RESPONSE TO REQUEST FOR ADDITIO NAL INFORMATION

10/11/2013

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 958-6608 REVISION 1**
SRP SECTION:	**03.08.03 – Concrete and Steel Internal Structures of Steel or Concrete Containments**
APPLICATION SECTION:	**3.8.3**
DATE OF RAI ISSUE:	**09/05/2012**

QUESTION NO. 03.08.03-94:

The staff evaluated the applicant’s response to RAI 858-6126, Question 03.08.03-48, dated February 28, 2012, regarding the Category 5 structures (the massive reinforced concrete sections) and the Category 6 structures (steel structures with nonstructural concrete fill). The RAI response provided descriptive information requested in the RAI. However, some of the items requested in the RAI were not addressed. Therefore, provide information to address the items listed below.

(1) For the Category 6 structures, information was not provided regarding how these structures were modeled in the seismic SSI analysis. Therefore, explain how these structures were modeled in the seismic SSI analysis.

(3) The staff also notes that the RAI response indicated that the information provided does not have any impact on the DCD nor the technical report. Since this response provided important analysis and design information, revise the technical report to incorporate, and revise the DCD to summarize, the important information provided in the RAI response which has not yet been included.

ANSWER:

There are three Category 6 structures modeled in the Containment Internal Structure (CIS) model as described in Technical Report MUAP-10006, Revision 3. They are: 1) the Pressurizer Support Slab, 2) the connection between the Upper Steam Generator (SG) Compartment and Refueling Cavity and 3) the Reactor Cavity water seal. These three structures are addressed below.

The Pressurizer Support Slab

Question (1):

The pressurizer support slab is modeled as uncracked concrete using shell elements composite with steel beam elements for both CIS stiffness conditions A and B.

Question (2):

The Pressurizer Support Slab is being designed as a steel grillage with structural in-fill that will be composite with a revised steel frame.

The connection between the Upper Steam Generator (SG) Compartment and Refueling Cavity

Question (1):

The Upper SG Compartment to Refueling Cavity connection was modeled as uncracked concrete with no steel plate contribution for Loading Conditions A and B. SOLID45 and SHELL63 elements were used to model the concrete slabs for the interior and exterior portions respectively. The elements are shown in orange in Figure 1 below.

Figure 1 - Upper SG Compartment to Refueling Cavity Connection SSI FEM

Question (2):

This structure is being designed as a steel plate structure composite with concrete in-fill.

The Reactor Cavity water seal

Question (1):

The reactor cavity water seal is not in the primary load path. It is modeled as uncracked concrete.

Question (2):

The design of the reactor cavity water has yet to be completed.

Additional Detailed Response to Question (2):

A parametric study was performed to assess the impact that extended Containment Internal Structure (CIS) Structural Stiffness values would have on the dynamic responses of the CIS. Details of this parametric study are provided in Attachment A of the response to RAI 977-6899 Question 03.08.03-97.

Section 2.2 of this Attachment A identifies the changes to Category 6 stiffness values for the extended upper bound stiffness conditions.

The Reactor Cavity water seal was unaltered since it provides no structural support to the CIS.

The Pressurizer Support Slab lower bound stiffness was revised from uncracked concrete composite with steel framing to cracked concrete, i.e., 50 percent concrete stiffness, composite with the revised steel framing. This stiffness is equivalent to the uncracked concrete stiffness with the existing steel frame as described in MUAP-10006.

The upper bound stiffness values for the Upper Steam Generator Compartment to Refueling Cavity Connection were revised to equivalent stiffness values for uncracked concrete composite with the steel plate structure. The lower bound stiffness values for the Upper SG Compartment to Refueling Cavity Connections were revised to equivalent stiffness values for cracked concrete, i.e., 50 percent concrete stiffness, composite with the steel plate structure. This lower bound stiffness is equivalent to the uncracked concrete stiffness as described in MUAP-10006.

Stiffness values for other Categories of the CIS structure were also extended as described in Section 2.2.

Section 3.1.5 summarizes the changes made to Category 6 steel concrete walls for the extended upper and lower bound stiffness FE models. Refinements were made to the Bottom Pressurizer Support and Upper SG Compartment to Refueling Cavity Connection so the extended lower bound stiffness of these structures is equivalent or stiffer than their stiffness for Loading Condition B in Technical Report MUAP-10006.

The Pressurizer Support Slab steel frame layout was revised and the steel member sizes were increased. Studs were also added to force composite behavior between the steel and concrete. The SHELL63 concrete elements were removed from the Study FE Models due to the inability of SHELL63 to provide shear deformation. Instead, equivalent steel and concrete composite properties were applied to the steel framing for both cracked and uncracked concrete.

The Upper SG Compartment to Refueling Cavity Connection steel plate sizes were increased and studs added to force composite behavior between the steel and concrete. Equivalent material properties were applied to the Category 6 elements for both uncracked and cracked concrete composite with steel plates. Two Upper Bound Study Models were developed to capture the range of equivalent isotropic stiffness values for the Steam Generator (SG) Compartment to Refueling Cavity connection since its stiffness properties are orthotropic. This was necessary because SASSI cannot accept orthotropic material properties. They are referred to as Upper Bound Low and Upper Bound High Study Models respectively.

Target FE models were created with properties from Loading Conditions A and B in Technical Report MUAP-10006, Rev. 3.

The study and target models were executed in SASSI using surface model analyses rather than embedded model analysis as presented in Technical Report MUAP-10006 Rev. 3. This was done in order to improve the efficiency of the analysis process, and is acceptable since the parametric study focused only on the stiffness differences in the CIS. Complete details are provided in Attachment A of the response to RAI 977-6899, Q03.08.03-97.

Section 4.0 provides the results from comparisons of In-Structure Response Spectra (ISRS), base reactions, and displacements. The results from the ISRS comparison show that when the range of upper and lower bound stiffness values is extended beyond those presented in Technical Report MUAP-10006 Rev. 3, the majority of the responses lie within the broadened target ISRS. There are small exceedances and frequency shifts in the Acceleration Response Spectra (ARS) responses; however, these are not expected to result in changes to the design of the structure or equipment. Further, the changes in base reactions are small and will not affect the structural design of the CIS.

The designs of Category 6 structures that are part of the primary load resisting system were refined so their lower bound stiffness values match the corresponding stiffness values in Technical Report MUAP-10006 Rev. 3. Therefore, the Category 6 stiffness values in Technical Report MUAP-10006 Rev. 3 are acceptable.

Impact on DCD

DCD Revision 4 is revised as shown in Attachment 1.

Impact on R-COLA

There is no impact on the R-COLA.

Impact on PRA

There is no impact on the PRA.

Impact on Technical/Topical Report

Technical Reports MUAP-10006, Rev. 3, and MUAP-11018, Rev. 1, are revised as shown in Attachment 2 and 3, respectively.

This completes MHI’s response to the NRC’s question.

reinforced concrete at the base of the structure as a result of either seismic or accident thermal loading. Thus, the stiffness is taken to be equal to that of uncracked concrete for both the A and B loading conditions.

Category 6 (both conditions): ~~The stiffness of in-fill concrete provided for shielding purposes is not modeled for the A and B loading conditions; only the mass of these sections is included. For the pressurizer support platform, which is comprised of a grillage of steel shapes with in-fill concrete, only the stiffness of the steel members is modeled.~~ This category includes structural elements that are part of the primary load resisting system, as well as other miscellaneous elements. The stiffness of the primary load resisting elements considers the stiffness of the steel elements and the composite action of infill concrete provided for shielding purposes. The miscellaneous elements that are not part of the primary load resisting elements are modeled considering concrete mass only with no stiffness. The stiffness of these elements is modeled as follows: RAI 03.08.03-94

- Lower Pressurizer Support: Full composite steel + cracked concrete
- Refueling Cavity to SG Compartment: Full composite steel + cracked concrete
- Other Category 6 Elements: Mass only, no stiffness

Damping values are assigned to each structural category based on the estimated level of Cracking (See Table 3.8.3-4). A damping value of 4% is assigned to composite SC walls with uncracked conditions (Condition A), and 5% when significant cracking is anticipated (Condition B). This is based on the results of the 1/10th scale test discussed in Technical Report MUAP-10002 (Reference 3.8-80). For walls and slabs modeled as reinforced concrete structures, 4% damping is specified in RG 1.61 (Reference 3.8-64) for the limited levels of cracking associated with the OBE, while 7% damping is specified for cracked response exhibited during SSE loading. The massive concrete in the containment internal structures (Category 5) is not expected to exhibit significant cracking, such that 4% damping is considered appropriate in all cases. It is noted that the structural steel members within the CIS are very limited in scope relative to the mass and stiffness of the SC and RC members in the CIS. ~~Recognizing that the amplified seismic response of the containment internal structure is dominated by the response of the SC walls, constant damping ratios of 4% for Condition A and 5% for Condition B are conservatively used for the seismic response analyses (See Table 3.8.3-4).~~ RAI 03.08.03-94 RAI 03.08.03-94

3.8.3.4.1 SC Module Stress Analyses

As discussed in Technical Report MUAP-11013 Section 3.2 (Reference 3.8-68), the design forces and moments for each member of the containment internal structure are calculated using two detailed 3-D FE models with stiffness and damping corresponding to loading Conditions A and B. Table 3.8.3-3 summarizes the analysis methods and objectives for the FE analyses performed for structural design. The geometry and element mesh of the detailed FE models are shown in Figure 3.8.3-10. Table 3.8.3-3 summarizes the objectives, analysis methods, and boundary conditions for the FE analyses performed with the detailed 3-D models.

As shown in Figure 3.8.3-10, the Category 1 and 2 SC modules are simulated within the detailed FE model using ~~three-dimensional~~3-D shell elements. The Category 3 (primary shield) SC modules are modeled using ~~three-dimensional~~3-D solid elements. Equivalent elastic stiffness constants are computed for each of the SC walls, as well as the RC slabs, RAI 03.08.03-94

Table 3.8.3-4 Summary of CIS Stiffness and Damping Values for Seismic Analysis

Structural Category	Description	Loading Condition A (*Ess + To*)			Loading Condition B (*Ess + Ta*)		
		Shear Stiffness	**Flexural Stiffness**	**Damping**	**Shear Stiffness**	**Flexural Stiffness**	**Damping**
1	SC Walls, T ≤ 56"	Uncracked $G_cA_c + G_sA_s$	Cracked-Transformed E_cI_{ct}	4%	Fully Cracked $0.5\left(\bar{\rho}^{-0.42}\right)G_sA_s$	Cracked-Transformed E_cI_{ct}	5%
2	SC Walls with T > 56"	Uncracked G_cA_c	Uncracked E_cI_c	4%	Cracked $0.5G_cA_c$	Cracked $0.5E_cI_c$	7%
3	Primary Shielding	Uncracked G_cA_c	Uncracked E_cI_c	4%	Uncracked G_cA_c	Uncracked E_cI_c	4%
4	Reinforced Concrete Slabs	Uncracked G_cA_c	Uncracked E_cI_c	4%	Uncracked G_cA_c	Cracked $0.5E_cI_c$	7%
5	Massive Reinforced Concrete Sections	Uncracked G_cA_c	Uncracked E_cI_c	4%	Uncracked G_cA_c	Uncracked E_cI_c	4%
6	Steel structure with ~~non-structural~~ concrete infill	~~No Concrete Stiffness or Damping Applied~~					
	Lower Pressurizer Support	$0.5G_cA_c + G_sA_s$	$0.5E_cI_c + E_sI_s$	4%	$0.5G_cA_c + G_sA_s$	$0.5 E_cI_c + E_sI_s$	4%
	Refueling Cavity to SG Compartment	$0.5G_cA_c + G_sA_s$	$0.5E_cI_c + E_sI_s$	4%	$0.5G_cA_c + G_sA_s$	$0.5 E_cI_c + E_sI_s$	4%
	Other Category 6 Elements (Mass Only)	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Note: The damping values provided in this table are ~~those~~ considered for SSI and SSSI analysis. Constant damping values are considered for seismic design analysis as described in Subsection 3.8.3.4.1

