Bending & Axial	-43	*	0	*	*	*	*

Table 3E.3.3-1—Governing Design Data for ESWB Slab63
Sheet 2 of 4

Locations	LC(1)	SC(1)	Condition	Governing Design Data(3)(4) (6)						
				M_{U-XX}(2)	M_{U-YY}(2)	N_{XX}(5)	N_{YY}(5)	N_{XY}(5)	V_{XX}(5)	V_{YY}(5)
				k-ft/ft	k-ft/ft	k/ft or k	k/ft or k	k/ft or k	k/ft or k	k/ft or k
	5251 - D + L + H + F + Fb + E'	Envelope	East-West - Bending & Axial	*	53	*	-1	*	*	*
	7201 - 0.9(D + H + F + Fb)+ E'	Envelope	North-South - In-plane Shear	*	*	*	2642	7250	*	*
	7513 - 0.9(D + H + F + Fb)+ E'	Envelope	North-South - Out-of-plane Shear	*	*	*	3563	*	*	806
	7005 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - In-plane Shear	*	*	402	*	3086	*	*
	7001 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - Out-of-plane Shear	*	*	417	*	*	417	*
	6009 - 0.9(D + H + F + Fb)+ L + E'	Envelope	East-West - In-plane Shear	*	*	4244	*	3573	*	*
	5063 - D + L + H + F + Fb + E' + SET	Envelope	East-West - Out-of-plane Shear	*	*	4275	*	*	415	*
	6201 - 0.9(D + H + F + Fb)+ L + E'	Envelope	East-West - In-plane Shear	*	*	464	*	2844	*	*
	6001 - 0.9(D + H + F + Fb)+ L + E'	Envelope	East-West - Out-of-plane Shear	*	*	464	*	*	423	*
	7009 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - In-plane Shear	*	*	1171	*	4229	*	*
	7005 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - Out-of-plane Shear	*	*	1166	*	*	432	*

Table 3E.3.3-1—Governing Design Data for ESWB Slab63
Sheet 3 of 4

Locations	LC(1)	SC(1)	Condition	Governing Design Data(3)(4) (6)						
				M_{U-XX}(2)	M_{U-YY}(2)	N_{XX}(5)	N_{YY}(5)	N_{XY}(5)	V_{XX}(5)	V_{YY}(5)
				k-ft/ft	k-ft/ft	k/ft or k	k/ft or k	k/ft or k	k/ft or k	k/ft or k
Slab 63 - 2	5059 - D + L + H + F + Fb + E’+ SET	Envelope	North-South - Bending & Axial	42	*	104	*	*	*	*
	6009 - 0.9(D + H + F + Fb)+ L + E’	Envelope	East-West - Bending & Axial	*	42	*	82	*	*	*
	7201 - 0.9(D + H + F + Fb)+ E’	Envelope	North-South - Bending & Axial	61	*	74	*	*	*	*
	5309 - D + L + H + F + Fb + E’	Envelope	East-West - Bending & Axial	*	161	*	12	*	*	*
	1007 - 1.4(D + F + Fb) + 1.7(L + H)	Envelope	North-South - Bending & Axial	-49	*	1	*	*	*	*
	5361 - D + L + H + F + Fb + E’ + SET	Envelope	East-West - Bending & Axial	*	-94	*	1	*	*	*
	7214 - 0.9(D + H + F + Fb)+ E’	Envelope	North-South - Bending & Axial	-96	*	-101	*	*	*	*
	5264 - D + L + H + F + Fb + E’ + SET	Envelope	East-West - Bending & Axial	*	-105	*	-99	*	*	*
	5002 - D + L + H + F + Fb + E’	Envelope	North-South - Bending & Axial	-106	*	-96	*	*	*	*
	5010 - D + L + H + F + Fb + E’	Envelope	East-West - Bending & Axial	*	-105	*	-89	*	*	*
	3563 - 1.4(D + F + Fb) + 1.7(L + H) + 1.0(Wt)+0.5(Wp) + Settl	Envelope	North-South - Bending & Axial	-44	*	-1	*	*	*	*

