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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 38 Related to ESBWR Design Certification Application – Structural Analysis - RAI Numbers 3.8-3, 3.8-6, 3.8-13, 3.8-14, 3.8-18, 3.8-19, 3.8-20, 3.8-23, 3.8-25, 3.8-26, 3.8-27, 3.8-40, 3.8-41, 3.8-46, 3.8-47, 3.8-48, 3.8-49, 3.8-51, 3.8-56, 3.8-63, 3.8-64, 3.8-82, 3.8-83, 3.8-87, 3.8-90, 3.8-91, 3.8-100, 3.8-104, 3.8-105 and 3.8-106**

Enclosure 1 contains GE's response to the subject NRC RAIs transmitted via the Reference 1 letter.

If you have any questions about the information provided here, please let me know.

Sincerely,

Kathy Sedney for

David H. Hinds
Manager, ESBWR

D068

Enclosure:

1. MFN 06-191 - Response to Portion of RAI Letter No. 38 for the ESBWR Design Certification Application - Seismic Category I Structures - RAI Numbers 3.8-3, 3.8-6, 3.8-13, 3.8-14, 3.8-18, 3.8-19, 3.8-20, 3.8-23, 3.8-25, 3.8-26, 3.8-27, 3.8-40, 3.8-41, 3.8-46, 3.8-47, 3.8-48, 3.8-49, 3.8-51, 3.8-56, 3.8-63, 3.8-64, 3.8-82, 3.8-83, 3.8-87, 3.8-90, 3.8-91, 3.8-100, 3.8-104, 3.8-105 and 3.8-106

Reference:

1. MFN 06-197, Letter from U. S. Nuclear Regulatory Commission to Mr. David H. Hinds, *Request for Additional Information Letter No. 38 Related to ESBWR Design Certification Application,* June 23, 2006

cc:	WD Beckner	USNRC (w/o enclosures)
	AE Cubbage	USNRC (with enclosures)
	LA Dudes	USNRC (w/o enclosures)
	GB Stramback	GE/San Jose (with enclosures)
	eDRF	0000-0055-3061

Enclosure 1

MFN 06-191

Response to Portion of RAI Letter No. 38 Related to ESBWR Design Certification Application

Seismic Category I Structures

RAI Numbers 3.8-3, 3.8-6, 3.8-13, 3.8-14, 3.8-18, 3.8-19, 3.8-20, 3.8-23, 3.8-25, 3.8-26, 3.8-27, 3.8-40, 3.8-41, 3.8-46, 3.8-47, 3.8-48, 3.8-49, 3.8-51, 3.8-56, 3.8-63, 3.8-64, 3.8-82, 3.8-83, 3.8-87, 3.8-90, 3.8-91, 3.8-100, 3.8-104, 3.8-105 and 3.8-106

NRC RAI 3.8-3

Provide additional information (description, plans, and sections) for the following structural elements. These include the reinforcement details around major reinforced concrete containment vessel (RCCV) piping penetrations, equipment hatches, and personnel airlocks; structural attachments to the containment internal wall (such as pipe restraints); containment external supports if any, attached to the wall to support external structures/elements; reactor pressure vessel (RPV) stabilizer (referred to in App. 3G.1.3.1.4); reactor building (RB) floor slabs made of composite sections (referred to in App. 3G.1.3.1.1); roof trusses and their supporting columns (referred to in App. 3G.1.3.1.1); and the basaltic concrete at the bottom of the containment. In addition, to facilitate the review, Figure 3.8-1 should be improved to identify a number of elements in the ESBWR containment structure which are not shown. These elements include: the shield wall, RPV stabilizer, RPV skirt, RPV insulation, equipment hatches, wetwell hatch, personnel airlocks, refueling seal, major equipment platforms, quenchers, representative vent pipe and safety relief valve (SRV) downcomer pipe with sleeve (from the drywell into the suppression pool).

GE Response

A global structural analysis has been completed in the ESBWR DCD. The purpose of the global analysis is to prove that there are no safety issues unresolved. GE believes that sufficient level of civil-structural detail has been provided in the DCD for plant certification. The construction level design details requested are not available at this stage.

The detail structural design is intimately connected among several disciplines and depends on them for final resolution, such as piping analysis results, equipment sizes, layout and routing of commodities such as cable trays, ducts, etc. It is an iterative process between disciplines.