RAI 03.08.03-94

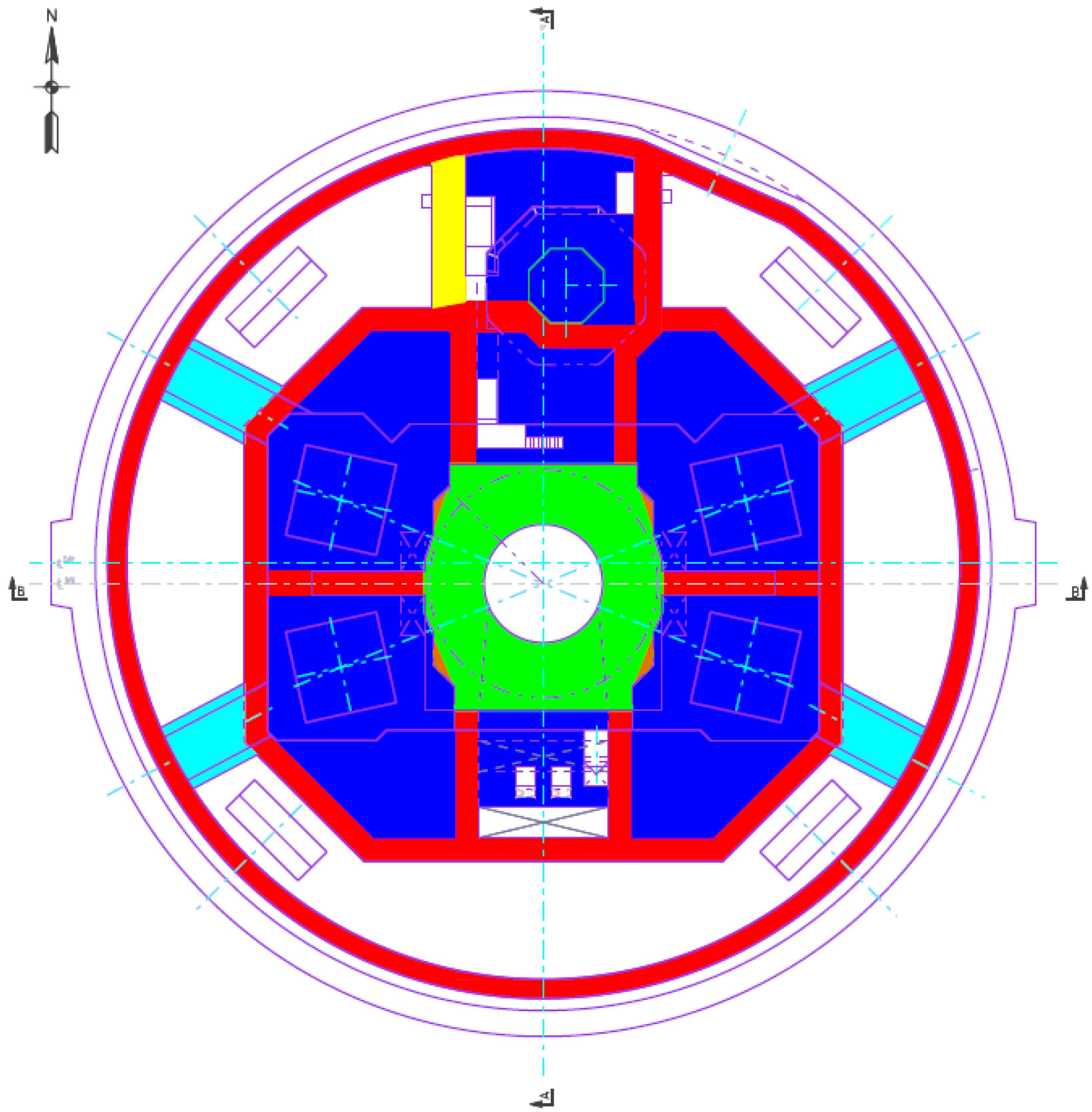
RAI 03.08.03-94

RAI 03.08.03-94

RAI 03.08.03-94

RAI 03.08.03-94

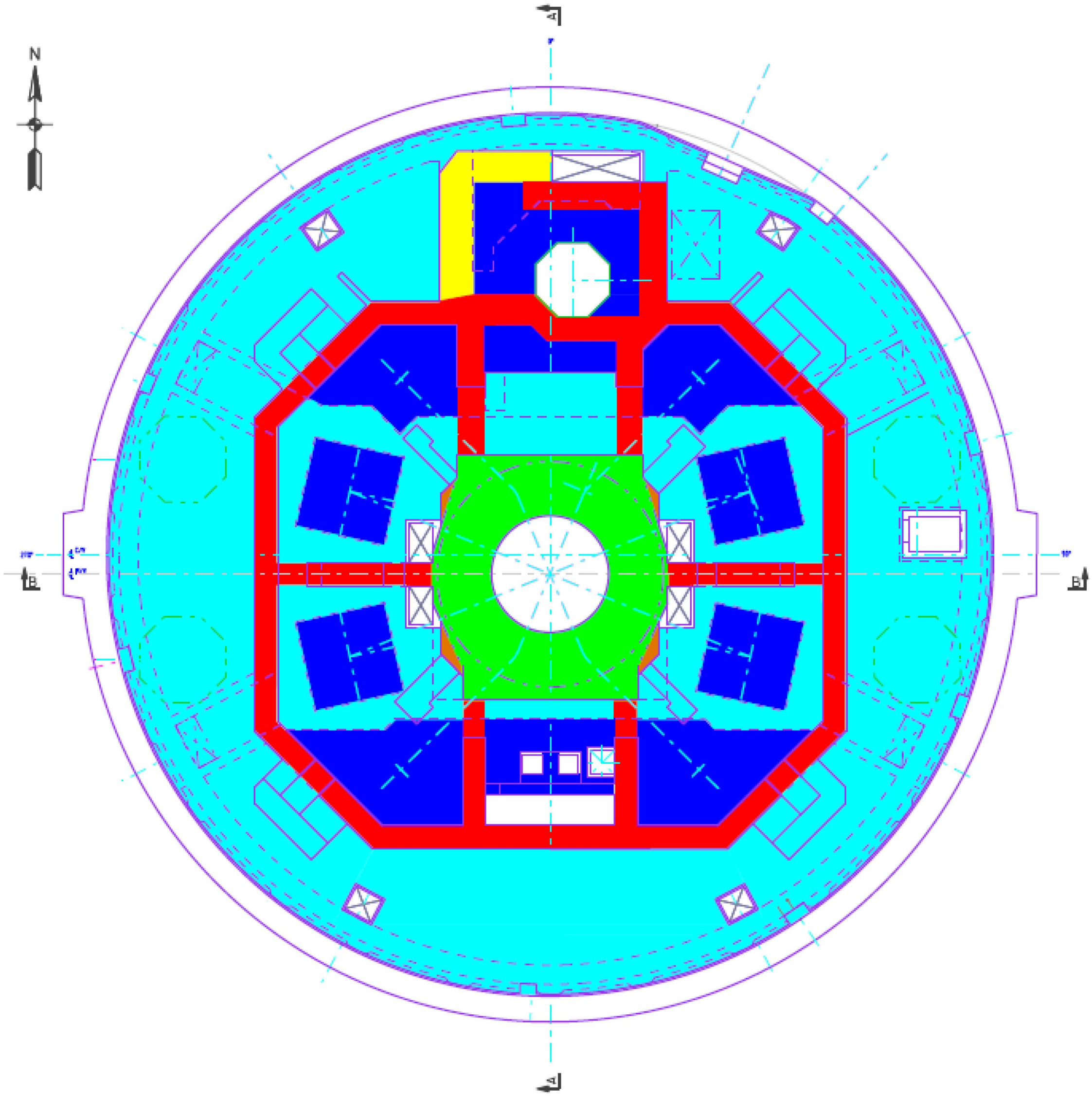
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T≤56"
	2	WALLS WITH T>56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-12 Structural Categories Between Elevations 3’-7” and 21’-0”

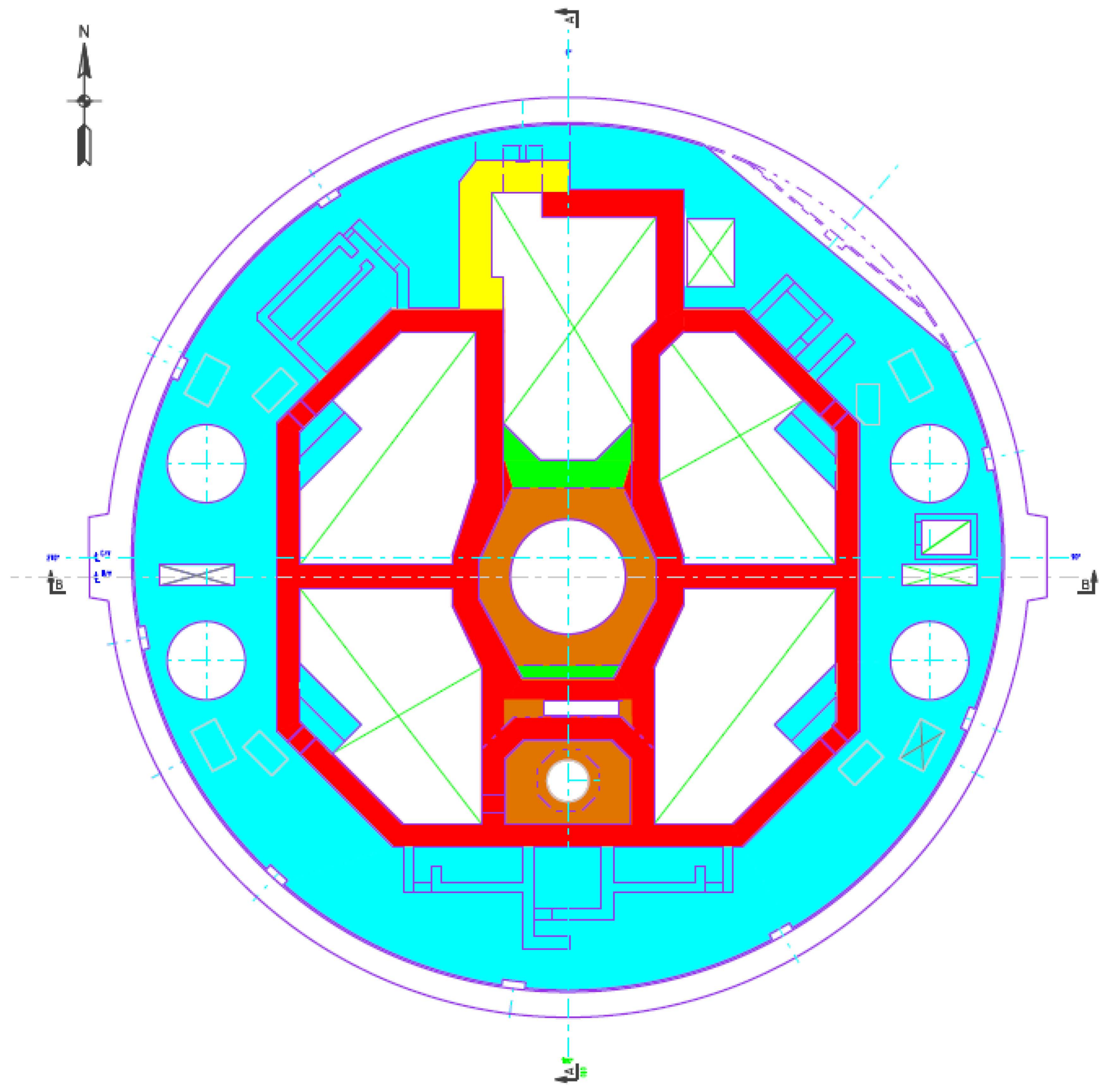
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T ≤ 56"
	2	WALLS WITH T > 56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-13 Structural Categories Between Elevations 21'-0" and 35'-11"

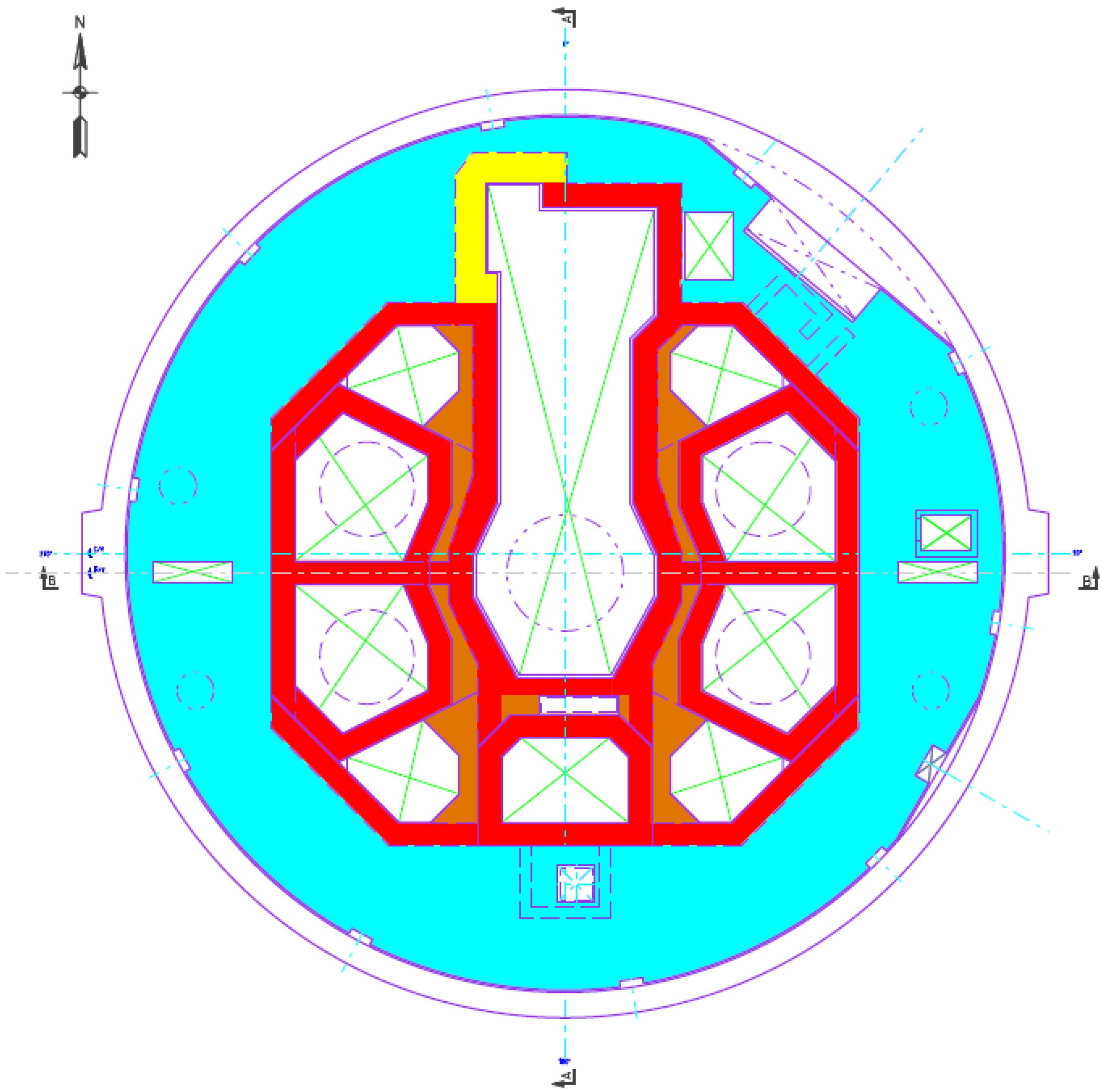
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
(red)	1	SC WALLS, T ≤ 56"
(yellow)	2	WALLS WITH T > 56"
(green)	3	PRIMARY SHIELDING WALLS
(cyan)	4	RC SLABS
(blue)	5	MASSIVE RC SECTIONS
(orange)	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-14 Structural Categories Between Elevations 37’-9” and 62’-4”