Table 3E.3.3-1—Governing Design Data for ESWB Slab63
Sheet 4 of 4

Locations	LC(1)	SC(1)	Condition	Governing Design Data(3)(4) (6)						
				M_{U-XX}(2)	M_{U-YY}(2)	N_{XX}(5)	N_{YY}(5)	N_{XY}(5)	V_{XX}(5)	V_{YY}(5)
				k-ft/ft	k-ft/ft	k/ft or k	k/ft or k	k/ft or k	k/ft or k	k/ft or k
	6077 - 0.9(D + H + F + Fb)+ L + E' + SET	Envelope	East-West - Bending & Axial	*	-91	*	-1	*	*	*
	6009 - 0.9(D + H + F + Fb)+ L + E'	Envelope	North-South - In-plane Shear	*	*	*	891	1241	*	*
	5513 - D + L + H + F + Fb + E'	Envelope	North-South - Out-of-plane Shear	*	*	*	710	*	*	286
	7005 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - In-plane Shear	*	*	402	*	3086	*	*
	7001 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - Out-of-plane Shear	*	*	417	*	*	417	*
	6009 - 0.9(D + H + F + Fb)+ L + E'	Envelope	East-West - In-plane Shear	*	*	4244	*	3573	*	*
	5063 - D + L + H + F + Fb + E' + SET	Envelope	East-West - Out-of-plane Shear	*	*	4275	*	*	415	*
	6201 - 0.9(D + H + F + Fb)+ L + E'	Envelope	East-West - In-plane Shear	*	*	464	*	2844	*	*
	6001 - 0.9(D + H + F + Fb)+ L + E'	Envelope	East-West - Out-of-plane Shear	*	*	464	*	*	423	*
	7009 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - In-plane Shear	*	*	1171	*	4229	*	*
	7005 - 0.9(D + H + F + Fb)+ E'	Envelope	East-West - Out-of-plane Shear	*	*	1166	*	*	432	*

Notes:

1. LC is the governing load combination, SC is the governing soil analysis case.
2. M_x is conservatively absolute summed with M_{xy} to obtain M_{u-xx}. The same is done for M_{xy} to obtain M_{u-yy}.
3. (–) indicates compression, (+) indicates tension.
4. GTSTRUDL forces and moments.
5. Units are k/ft in flexural design and k for shear design.
6. (*) indicates that reinforcing is not applicable.

Table 3E.3.3-2—Reinforcement Detail for ESWB Slab63

Locations	Type	Thickness	Condition	*[Required As-req (in^2 / ft)*	Reinforcement Pattern	Provided $A_{s\text{-}pro}$ (in^2 / ft)	Reinforcement Ratio ($A_{s\text{-}pro}/A_{s\text{-}req}$)
Slab63-1	North-South	2.5 ft	Tangential Shear, Membrane, and Bending	*1.63*	#10 @ 8 in EF	1.91	1.17
	East-West		Tangential Shear, Membrane, and Bending	*1.71*	#10 @ 6 in EF	2.54	1.49
	Stirrup		Out-of-plane Shear	*0.00*	None	0.00	-
Slab63-2	North-South	2.5 ft	Tangential Shear, Membrane, and Bending	*1.80*	#10 @ 8 in EF	1.91	1.06
	East-West		Tangential Shear, Membrane, and Bending	*2.38*	#10 @ 6 in EF	2.54	1.07
	Stirrup		Out-of-plane Shear	*0.00]**	None	0.00	-

Notes:

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

Figure 3E.3.3-1—ESWB Slab 63 Flexural and North-South Shear Design Regions (FEM)