Among the various structural elements identified in this RAI, GE will provide to the NRC the details of reinforcement around MS/FW penetrations and a representative hatch through the RCCV, which will be included in the response to RAI 3.8-17 in the release on Oct. 31, 2006. They represent an example of the detail structural design. DCD Figure 3.8-1 is intended to depict only the containment boundary. Other items can be found in the following figures.

a. Shield wall. See DCD Figure 3G.1-58.
b. RPV Stabilizers. See DCD Figure 5.3-3.
c. RPV skirt (it is termed sliding support in the ESBWR DCD). See DCD Figure 5.3-3.
d. RPV insulation. Detailed design phase.
e. Equipment hatches. See DCD Figure 3G.1-52.
f. Wetwell hatch. See DCD Figure 3G.1-53.
g. Personnel airlocks. See DCD Figure 3G.1-54.
h. Refueling seal. See DCD Figure 5.3-3.
i. Major equipment platforms. Detailed design phase.

j. Quenchers. See DCD Figure 6.2-1.

k. Representative vent pipe and safety relief value (SRV) downcomer pipe with sleeve (from the drywell into the suppression pool). See DCD Figure 3G.1-57.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-6

The description of live load used inside containment given in DCD Section 3.8.1.3.1 needs to be expanded, similar to the description presented in Section 3.8.4.3.1.1, if applicable. The description should cover the types of loads included in live loads (e.g., floor area live loads, laydown loads, equipment handling loads), situations where floor area live loads are omitted, and the magnitude of live load that is used for inertia effects caused by seismic and hydrodynamic loadings in the overall building model and in the design of individual local members. If a fraction of the live load is utilized for seismic and hydrodynamic effects, then provide justification for the reduced live load magnitude.

GE Response

Live load for structures inside the containment is 9.6 kPa (200 psf) during outages and laydown operations. The loads are applied to the containment interior floors, except the suppression pool floor slab. During normal operation, the live load is not considered since the containment is inerted and therefore inaccessible. The overall building dynamic analysis model for seismic loads reflects the normal operation conditions and, hence, does not include the live load inertia effects of containment internal structures. In the dynamic analysis model for hydrodynamic loads, live load inertia equal to 25% of full live loads was included for containment internal structures and the effect on structural response is negligible. Design of individual members is based on the worst loading conditions, including those that contain live load.

DCD Section 3.8.1.3.1 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-13

For the soil springs used in the containment and RB model (DCD Section 3.8.1.4.1.1 and Appendix 3G):

a) *Explain why the foundation soil springs for rocking and translation are determined based on soil parameters corresponding to the "Soft Site" conditions for seismic and other loads. Include a discussion of the conservatism of this assumption and the basis for the conclusion.*

b) *Explain how the soil springs for the non-seismic loads were determined. If the springs are modeled as having perfectly elastic stiffness, then explain why these stiffness values are so much smaller than the seismic soil springs.*

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

a) The deformations of buildings are greater for the case of Soft soil than for Hard rock. Therefore, it leads to larger section forces for member design. Hence, the Soft soil condition is used. Note that the enveloped seismic loads of all soil cases as described in DCD Section 3A.9 were conservatively applied to the soft soil condition.

b) The pressures acting on the foundation soil in the vertical direction differ in character between horizontal earthquake loads and other loads. When horizontal earthquake loads are excluded, vertical pressures are produced according to the force in the vertical direction, and the foundation soil resists them by vertical stiffness of the soil springs. For this reason, vertical soil springs, kv_1, can be estimated as follows:

$$kv_1 = Kv/A \qquad (3.8\text{-}13\text{-}1)$$

where,

Kv: stiffness of vertical soil spring (used in seismic response analysis)

A: area of basemat

On the other hand, for the horizontal seismic loads, vertical pressures are produced due to overturning moments, and the foundation soil resists them by its rotational rigidity. So, vertical soil springs, kv_2, under seismic loading conditions can be estimated as follows:

$$kv_2 = Kr/I \qquad (3.8\text{-}13\text{-}2)$$

where,

Kr: stiffness of rotational soil spring (used in seismic response analysis)

I: moment of inertia of basemat bottom surface

The inherent rotational stiffness of the soil is larger than its vertical stiffness as shown in DCD Table 3A.5-1. That is why soil springs are larger in stiffness than that of the non-seismic case.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-14