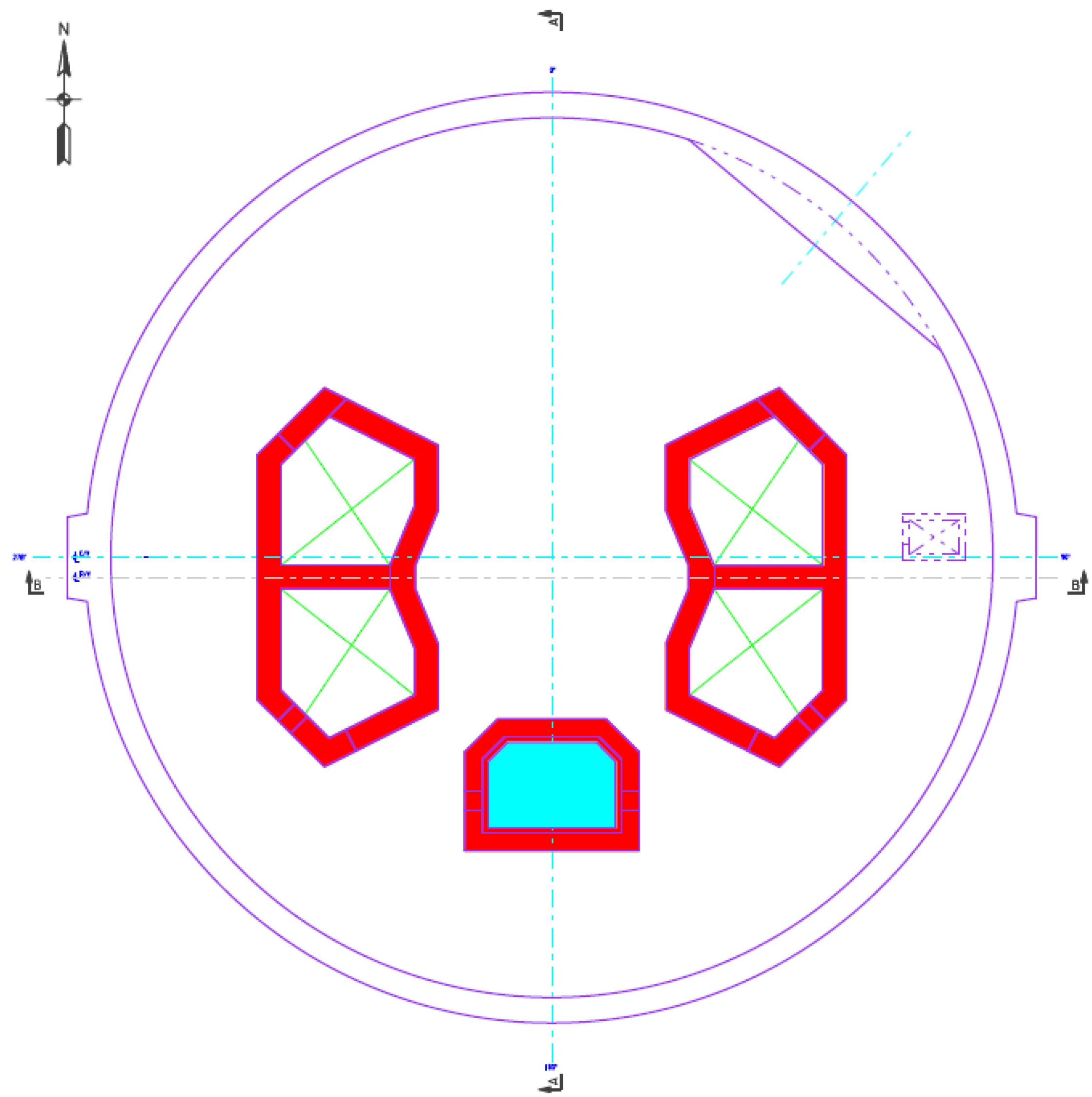
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
(red)	1	SC WALLS, T ≤ 56"
(yellow)	2	WALLS WITH T > 56"
(green)	3	PRIMARY SHIELDING WALLS
(cyan)	4	RC SLABS
(blue)	5	MASSIVE RC SECTIONS
(orange)	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-15 Structural Categories Between Elevations 62'-4" and 76'-5"

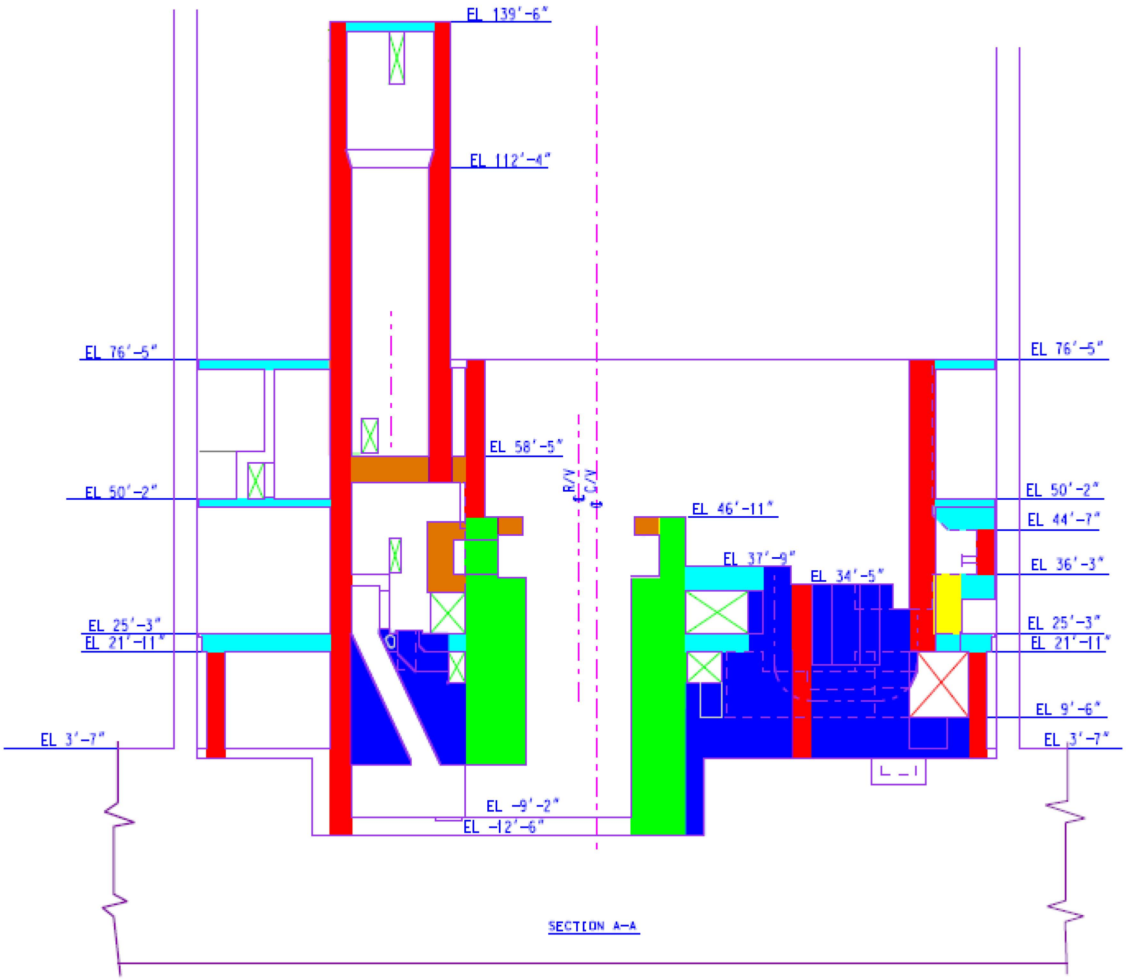
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
(red)	1	SC WALLS, T ≤ 56"
(yellow)	2	WALLS WITH T > 56"
(green)	3	PRIMARY SHIELDING WALLS
(cyan)	4	RC SLABS
(blue)	5	MASSIVE RC SECTIONS
(orange)	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-16 Structural Categories Between Elevations 76'-5" and 139'-6"

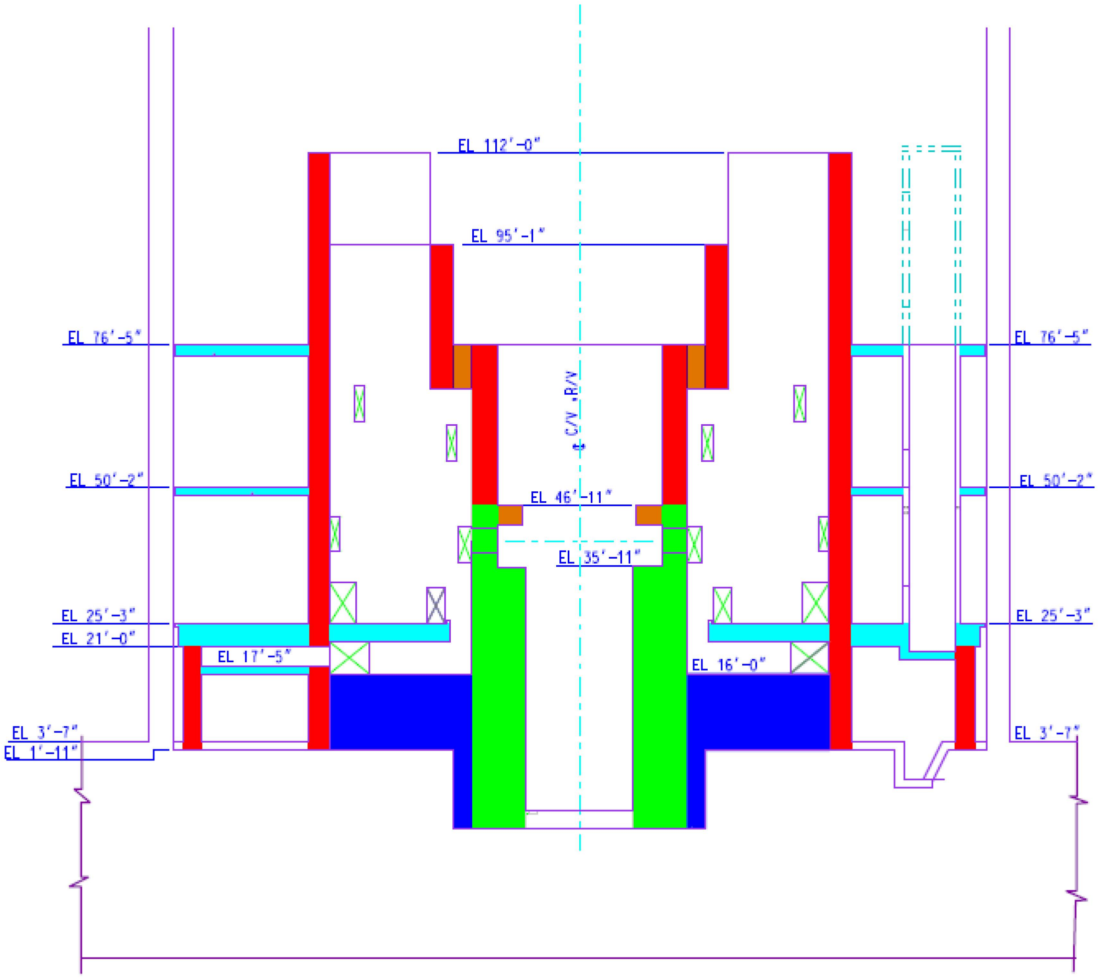
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T ≤ 56"
	2	WALLS WITH T > 56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-17 Structural Categories, Section A-A (Looking West)

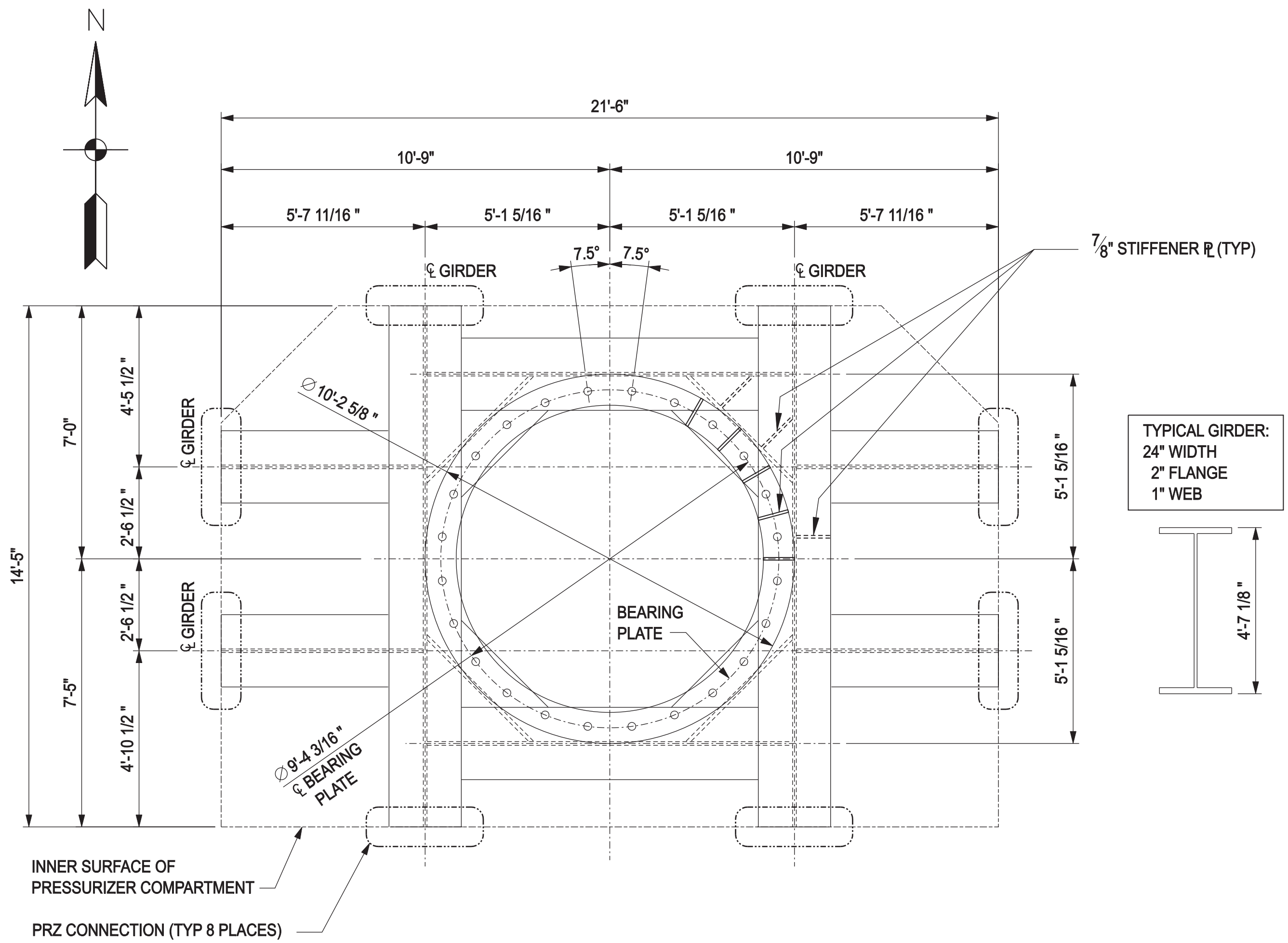
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
(red)	1	SC WALLS, T ≤ 56"
(yellow)	2	WALLS WITH T > 56"
(green)	3	PRIMARY SHIELDING WALLS
(cyan)	4	RC SLABS
(blue)	5	MASSIVE RC SECTIONS
(orange)	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 3.8.3-18 Structural Categories, Section B-B (Looking North)