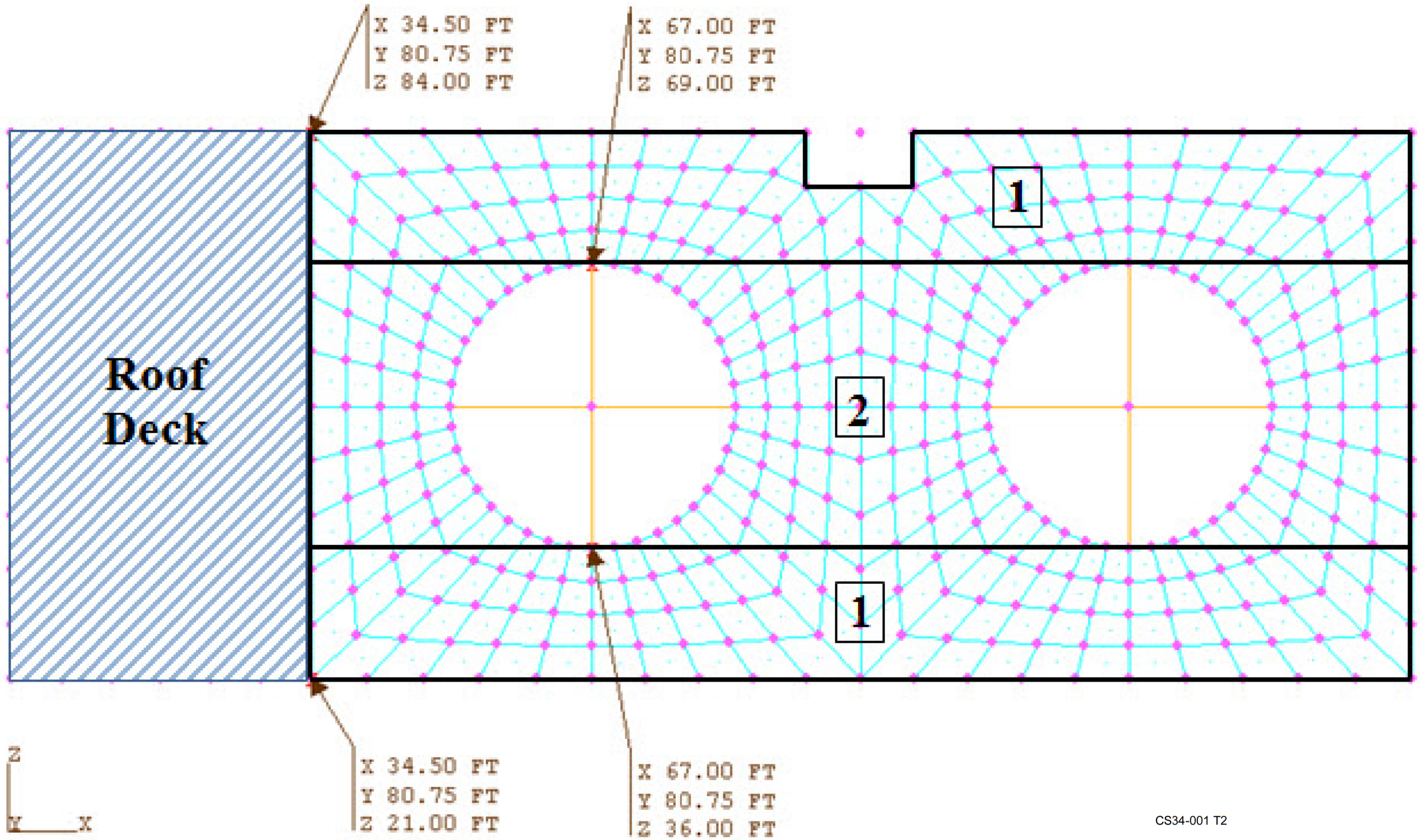

Figure 3E.3.3-2—ESWB Slab 63 East-West Shear Design Regions (FEM)