Based on the information presented in Appendix 3G.1.5.2.1.6 – Thermal Loads and Table 3G.1-6, explain the following:

a) Even though equivalent linear temperature distributions are tabulated in DCD Table 3G.1-6, explain how nonlinear temperature gradients (e.g. SRV discharge or accident temperatures) through the containment wall are considered. This should include a description of the nonlinear temperature effects on the concrete, liner and liner anchors.

b) Temperature values in DCD Table 3G.1-6 are presented for "Winter." Indicate whether temperature distributions are considered for other times of the year as well; if not, then explain.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

a) The evaluation method of temperature effect on the concrete design is based on ACI 349-01 Commentary Fig. RA.1. The equivalent linear temperature gradient is so determined such that it produces the same uncracked moment about the center line of the section as does the nonlinear temperature distribution.

   Constant temperature distributions are considered for the thin liner and liner anchors.

b) Among all seasons of the year, winter and summer have the most extreme variation in temperatures and they are therefore selected for design conditions for environmental temperature loading. Sectional moments in concrete structures for the winter conditions are, in general, larger than those for the summer considering the temperature differences between room and exterior or inside and outside RCCV. Therefore, only the controlling "winter" case is presented in the DCD.

(1) The applicable detailed report/calculation that will be available for NRC audit are,

- 26A6649, RB FB Heat Transfer Analysis Report, Revision 0, September 2005, containing the evaluation results of temperature loads used for the design of the RB and the FB.
- 26A6650, RCCV Structural Design Report, Revision 1, November 2005, containing the structural design details of the RCCV.
- 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Appendix 3G.1.5.2.1.6 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-18

Describe how the reinforced concrete containment shell and basemat material and stiffness properties are represented in the shell finite element NASTRAN model (e.g., monolithic concrete properties with Young's modulus, thickness, Poisson's ratio, and density corresponding to only concrete – neglecting the steel). For pressure, thermal, seismic, and hydrodynamic loads, explain how the effects of concrete cracking are considered in the NASTRAN overall building analysis. If the concrete stresses are very low for some loading combinations, there may still be regions where cracking in the concrete develop due to the containment structural integrity tests (SIT), thermal loads, and pressure loads. (DCD Section 3.8.1.4.1)

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Concrete properties for the containment shell and basemat material include all those as stated and they are considered to be linear elastic in the NASTRAN model as described in DCD Section 3.8.1.4.1.2. Reinforcing steel is not explicitly modeled and its weight is included in the overall reinforced concrete density.

Cracking of concrete is not explicitly considered in the NASTRAN calculations as allowed in ASME Sec. III, Div. 2, CC-3320. However, cracking is considered in the design of the cross section utilizing the SSDP-2D program as described in DCD Section 3.8.1.4.1.2, which does not allow tensile stress in the concrete. Section forces generated by NASTRAN are input to the SSDP-2D program. This procedure is used for all loads except LOCA thermal loads.

The concrete cracking effects for LOCA thermal loads are explicitly included by performing a non linear concrete cracking analysis using ABAQUS/ANACAP software as described in DCD Section 3.8.1.4.1.3.

(1) The applicable detailed report/calculation that will be available for NRC audit are,

- 26A6650, RCCV Structural Design Report, Revision 1, November 2005, containing the structural design details of the RCCV
- 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of he Reactor Building

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-19

Provide a figure showing the 3-D model (including boundary conditions) used to evaluate concrete cracking under thermal loads, which is discussed in DCD Section 3.8.1.4.1.3. Explain how the approach described in this section, which calculates scale factors of the individual member forces at each critical design-basis section, correctly considers the effect of redistributing the loads due to concrete cracking in the overall containment & building model.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Figure 3.8-19(1) illustrates the 3D model and boundary conditions used in the thermal analyses that define the temperature distributions for the thermal stress and concrete cracking analysis. The model is first initialized for the temperature conditions under normal operating conditions with a steady state thermal analysis, and then a transient thermal analysis is conducted using the boundary conditions and temperature histories representing the design basis accident (or LOCA) shown in the figure. Boundary conditions on exterior surfaces and interior walls exposed to air use a heat transfer coefficient and a reference air temperature. Surfaces in contact with water or the ground use a very large heat transfer coefficient to essentially set the surface temperature to the specified water or ground temperature. Note that analyses are conducted for conditions representing both winter and summer conditions. The stress analyses are then conducted using the 3D ABAQUS/ANACAP model with the temperature distributions from the transient thermal analyses at the specified times of 5 sec, 6 min, 10 hr, and 72 hours. A typical case with time at 6 min. is shown in Figure 3.8-19(2). The stress model is initialized to be stress free at a reference temperature of 15.5 °C (60 °F). This model is used for both a linear stress analysis and a nonlinear concrete cracking analysis for the thermal loads at each of the specified evaluation times. For the nonlinear cracking analyses, the steady state temperature distribution for normal operating conditions is incrementally applied, and then the temperature distributions corresponding to the above evaluation times are incrementally applied allowing concrete cracking and stress redistribution with iterations for static equilibrium.