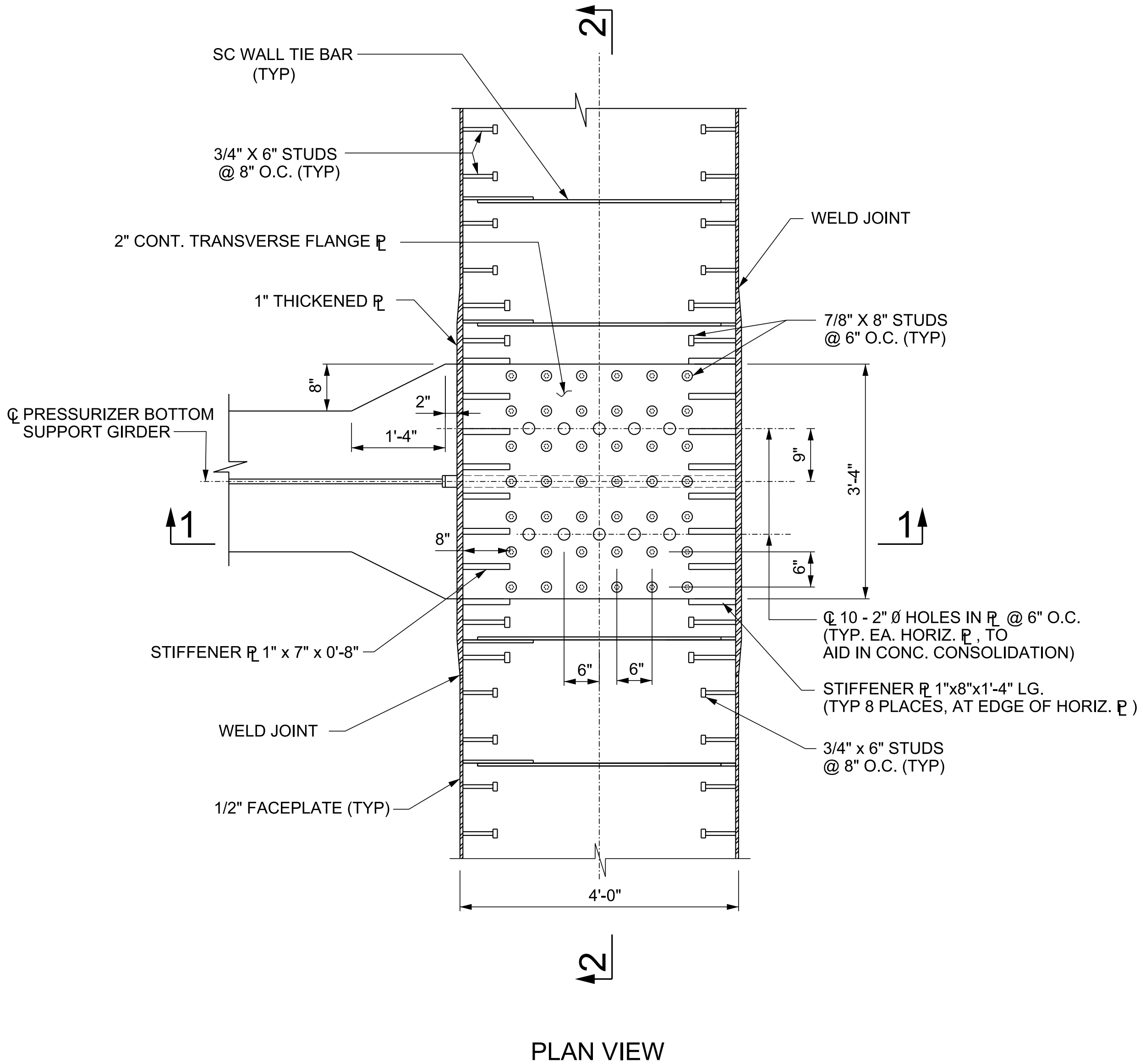
RAI 03.08.03-94



Note: Final connection configuration and beam arrangement may vary and are subject to changes necessary for equipment installation, fabrication and/or constructability.

Figure 3L-72 PZR Girder Connection to SC Wall – General Area (ID 11)

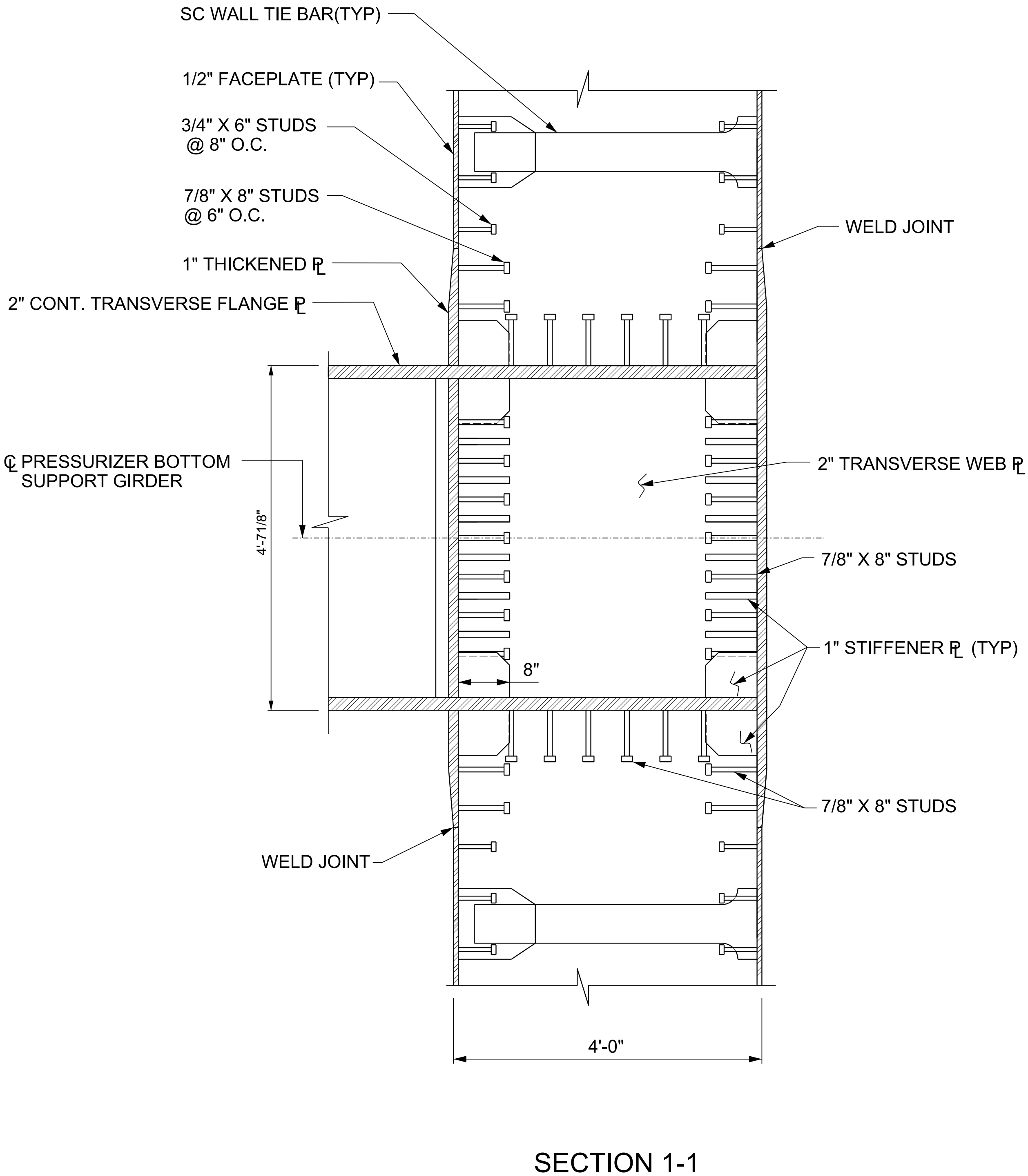
RAI 03.08.03-94



Note: Final connection configuration details may vary and are subject to changes necessary for fabrication and/or constructability.

Figure 3L-73 PZR Girder Connection to SC Wall – Plan (ID 11)

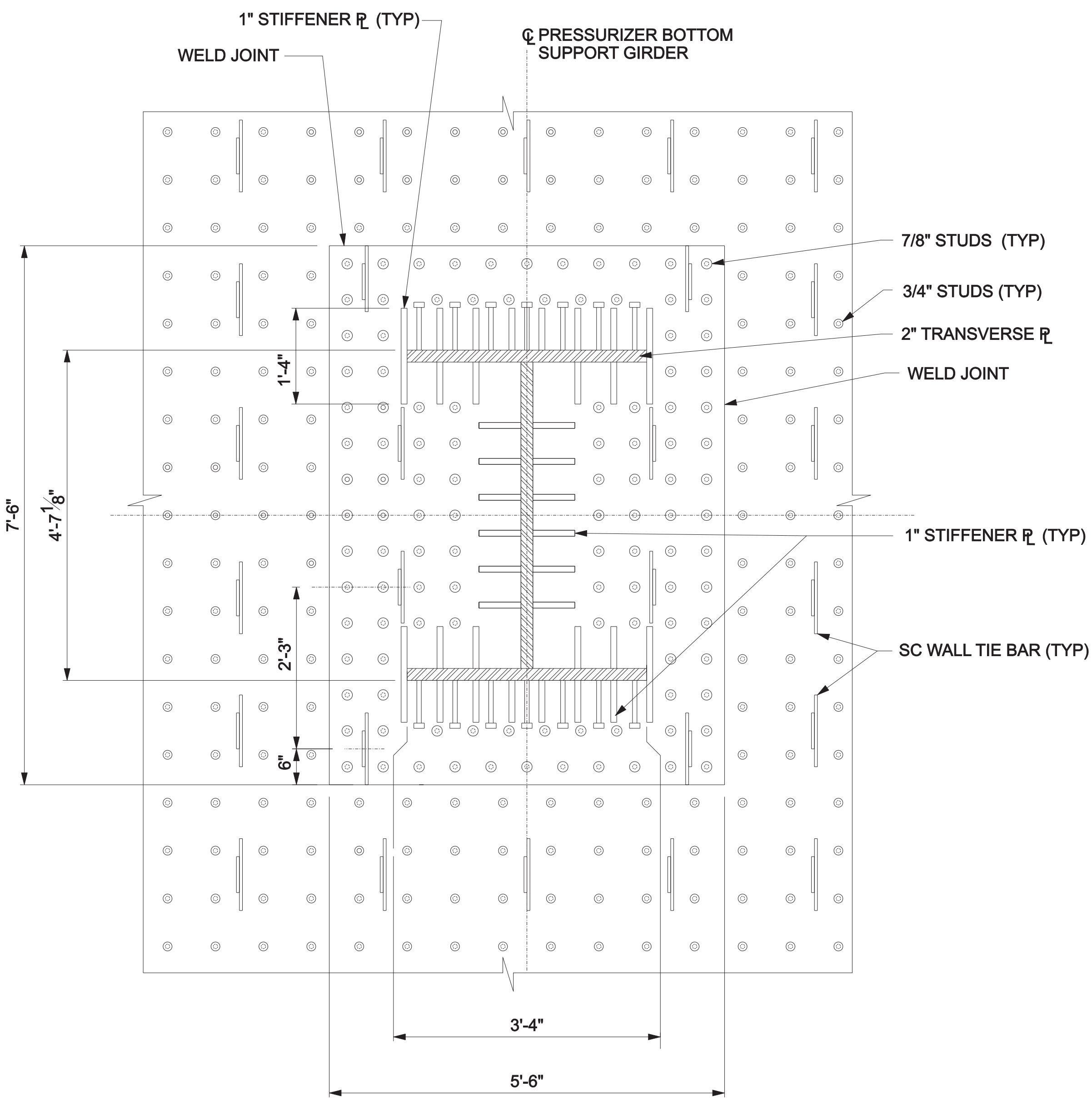
RAI 03.08.03-94



Note: Final connection configuration details may vary and are subject to changes necessary for fabrication and/or constructability.

Figure 3L-74 PZR Girder Connection to SC Wall – Section (ID 11)

RAI 03.08.03-94



SECTION 2-2

Note: Final connection configuration details may vary and are subject to changes necessary for fabrication and/or constructability.