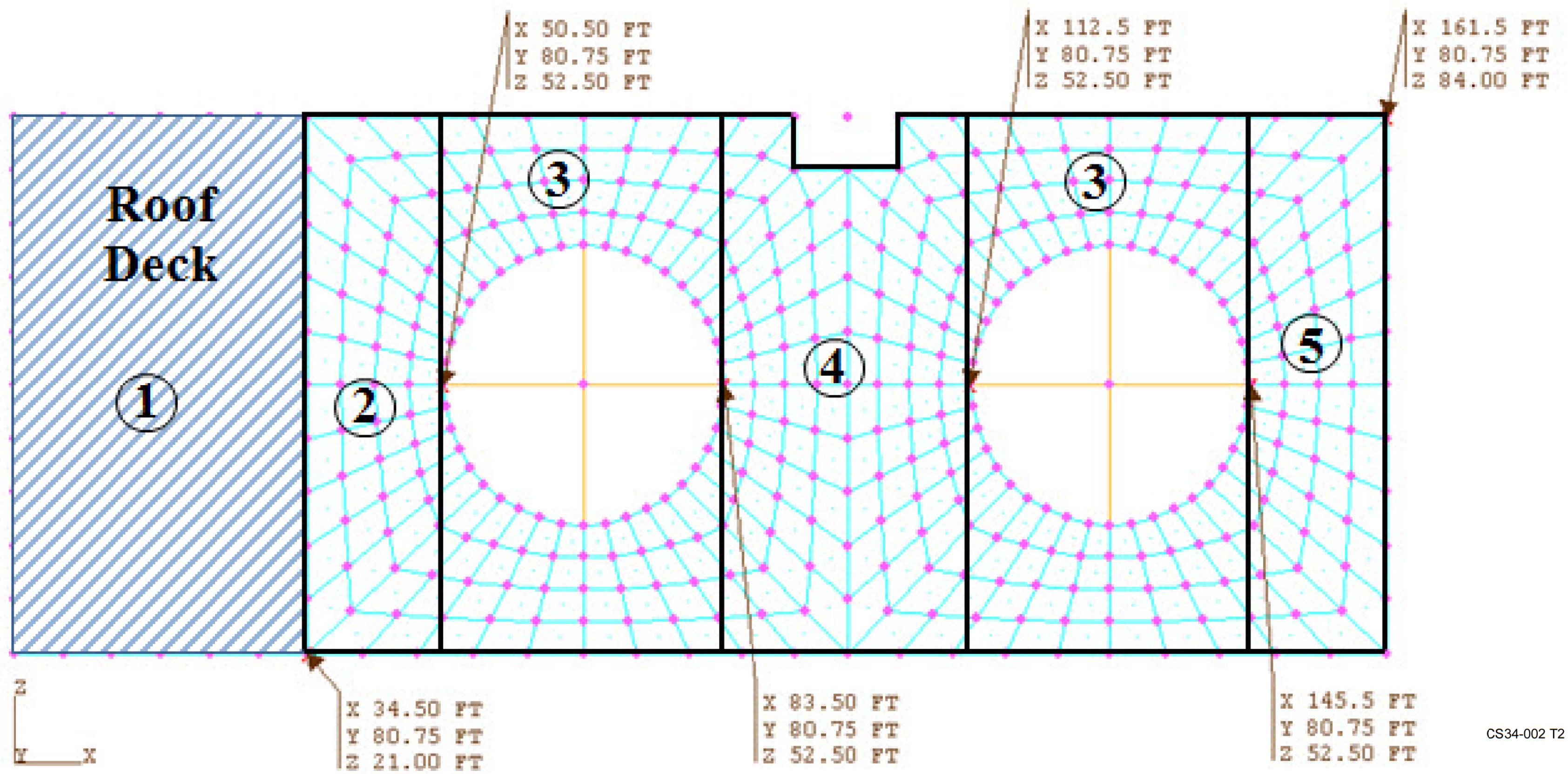

Figure 3E.3.3-3—ESWB Slab 63 Axial Force (Tension) and Bending Moment Critical Design Cuts (FEM)