The section forces and moments at the specified sections are calculated for both the linear stress analyses and the nonlinear concrete cracking analyses at each of the specified time snapshots. The thermal ratios or scale factors are then computed for each section force component by taking the ratio of the nonlinear cracking result to the linear stress result where each has been calculated with the same continuum element model as the basis. These ratios are then used to scale the results from the overall containment and building model design basis analyses, which use linear analyses with plate elements, for thermal stresses at corresponding section cuts. This correctly incorporates the effect of cracking and load redistribution into the design basis model because the physical effect is independent of the type of model used, and ratios specific to each section cut are used to scale the linear results from the plate element model.

The following simple example is presented for illustration. Suppose a reinforced concrete beam is restrained at each end and then uniformly cooled by ΔT from a reference, stress free temperature. The beam will try to contract, but the end restraints will prevent movement, and tensile stress on the section will develop. The stress in the concrete is

$$\sigma_c = E_c \cdot \alpha_c \Delta T \qquad (3.8\text{-}19\text{-}1)$$

and the stress in the longitudinal reinforcement is

$$\sigma_s = E_s \cdot \alpha_s \Delta T \qquad (3.8\text{-}19\text{-}2)$$

The section force due to the restrained thermal load is

$$F = A_c \sigma_c + A_s \sigma_s \qquad (3.8\text{-}19\text{-}3)$$

In the above, E is the elastic modulus, α is the coefficient of thermal expansion, and A is the cross-sectional area. Now, Eα for steel is about 10 times Eα of concrete, and if there is 1% reinforcement, then A of steel = 1/100 of that for the concrete, so that the force component for the steel is about 1/10 that of the concrete. When the thermal load is large enough to cause cracking in the concrete, then the stress (and force) in the concrete is reduced to zero. Since this thermal load is self-limiting, this thermal stress in the concrete is dissipated, i.e. it does not get redistributed to the steel because the stress in the steel is still EαΔT. Therefore, after cracking, the section force is reduced by a factor of 0.1/1.1 = 0.09. The results from any linear analysis (no matter how the analysis is performed) must be scaled by this thermal ratio to correctly consider the effects of cracking under thermal load. This scale factor or thermal ratio can be calculated by taking the ratio of force from the nonlinear analysis to that from a corresponding linear analysis. If the thermal load does not induce concrete cracking, then the ratio will be 1.0.

The same holds true for bending loads in thick concrete sections where a temperature gradient, dT, exists across the thickness. Here, the linear or un-cracked stress has a linear distribution across the section with the concrete fiber stress determined by

$$\sigma = \tfrac{1}{2} E\alpha \cdot dT \qquad (3.8\text{-}19\text{-}4)$$

and the thermal induced section moment is

$$M = \frac{EI\alpha \cdot dT}{t} \qquad (3.8\text{-}19\text{-}5)$$

where I is the bending moment of inertial and t is the thickness of the section. Again, as the thermal load increases, concrete cracking develops to dissipate the stress on the tension side of the section, and only the remaining thermal induced stress in the rebar needs to be balanced with compressive stress in the concrete on the compression side. Thus, the concrete stress and the section moment are reduced, and the appropriate scale factor can be determined from the ratio of the moment calculated using a nonlinear cracking analysis to that obtained from a linear analysis. It is clear that the thermal stresses and thus thermal ratios are functions of the modulus and the amount of reinforcement.