Figure 3L-75 PZR Girder Connection to SC Wall – Section (ID 11)

RAI
03.08.03-94

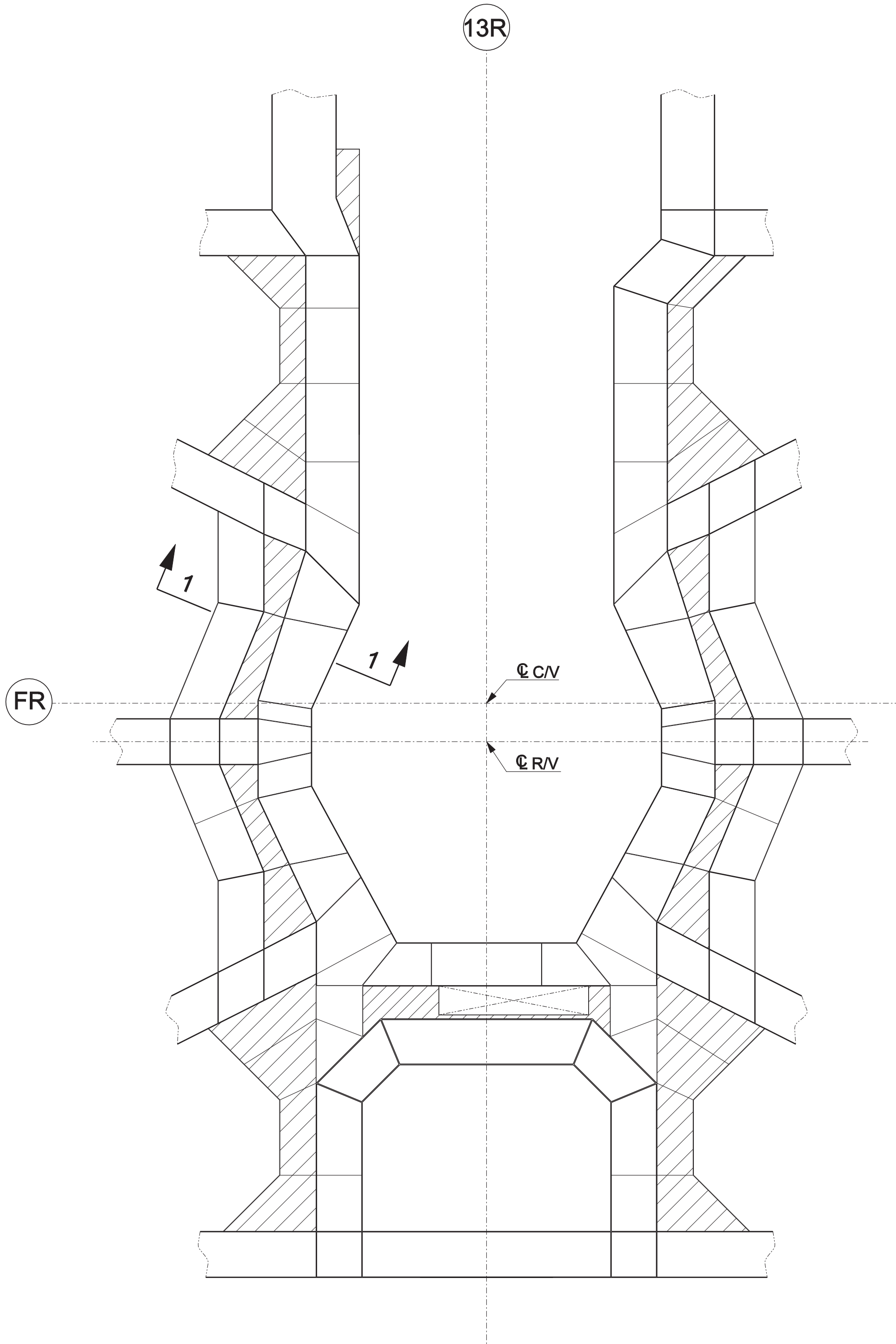
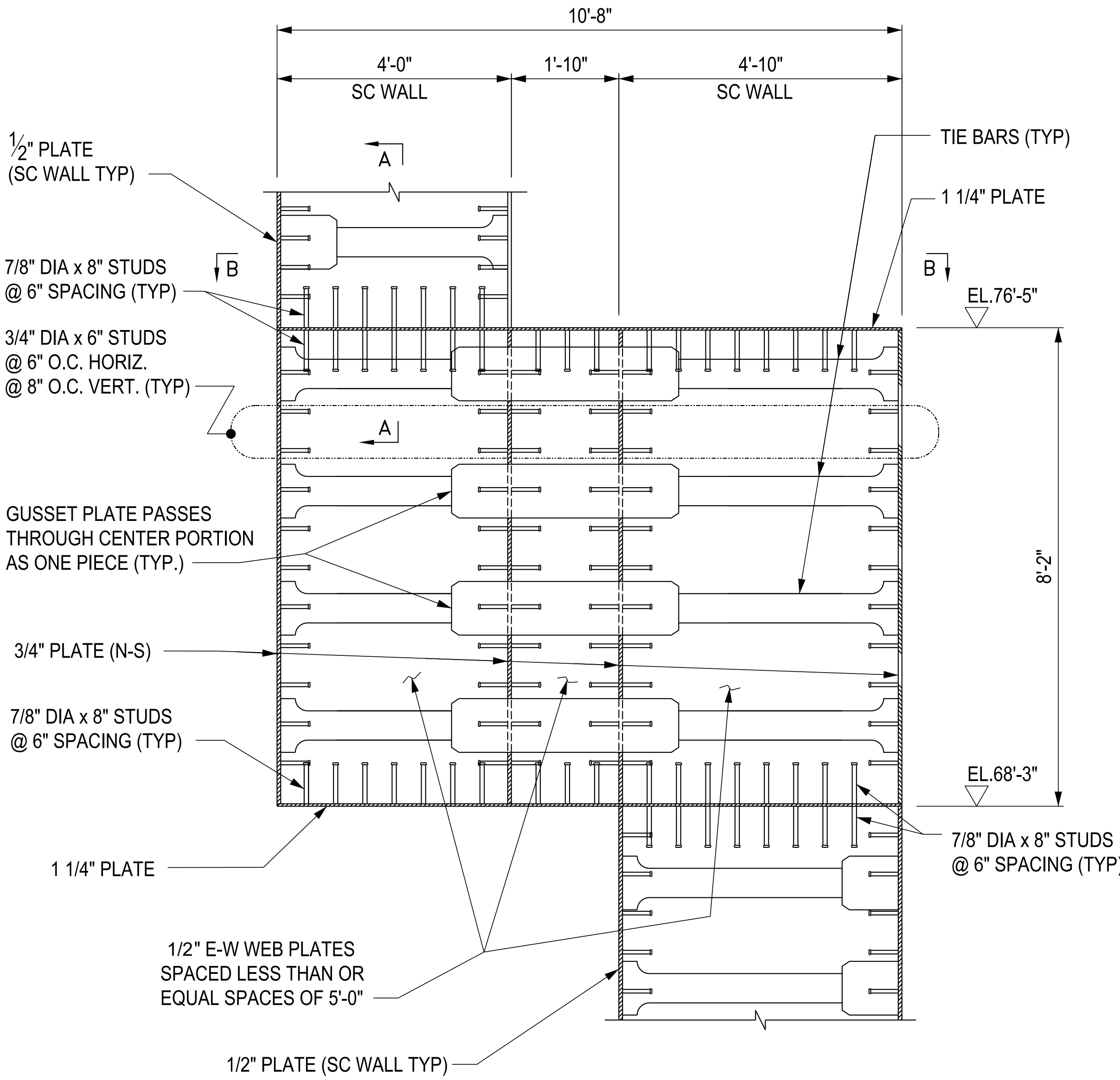


Figure 3L-76 Refueling Cavity Wall and Connection Beam – Plan (ID 12)

RAI 03.08.03-94

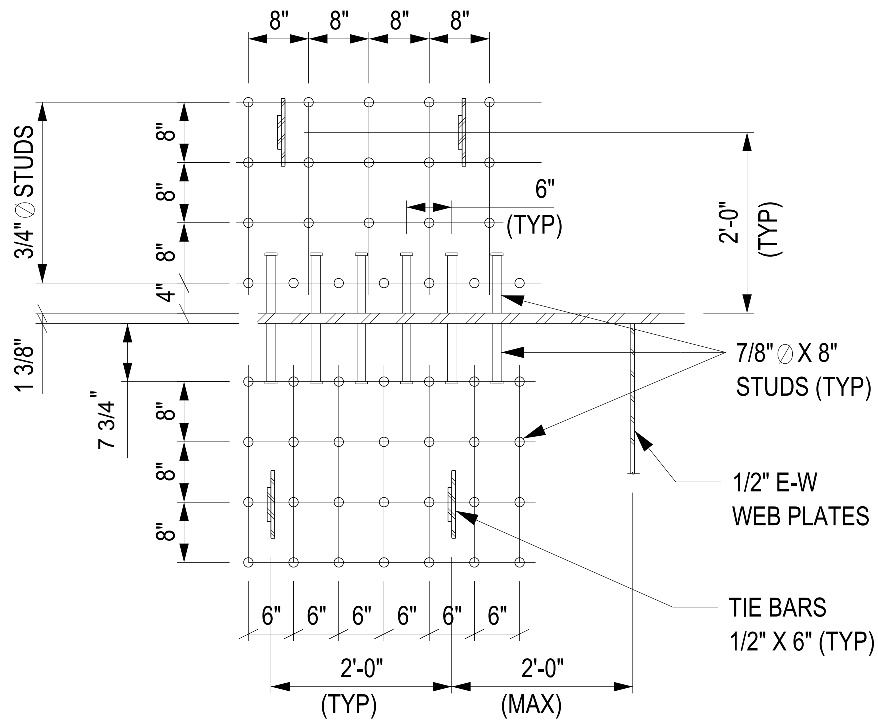


SECTION 1-1

Note: Final connection configuration details may vary and are subject to changes necessary for fabrication and/or constructability.

Figure 3L-77 Refueling Cavity Wall Connection – Section (ID 12)

RAI
03.08.03-94

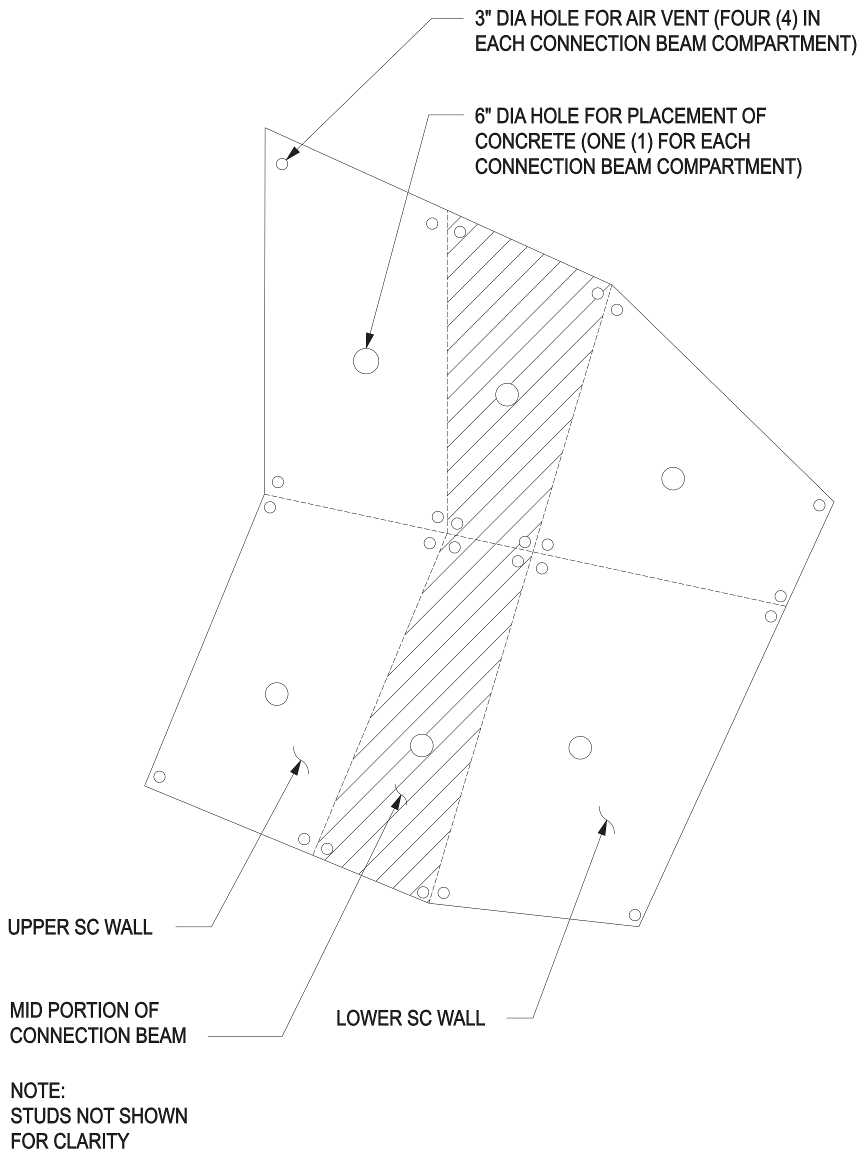


SECTION A-A

Note: Final connection configuration details may vary and are subject to changes necessary for fabrication and/or constructability.

Figure 3L-78 Section A-A Stud and Tie Bar Layout (ID 12)

RAI 03.08.03-94



SECTION B-B

Note: Final connection configuration details may vary and are subject to changes necessary for fabrication and/or constructability. Bottom faceplate in the connection beam is formed similarly above the area of the lower refueling cavity wall.

Figure 3L-79 Connection Beam Top Faceplate – Plan (ID 12)

The Young's Modulus (E_c) and Shear Modulus (G_s) of normal weight concrete are (Reference 02-4):

$$E_c = 57\sqrt{f_c'} = 57 \cdot \sqrt{5000} = 4031\,\text{ksi} = 580393\,\text{ksf}$$

$$G_c = \frac{E_c}{2(1+\nu)} = \frac{580393}{2(1+0.17)} = 248031\,\text{ksf}$$ Equation 02.4.1.1.2-1

The shear wave velocity of the concrete is:

$$Vs_c = \sqrt{\frac{G_c \cdot g}{\gamma}} = \sqrt{\frac{248031 \cdot 32.2}{0.15}} = 7297\,\text{ft/sec}$$ Equation 02.4.1.1.2-2

Wavelength of the wave with frequency of 70 Hz:

$$\lambda_c = TVs_c = \frac{Vs_c}{f_{\max}} = \frac{7297}{70} = 104.2\,\text{ft}$$ Equation 02.4.1.1.2-3

The maximum size of an element determined by wave passage in the structure alone:

$$d_{FE} = \frac{\lambda_c}{5} = \frac{104.2\,\text{ft}}{5} \approx 21\,\text{ft}$$ Equation 02.4.1.1.2-4

Therefore, the mesh size of the model should be equal to or less than 21 ft in order to be able to transfer shear waves with frequencies of up to 70 Hz. The average mesh size in the Dynamic FE model of 9 ft satisfies this requirement.