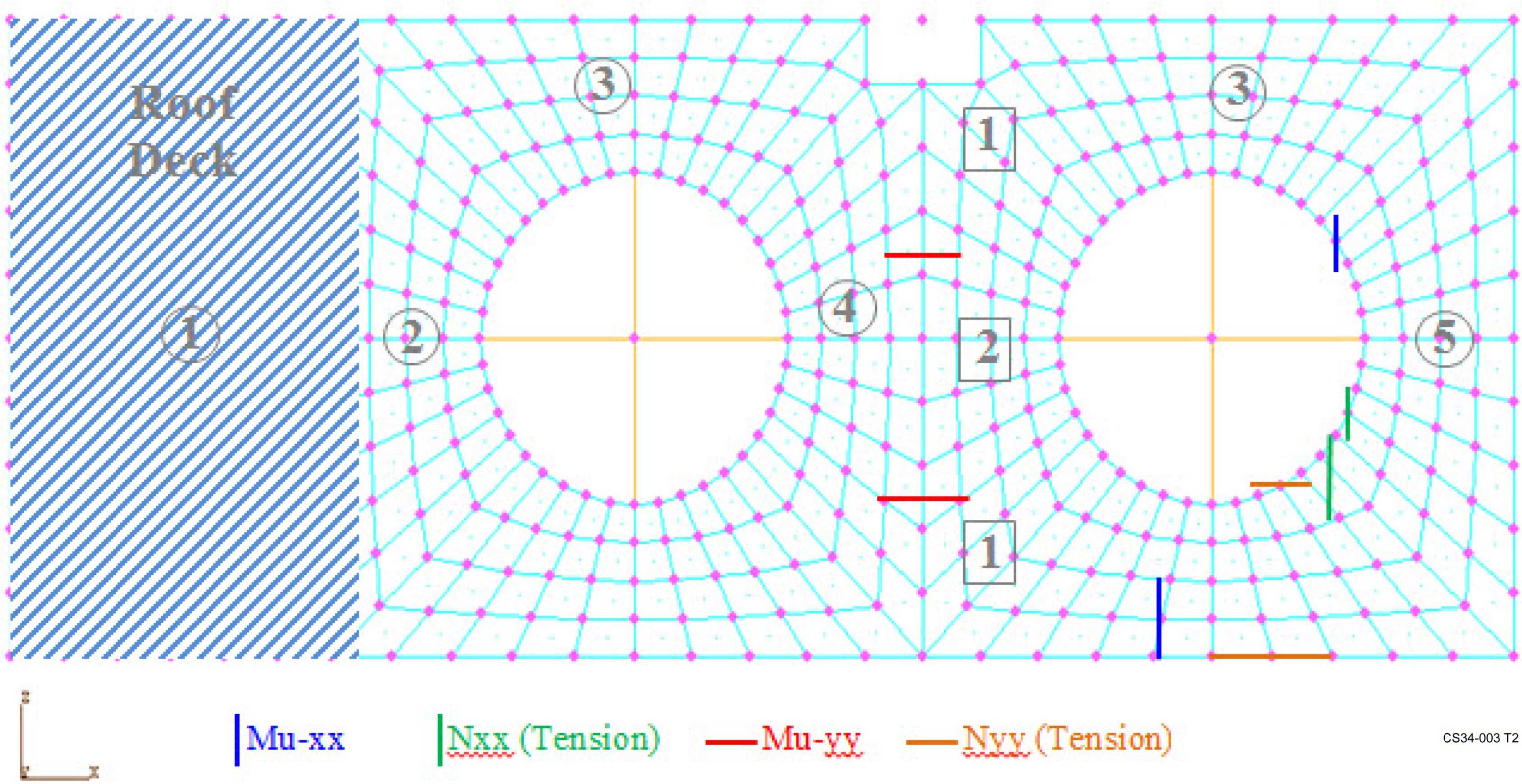

Figure 3E.3.3-4—ESWB Slab 63 In-Plane and Out-of-Plane Shear Critical Design Cuts (FEM)