In the ESBWR containment thermal stress analyses, the nonlinear cracking analyses using the 3D brick element model correctly considered the dissipation of thermal stress and redistribution of thermal load through the enforcement of concrete limit states at each integration or material

point in the model. As the appropriate temperature distributions are incrementally applied and as concrete sections develop cracking, the associated concrete thermal stress is dissipated and the section forces are reduced. This reduction in the thermal stiffness of sections can in turn change the restraint conditions for nearby sections for redistribution of the thermal loads. By conducting a sister analysis assuming linear response, and calculating thermal ratios or scale factors between the nonlinear and linear results, the effect of this concrete cracking, stress dissipation, and redistribution of loads can be transferred to the design basis model by scaling the section forces and moments obtained with the linear analysis by the appropriate thermal ratios.

(1) The calculation report 26A6625, Revision 1, October 2005 will be available for staff review in San Jose. This report documents the non-linear analyses for the thermal loads taking into account of concrete cracking and the redistribution of section forces due to concrete cracking.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

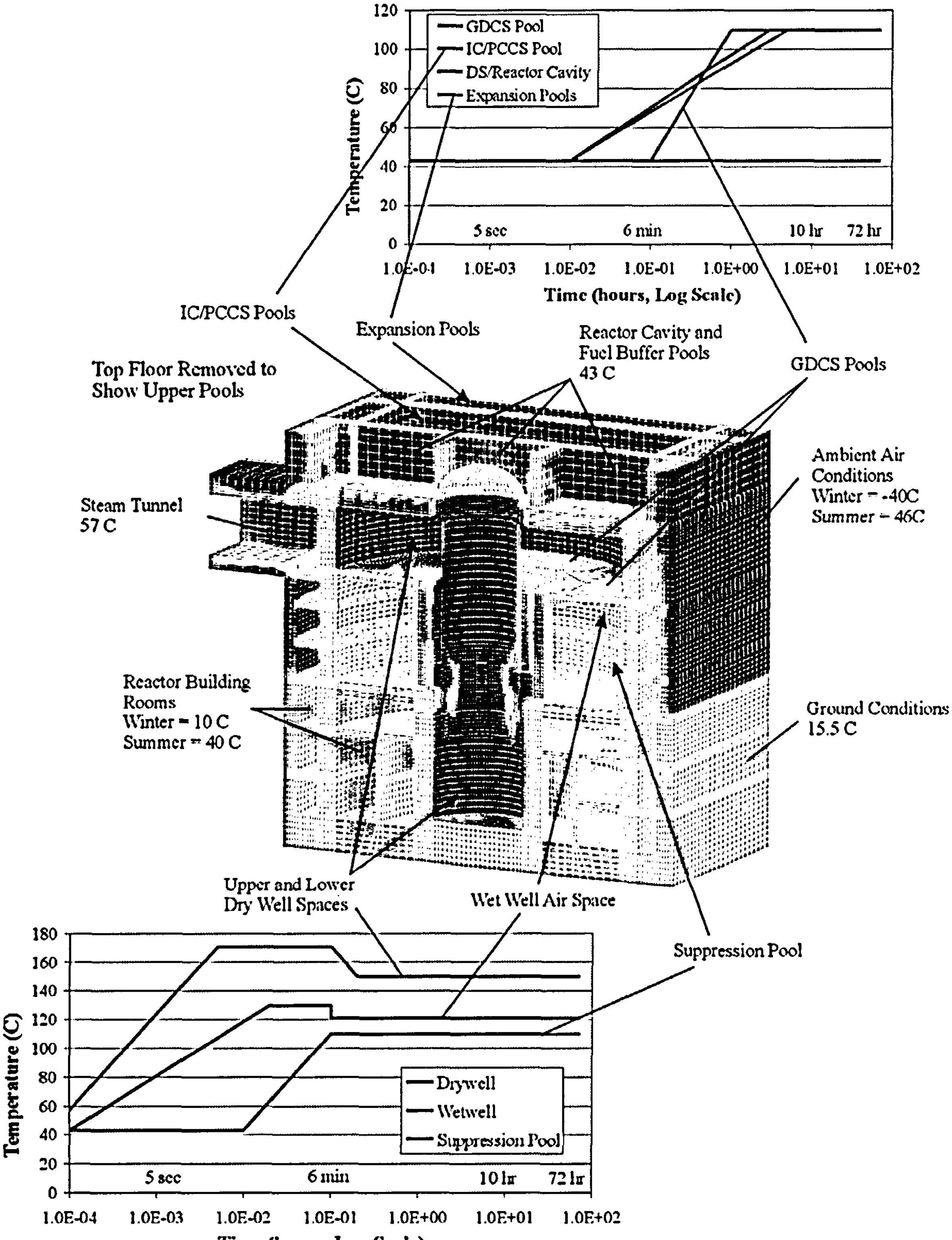

Figure 3.8-19(1). 3D Model and Boundary Conditions for Transient Thermal Analysis