02.4.1.1.3 Modeling of Stiffness and Damping

The SASSI house module introduces the stiffness and damping properties of the structure into SSI analysis in the form of a frequency independent complex stiffness matrix (Refer to the SASSI Theoretical Manual, Reference 02-1). Complex moduli are used to represent the stiffness and damping properties of the different structural materials. This leads to stiffness and damping ratios which can be different for different materials assigned to the finite elements.

While maintaining geometry, mass and FE meshing, two different levels of stiffness are assigned to the model in order to address the effect of uncracked and cracked concrete on the seismic response. The responses obtained from the analyses of the models with two different stiffness properties are enveloped to develop design seismic loads and ISRS used for the seismic design of pipe and equipment.

Table 02.4.1.1.3-1 provides the stiffness and damping properties assigned to the SASSI Dynamic FE model. Section 02.4.2 provides the background information for the values in this Table.

Two sets of stiffness and damping values are developed to capture the potential range of stresse and associated cracking levels in each of the different concrete structure types (or categories) in the CIS, including various Reinforced Concrete (RC) structural elements, the SC primary and secondary shielding walls, and the massive concrete portions of the structure. There is also structural steel with ~~non-structural~~ concrete infill in some portions of the CIS. ~~For these sections, no concrete stiffness or damping is applied.~~ There are three of these structures modeled in the CIS. They are: 1) the Pressurizer Support Slab, 2) the connection between the Upper Steam Generator (SG) Compartment and Refueling Cavity, and 3) the Reactor Cavity RAI 03.08.03-94 water seal. The Pressurizer Support Slab is modeled as uncracked concrete using shell elements composite with steel beam elements for both sets of stiffness and damping values. The Upper SG Compartment to Refueling Cavity connection is modeled as uncracked concrete with no steel plate contribution for both sets of stiffness and damping values. The Reactor Cavity water seal is not in the primary load path and therefore is modeled as uncracked concrete. The first set of values represents limited concrete cracking and higher stiffness anticipated for seismic loading during normal plant operations (referred to as Loading Condition A), and the second set of values represents a significant reduction in stiffness associated with extensive concrete cracking under seismic loading coupled with accident thermal conditions (referred to as Loading Condition B). The two sets of category-specific stiffness and damping values are listed in Table 02.4.1.1.3-2. When the CIS is combined with other buildings in the R/B complex, Loading Condition A is considered as the Full Stiffness condition and Loading Condition B as the Reduced Stiffness condition. Stiffness and damping of the steel framing and massive concrete in the CIS are assigned according to Table 02.4.1.1.3-1. RAI 03.08.03-94

02.4.1.1.4 Modeling of Mass

The mass included in the R/B complex Dynamic FE model includes contributions from the structural mass in addition to that of equipment, dead loads, and live loads.

Generally, the structural mass is assigned as a density to the finite elements based on the material properties of the components of the structures. The density is then increased to account for equipment, live, snow and other applicable loads. A mass equivalent to 25% of floor design live load and 75% of roof design snow load is included in the model in accordance with SRP 3.7.2 Acceptance Criteria II.1.D (Reference 02-5). Each load is applied over a particular area and the density of the elements in that area is increased such that the total increase in mass matches the mass of the applied loads.

Equipment load also includes a 50 psf dead load to account for miscellaneous pipe, minor equipment, and raceway loads applied on slabs in the R/B complex model, with the exception of a few locations where a heavier pipe load is used instead (e.g., main steam and feedwater pipe).

The above process is not applicable for the NSSS and major pipe that constitutes the RCL. The RCL dynamic mass is included directly in the RCL model.

The mass is applied to the Dynamic FE model in two steps. First, a mass density equal to the sum of the structural self-weight and pipe load is calculated and assigned to each of the shell elements modeling the R/B complex slabs. Where mass is carried by grating not explicitly modeled, the total mass supported is evenly distributed on the supporting walls and slabs.

The remaining loads are applied as either additional mass densities on slab shell elements or concentrated lumped masses on wall and slab key points.

The density and thickness of the elements are further modified to account for stiffness reductions due to minor openings and cracking, but it is done in such a way as to not change the mass of the elements. Refer to Section 02.4.1.1.5 for further discussion.

The PCCV Polar Crane and Fuel Handling cranes are modeled in their respective parked locations with trolley masses and lifted load masses (Spent fuel cask, RV head, etc.) included.

The mass used for the New Fuel Storage Pit (NFSP) and Spent Fuel Pit (SFP) includes the mass of the fuel and the fuel storage racks contained within the pits. This is accomplished as described above by adding the masses as lumped masses to the concrete slabs of the pits

Table 02.4.1.1.3-2 Summary of SC Module Stiffness and Damping Values

~~(see Table 7-1 of MUAP-11018, Reference 02-11)~~

RAI 03.
08.03-94

RAI 977-6899
Question 3.8.3-94
Attachment 3

EXECUTIVE SUMMARY

The US-APWR CIS is a complex structure that includes six different structure categories: (1) SC composite walls with thickness less than or equal to **[ ]**, (2) SC-type walls with thickness greater than **[ ]**, (3) SC-type primary shield walls with three steel plates and thickness from **[ ]**, (4) RC slabs, (5) massive RC structures, and (6) steel structures with non-structural concrete filling.

As shown in the Figures presented in Chapter 2 of this TeR, a majority of the CIS consists of Category 1 SC walls. This category includes the **[ ]**-thick SC walls that comprise the walls of the Steam Generator (SG) compartments, the **[ ]**-thick walls forming the Pressurizer compartment, the **[ ]**-thick outer walls of the Refueling Water Storage Pit (RWSP), and the **[ ]**-thick walls that comprise a majority of the Refueling Cavity. Some relatively small portions of the CIS utilize thicker SC walls, such as the **[ ]**-thick walls used for a limited segment of the Refueling Cavity. The only walls thicker than **[ ]** are the primary shield walls, which enclose the reactor cavity and support the reactor vessel. The primary shield is an SC-type structure that is **[ ]** thick over the majority of its height and consists of three steel plates (one on each surface and one in the middle) and numerous transverse steel plates.

Structure Categories 4 and 5 utilize conventional RC construction. Category 4 consists primarily of three major floor slabs at intervals along the height of the CIS, with thickness varying from **[ ]** Category 5 consists of the massive concrete structures at the base of the CIS, which form the bottom of the refueling cavity and also provide vertical support to the steam generators and the reactor coolant pumps. Lastly, Category 6 ~~involves some steel structures (e.g., floor grids) with plain (nonstructural) concrete infill for radiation shielding~~ <u>includes steel and concrete composite structures that are part of the primary load resisting systems, as well as steel structures, that are not part of the primary load resisting system, with plain (nonstructural) concrete infill</u>. RAI 03. 08.03-94

This TeR presents the approach for estimating the structural stiffness and damping values of the various structure categories of the CIS, and modeling them using Linear Elastic Finite Element (LEFE) models to determine: (i) the In-Structure Response Spectra (ISRS) for equipment design and qualification, and (ii) structural member force demands for design.

The stiffness and damping values are commensurate with the level of concrete cracking expected to occur in the various structure categories of the CIS. The extent of concrete cracking varies for each loading combination applicable to the CIS design. Two basic loading combinations dominate in terms of dynamic response: (A) seismic loading during normal operating conditions, and (B) seismic loading plus accident thermal loading. These are referred to as Condition “A” and Condition “B”, respectively.

This TeR presents the stiffness and damping values for each of the structure categories of the CIS while accounting for the extent of concrete cracking associated with these two fundamental loading conditions.

Since a majority of the CIS consists of SC walls, and since there are no accepted U.S. codes that define the stiffness of SC walls for use in dynamic response analysis, this TeR gives particular attention to their behavior. In general, the behavior of SC walls is similar to that of RC walls that are conventionally used in safety-related nuclear facilities. Both of these structure types consist of thick concrete sections reinforced by steel. As a result, the extent of

RAI 977-6899
Question 3.8.3-94
Attachment 3

Based on this discussion, for Category 2 and 3 SC-type walls, the stiffness and damping values are based on those of RC walls published in ASCE 43-05, and summarized as follows:

The Category 2 SC-type walls are demonstrated in this TeR to remain effectively uncracked for loading condition “A”. They are assumed to be fully cracked for loading condition “B”. The Category 3 primary shield structure SC-type walls are demonstrated to remain uncracked for both loading conditions “A” and “B” in the TeR. For loading condition “B” (accident thermal), the primary shield structure remains uncracked due to significant restraint from the surrounding massive RC structure, and its large thickness.

The stiffness and damping values for category 4 and 5 RC structures are based on values published in ASCE 43-05, and summarized as follows.

The Category 4 RC slabs are demonstrated in this TeR to remain effectively uncracked for loading condition “A”. They are assumed to be cracked in flexure for loading condition “B”. The Category 5 massive RC structures are assumed to remain uncracked for both loading conditions “A” and “B” in this TeR due to their significant size, thermal inertia, and thickness.

The stiffness and damping values for Category 6 ~~steel structures with non-structural concrete infill~~ structures that are part of the primary load resisting system are based on the stiffness of the steel and concrete infill composite structure~~ alone~~. ~~The mass associated with the non-structural concrete infill is included directly in the models, but the concrete is not accorded any structural stiffness~~The mass of Category 6 structures that are not part of the primary load resisting system is included directly in the models, but the concrete is not accorded any structural stiffness. RAI 03.08.03-94

Thus, the stiffness and damping values for the different structure categories of the CIS are based on experimental results, understanding of structural behavior, good engineering

2.0 STRUCTURE CATEGORIES[1]

As discussed above, the US-APWR CIS is comprised of a variety of structure types with significant differences in their construction and expected behavior. The structures in the CIS are classified into six categories to enable the use of appropriate analysis models and design methodologies for each of the structure categories. These six structure categories include three SC-type and three non-SC type categories, as explained in the following sub-sections. Figures 2-1 through 2-7 show several plan and elevation views of the US-APWR CIS that identify the six structure categories using a color-coded scheme. These figures have been developed from the drawings provided in References 5 and 6.

2.1 SC-type Structure Categories

The composite stiffness and strength of SC walls have been thoroughly established in experiments involving walls with an overall thickness less than or equal to **[ ]** Typical SC designs evaluated in these experiments consist of a single concrete core sandwiched between two steel faceplates, as shown in Figure 2-8. The steel faceplates are typically connected to the concrete core using headed stud anchors or embedded steel shapes, and the two steel faceplates are typically connected to each other using embedded steel shapes, tie bars, or web plates. The steel faceplate reinforcement ratios (ρ) in the experimental database vary between 1.5% and 5.0%, with ρ defined as follows:

Equation (2-1)

$$\rho = \frac{2 \cdot t_p}{T}$$

where t_p is the single faceplate thickness and T is the thickness of the overall section.

Most of the SC-type walls in the US-APWR CIS have material and geometric parameters that are within the range evaluated by the aforementioned experimental database. However, some of the walls have overall thicknesses and/or steel plate geometries that exceed this range. In these cases the fully composite stiffness cannot be assumed. Hence, the SC-type walls in the CIS are divided into the following three categories:

<u>Category 1</u>: *SC Walls with thickness less than or equal to 56 in.* These SC walls have material and geometric parameters that are within the range of the experimental database. This category includes the majority (approximately 80%) of the secondary shielding walls in the CIS. **[ ]**

<u>Category 2</u>: *SC Walls with thickness greater than* **[ ]** This category includes a relatively small portion of the CIS SC walls with <u>a</u> thicknesses ranging ~~from~~ <u>of</u> **[ ].** RAI 03. 08.03-94

<u>Category 3</u>: *Primary Shield Walls.* The primary shield walls below elevation **[ ]** range in thickness from **[ ]** They have a multi-cellular arrangement comprised of two steel faceplates, a mid-thickness steel plate, and numerous transverse web plates. <u>The primary shield walls between elevations [ ] also have a multi-cellular arrangement consisting of inner and outer faceplates and multiple transverse web plates.</u> RAI 03. 08.03-94

[1] The information in this section is also provided in TeR MUAP-11013 (Reference 2).It is repeated in this TeR for clarity.

2.2 Non-SC Structure Categories

The non-SC type walls in the CIS are classified into three additional structure categories:

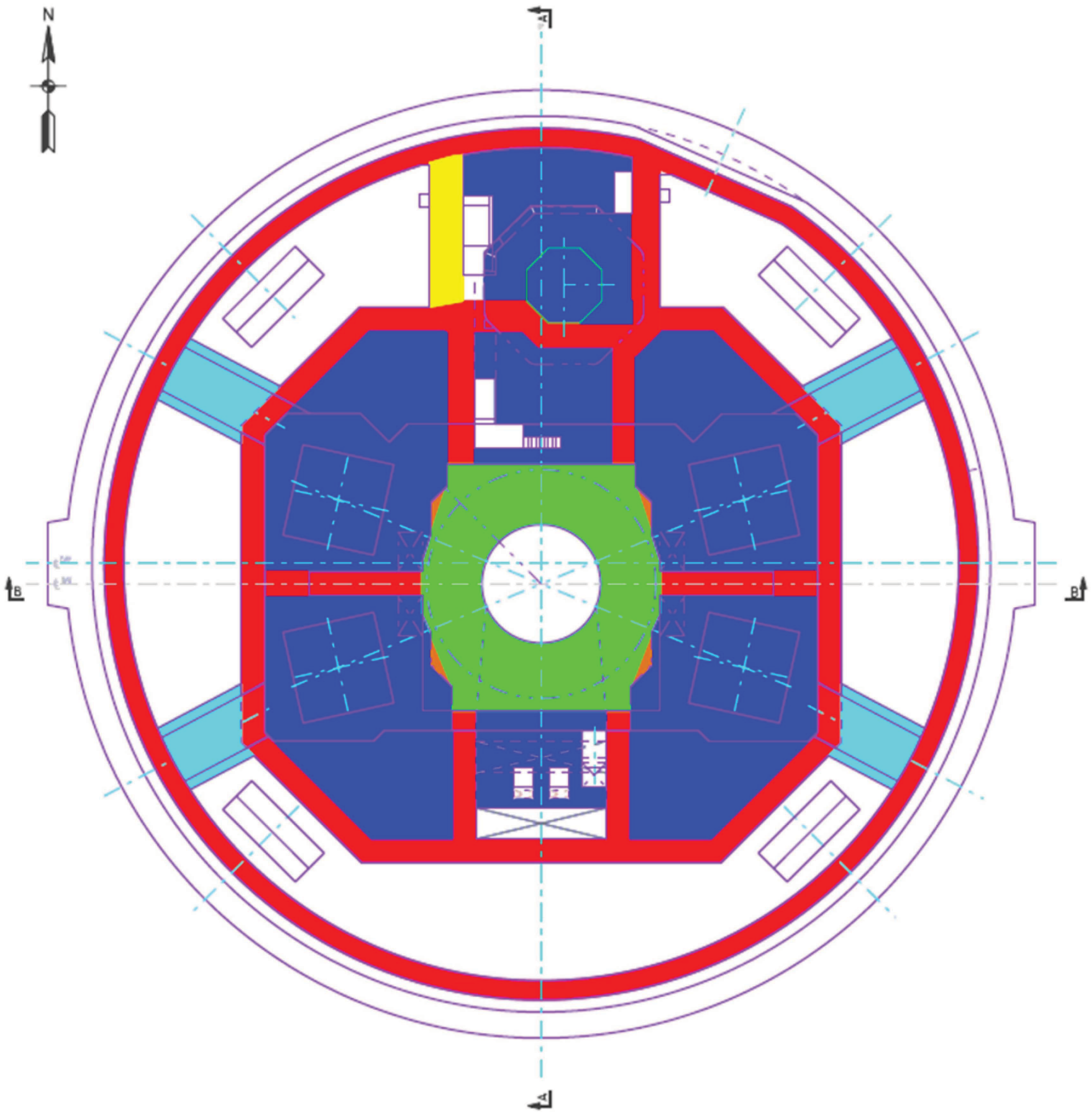
Category 4: RC s*labs.* Standard RC floor slabs are used at various elevations throughout the CIS.