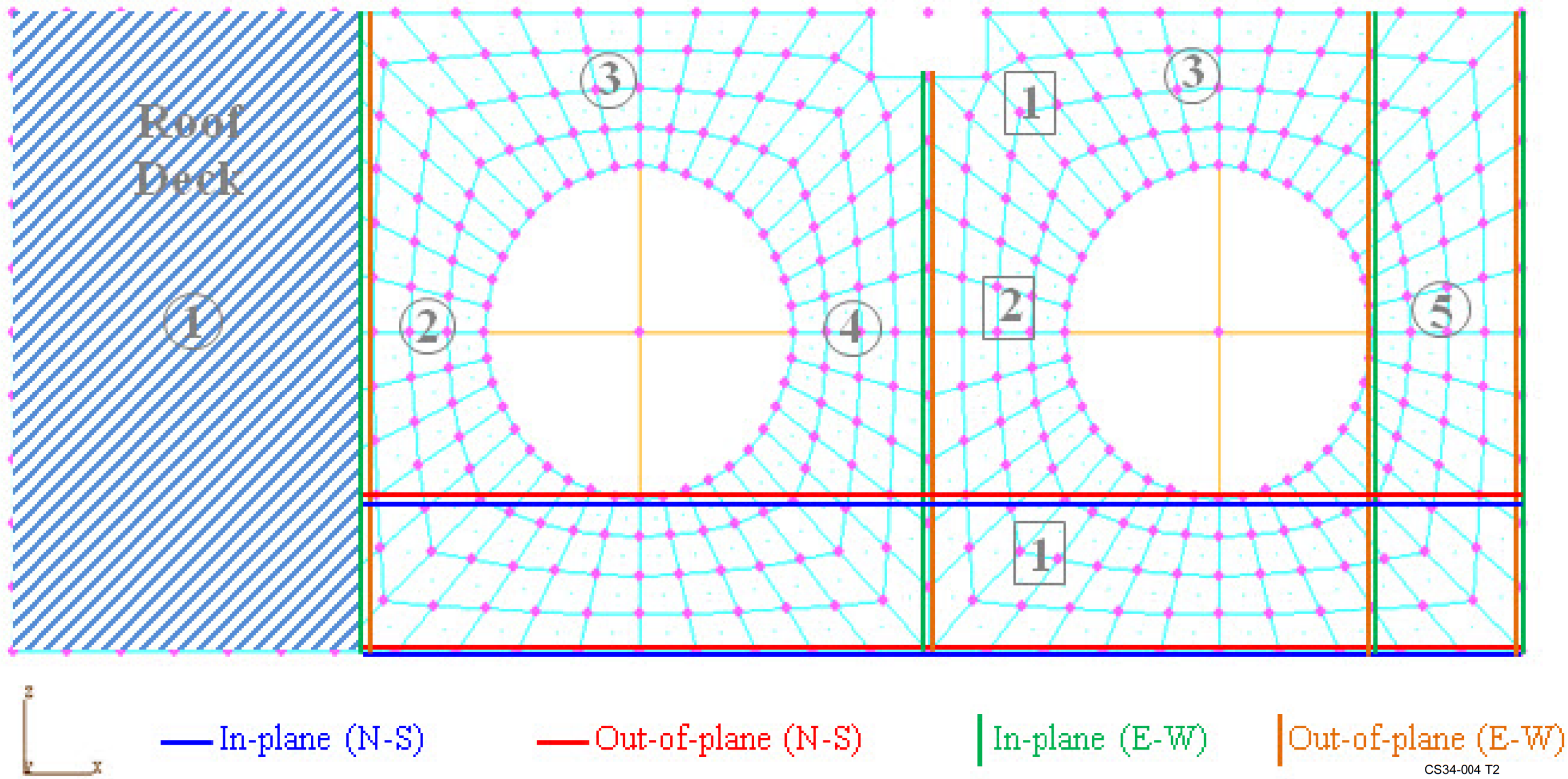

Figure 3E.3.3-5—GTSTRUDL Finite Element Planar Reference Frame Systems (Plate Bending)