Category 5: *Massive RC.* This category includes the thick RC blocks at the base of the CIS that support the steam generators and reactor coolant pumps. These blocks are nominally **[ ]** deep and are anchored to the basemat of the R/B complex with steel reinforcement.

Category 6: ~~*Steel structures with nonstructural concrete infill.*~~ These structures consist of steel plates or steel shape grillages with ~~nonstructural~~ composite concrete ~~provided for shielding purposes~~infill. RAI 03.08.03-94

The US-APWR CIS also includes steel members that support the elevated RC slabs at elevations **[ ]**, as well as extensive secondary framing provided for support of operating platforms at various elevations. The columns that support the perimeter of the RC slabs are explicitly modeled in the SSI and detailed design models in order to provide the correct vertical load path and boundary conditions for the slabs, but the remainder of the secondary framing is included only as mass. In either case, the relative contribution of the steel framing stiffness and damping to the dynamic response of the primary structure is considered insignificant, such that these members are not included in the major structure categories identified for evaluation in this TeR.

RAI 03.
08.03-94

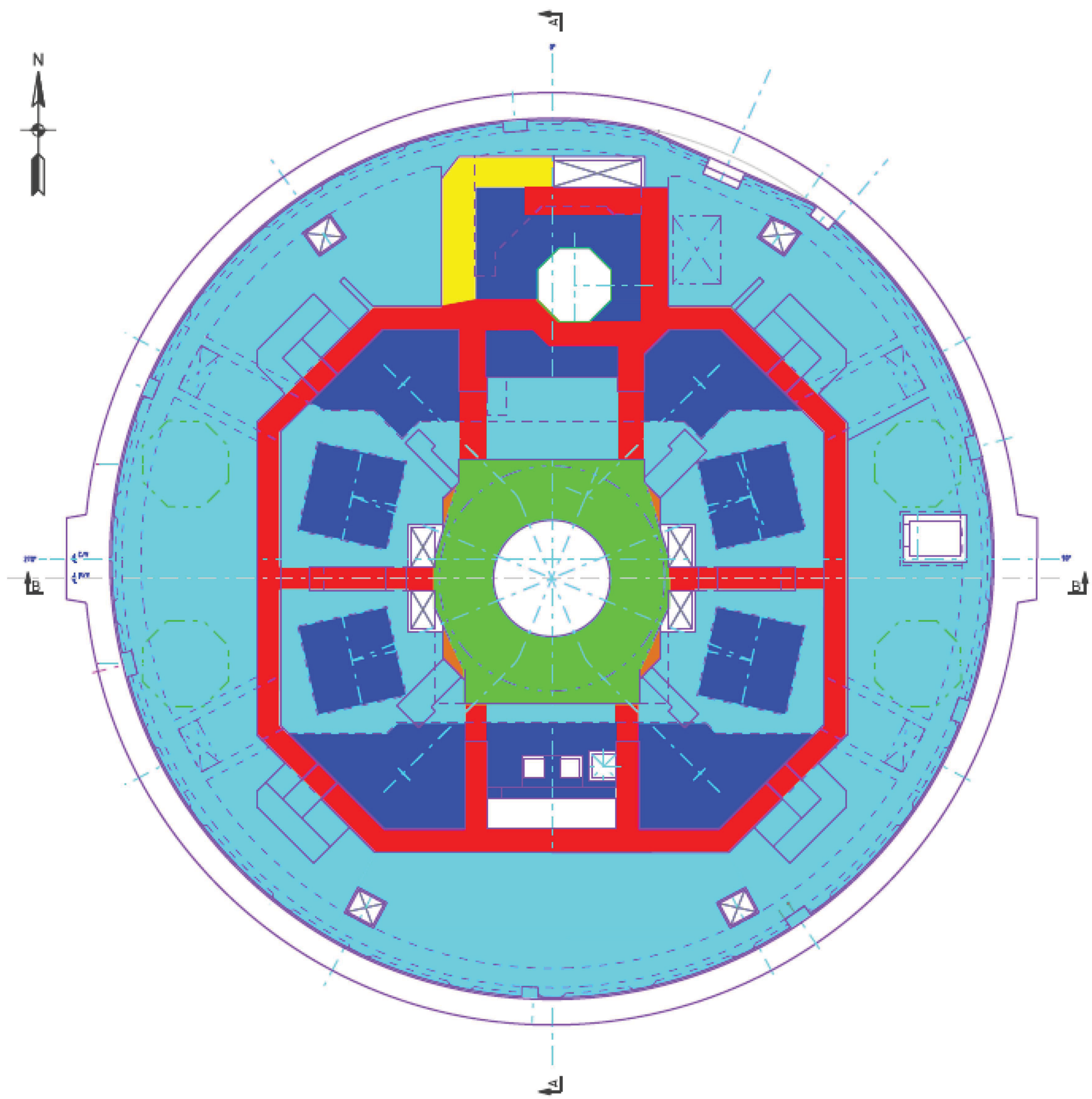


	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T ≤ 56"
	2	WALLS WITH T > 56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-1 CIS Structure Categories, Elevations 3'-7" to 21'-0"

RAI 977-6899
Question 3.8.3-94
Attachment 3

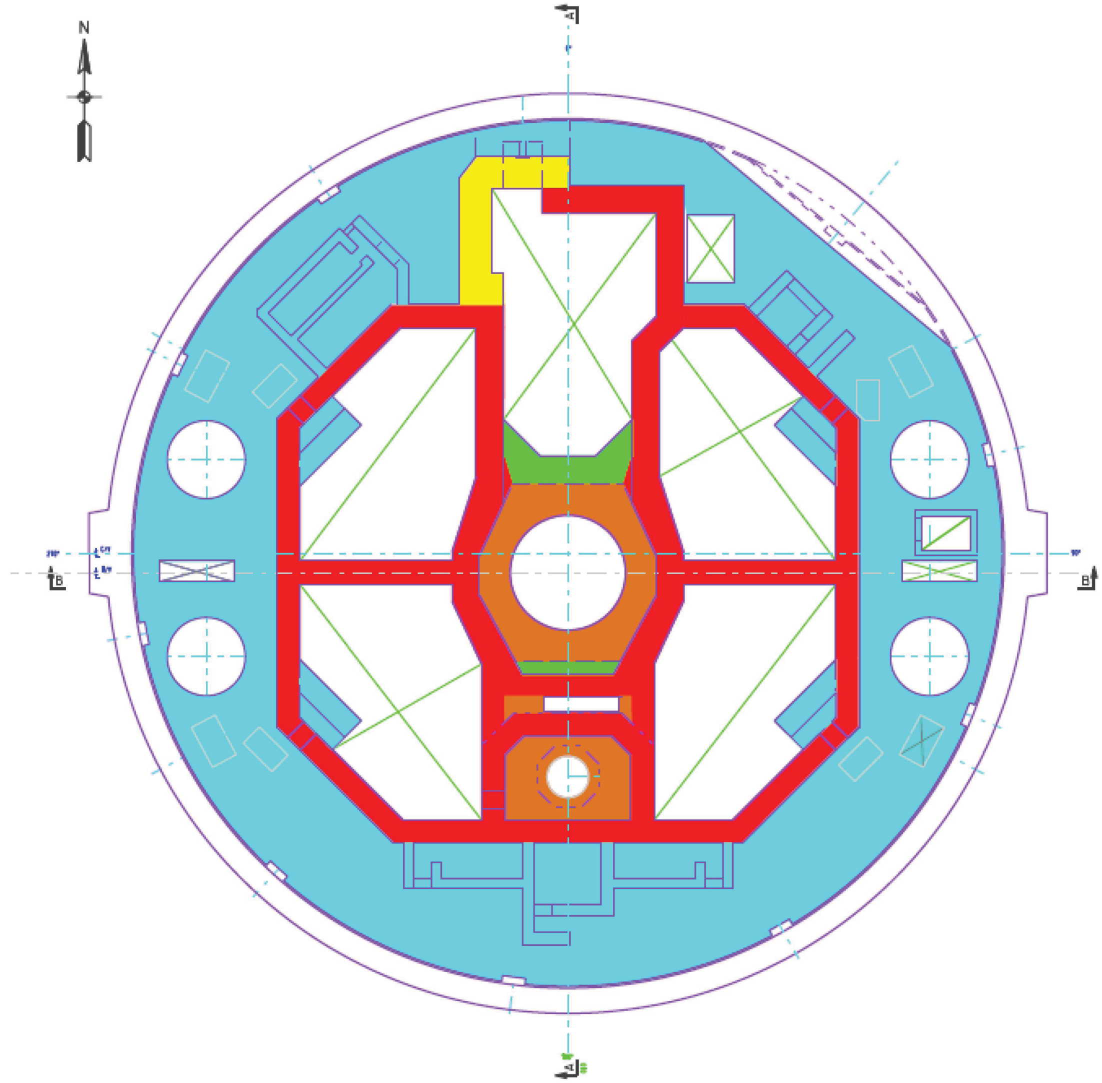
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T ≤ 56"
	2	WALLS WITH T > 56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-2 CIS Structure Categories, Elevations 21'-0" to 35'-11"

RAI 03.
08.03-94

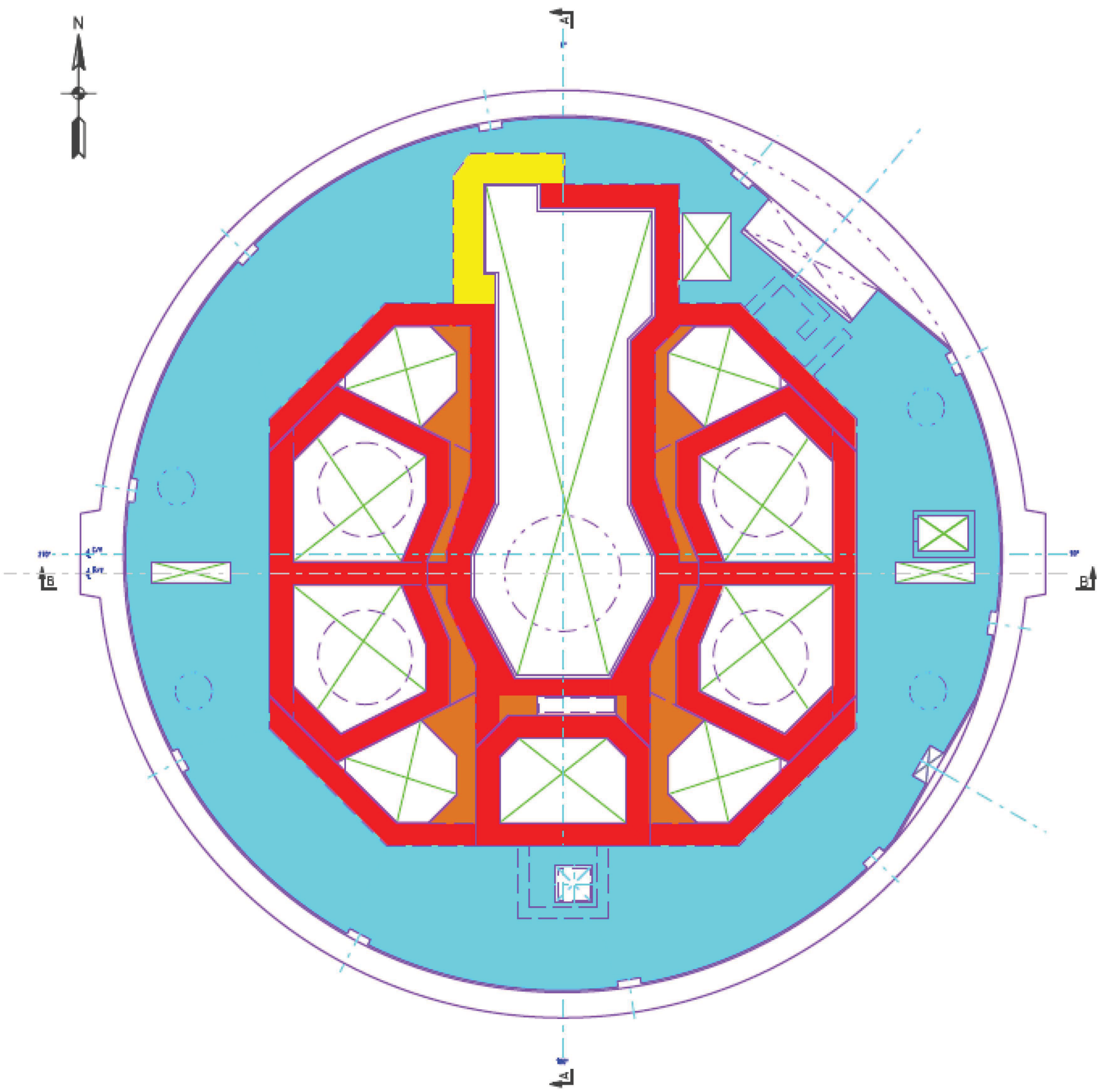


	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T≤56"
	2	WALLS WITH T>56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-3 CIS Structure Categories, Elevations 37'-9" to 62'-4"

RAI 977-6899
Question 3.8.3-94
Attachment 3

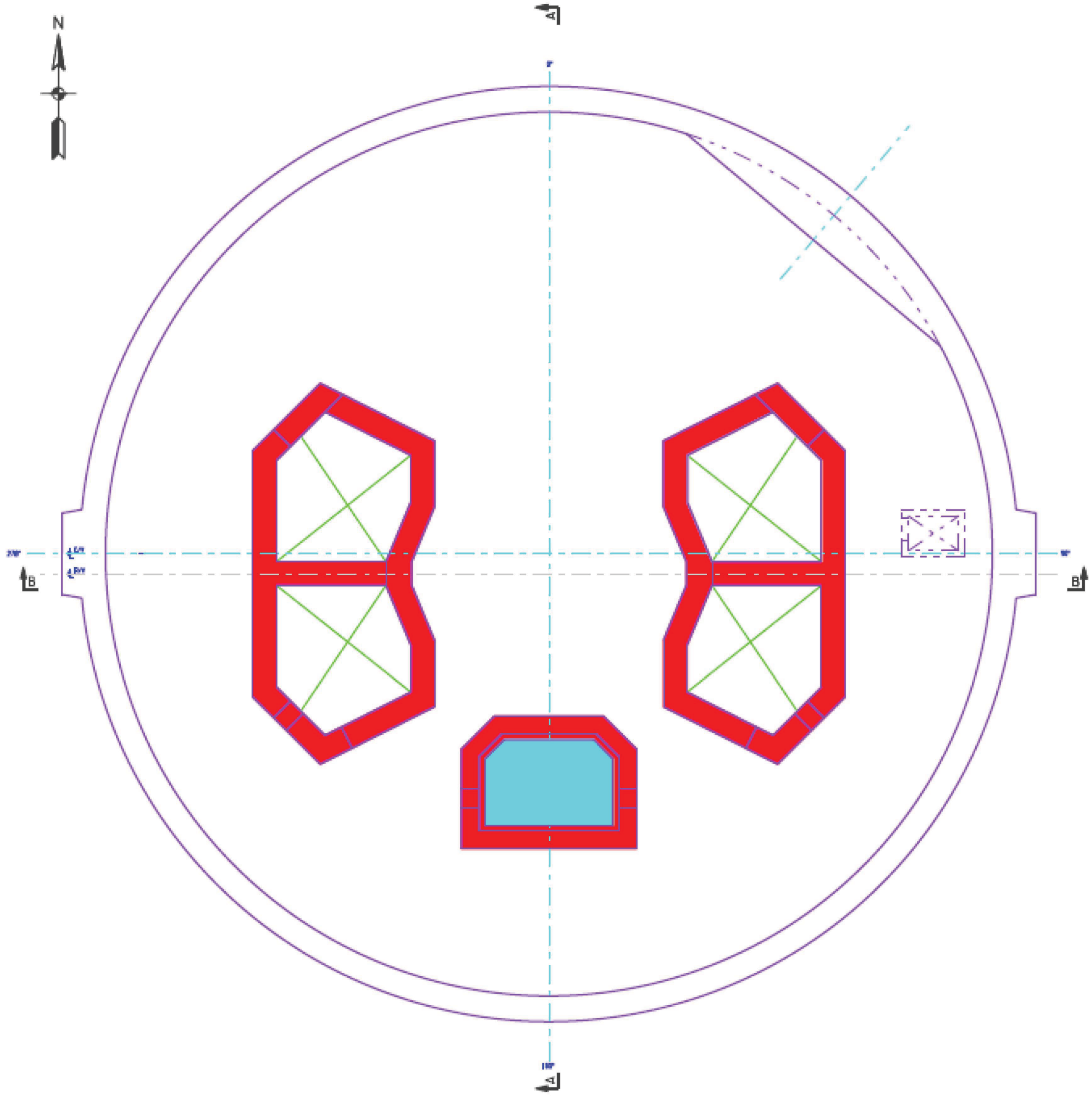
RAI 03.08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
(red)	1	SC WALLS, T≤56"
(yellow)	2	WALLS WITH T>56"
(green)	3	PRIMARY SHIELDING WALLS
(light blue)	4	RC SLABS
(dark blue)	5	MASSIVE RC SECTIONS
(orange)	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-4 CIS Structure Categories, Elevations 62'-4" to 76'-5"

RAI 03.
08.03-94

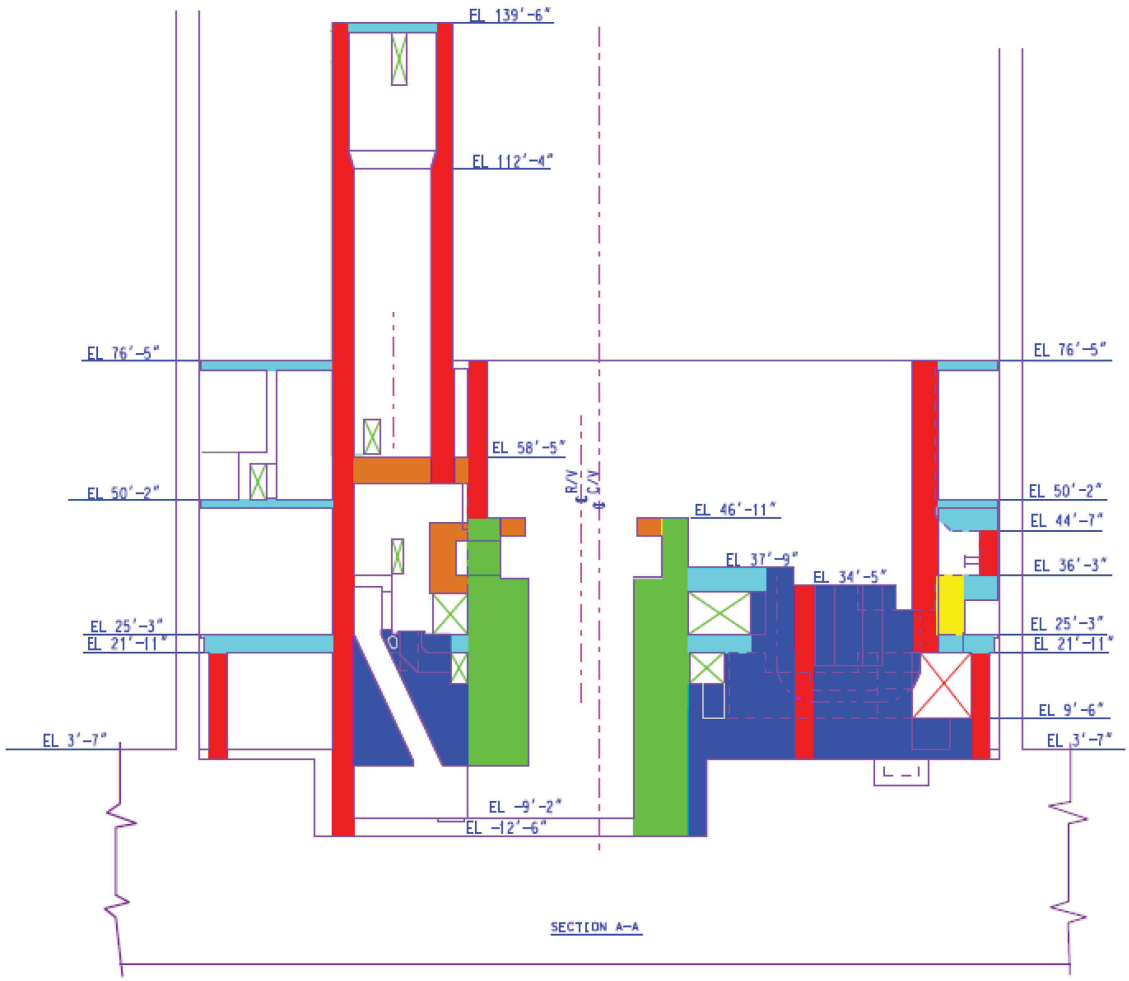


	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T ≤ 56"
	2	WALLS WITH T > 56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-5 CIS Structure Categories, Elevations 76'-5" to 139'-6"

RAI 977-6899
Question 3.8.3-94
Attachment 3

RAI 03.
08.03-94

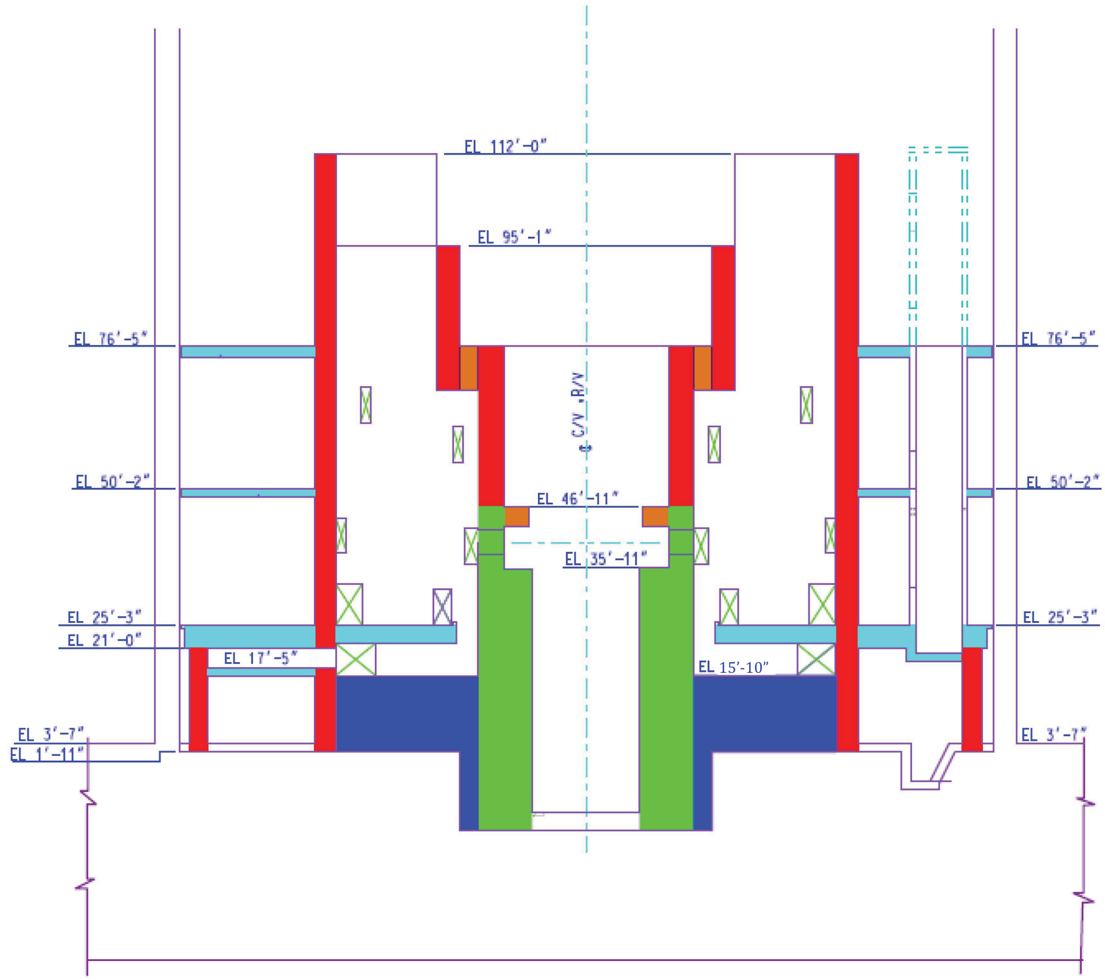


	STRUCTURAL CATEGORY	DESCRIPTION
	1	SC WALLS, T≤ 56"
	2	WALLS WITH T> 56"
	3	PRIMARY SHIELDING WALLS
	4	RC SLABS
	5	MASSIVE RC SECTIONS
	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-6 CIS Structure Categories, Centerline Section Looking West

RAI 977-6899
Question 3.8.3-94
Attachment 3

RAI 03.
08.03-94



	STRUCTURAL CATEGORY	DESCRIPTION
(red)	1	SC WALLS, T≤56"
(yellow)	2	WALLS WITH T>56"
(green)	3	PRIMARY SHIELDING WALLS
(light blue)	4	RC SLABS
(dark blue)	5	MASSIVE RC SECTIONS
(orange)	6	STEEL STRUCTURE WITH CONCRETE INFILL

Figure 2-7 CIS Structure Categories, Centerline Section Looking North

In keeping with the approach identified in these standards, stiffness and damping values will be assigned to the structures of the CIS for each of the two loading conditions considered on the basis of anticipated cracking. The assessment of cracking for each condition is described in Sections 5.0 and 6.0.

4.4 CATEGORY 6 MODELING

This category includes structural elements that are part of the primary load resisting system, as well as other miscellaneous elements. The stiffness of the primary load resisting elements considers the stiffness of the steel elements and the composite action of the infill concrete provided for shielding purposes. The miscellaneous elements that are not part of the primary load resisting elements are modeled considering concrete mass only with no stiffness. The stiffness of these elements is modeled as follows: RAI 03. 08.03-94

- Lower Pressurizer Support: Full composite steel + cracked concrete;
- Refueling Cavity to SG Compartment: Full composite steel + cracked concrete;
- Other Category 6 Elements: Mass only, no stiffness.

~~As stated in Section 2.2, the Category 6 structures in the CIS consist of grillages of steel plates or shapes (e.g., wide-flange sections) that are filled with concrete for shielding purposes. The concrete in these structures is nonstructural, as it is not detailed to act compositely with the steel. Hence the CIS analysis models for Tasks 1-A and 1-B will include the stiffness of the steel members only. The concrete infill will be considered only as lumped mass on the steel structures.~~

RAI 977-6899 Question 3.8.3-94
Attachment 3

Table 7-1 Summary of CIS Stiffness and Damping Values

RAI 03.
08.03-94