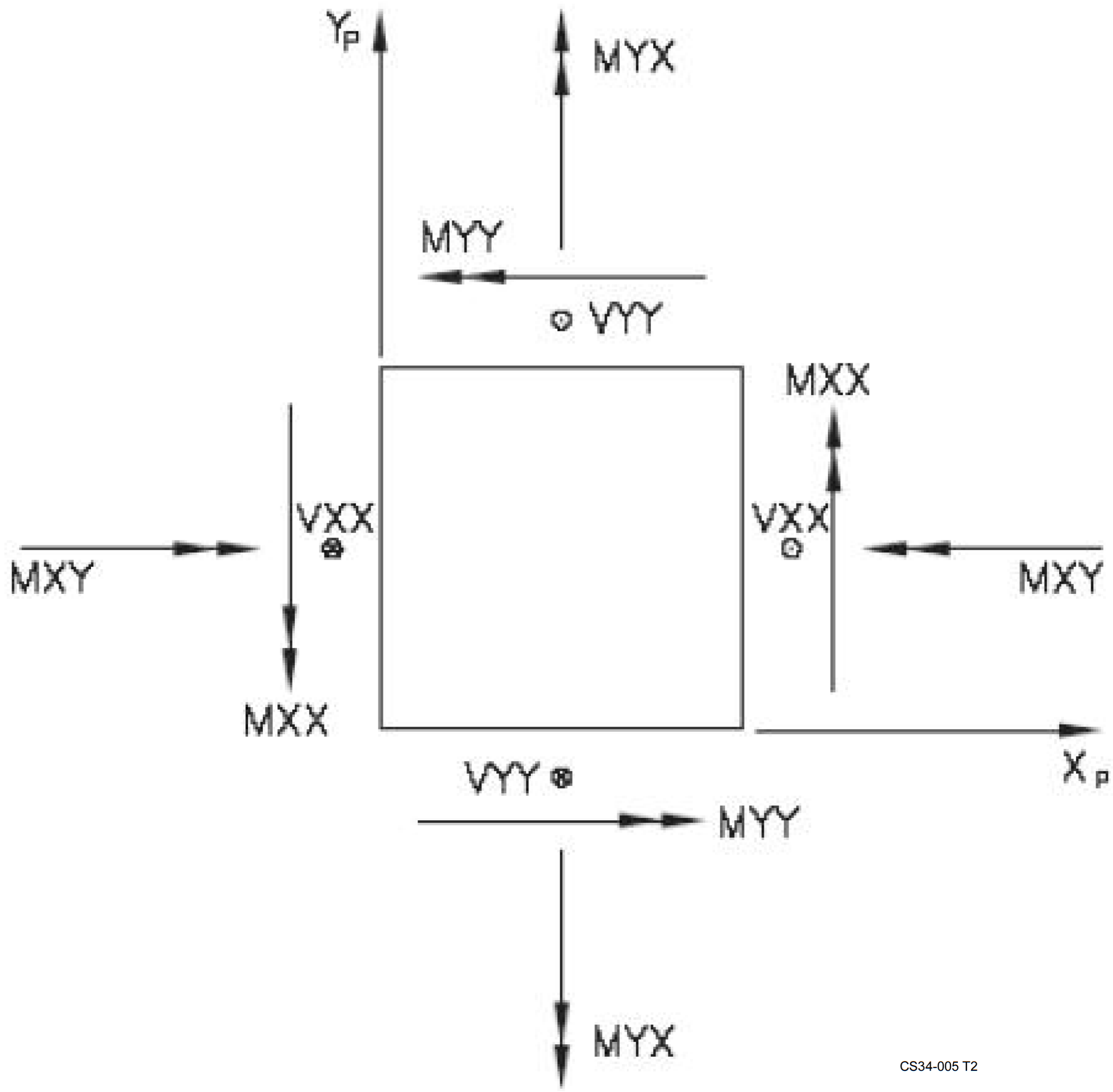

Figure 3E.3.3-6—GTSTRUDL Finite Element Planar Reference Frame Systems (Plane Stress/Strain)

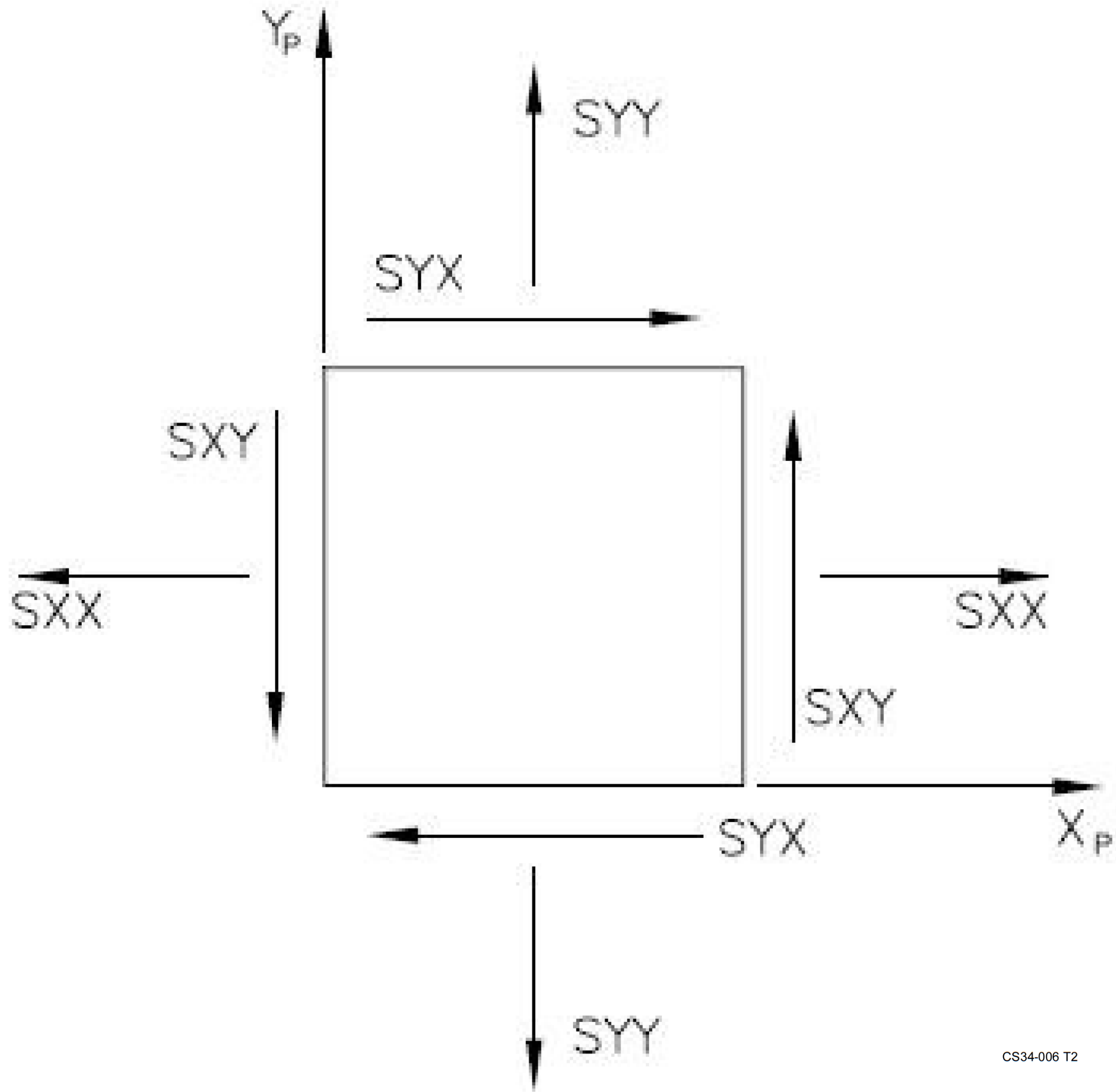

Figure 3E.3.3-7—ESWB Slab 63 Reinforcement

Next File