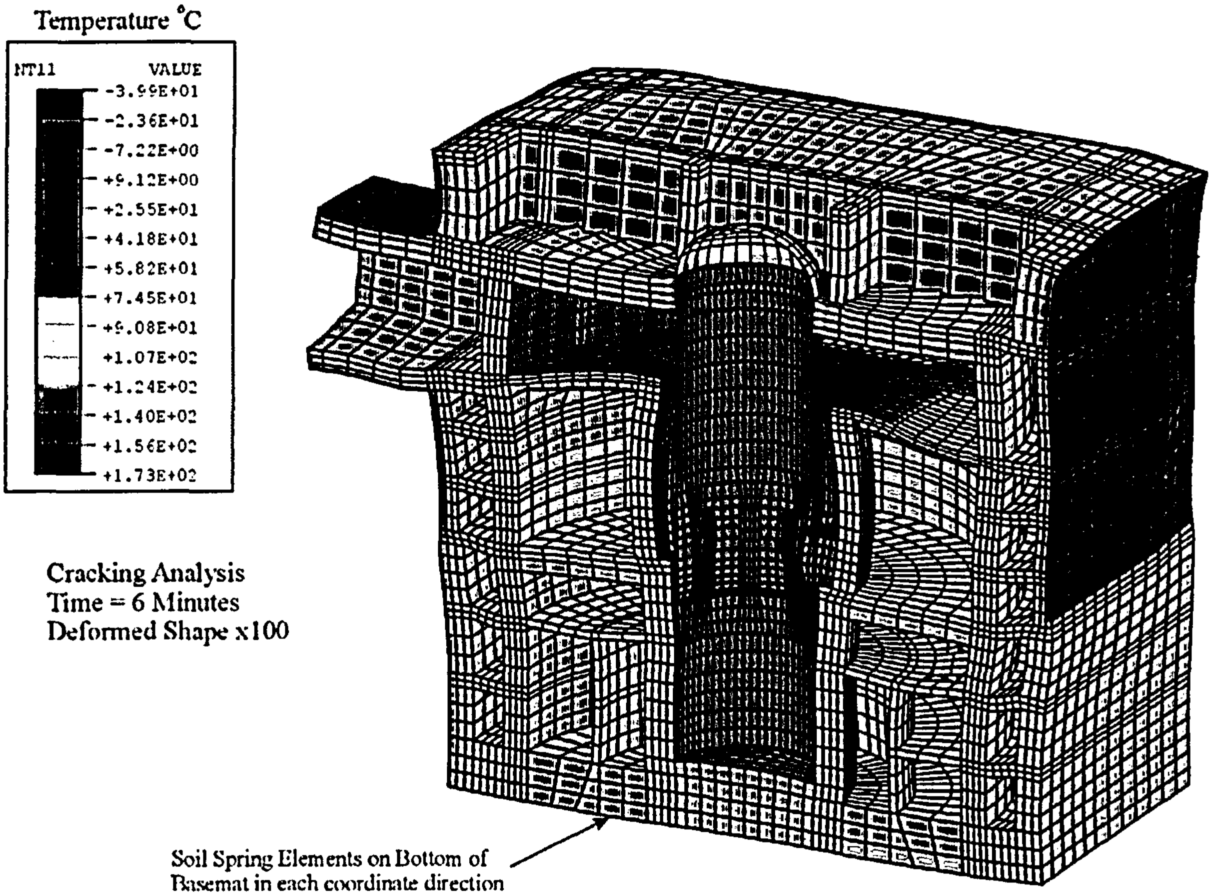

Figure 3.8-19(2). 3D Model for Cracking Analysis Showing temperature Distribution at 6 min.

NRC RAI 3.8-20

Based on the information contained in App. 3G.1.5.2.1.13, it is not clear how seismic member forces for each section are obtained for use in design. If the figures provided in app. 3G are used (i.e., plots of shear, moment, and torsion for the entire "stick model" building versus elevation), rather than individual member forces obtained directly from the NASTRAN model, then explain how the individual member forces (for use in design) are derived. (DCD Section 3.8.1.4.1 and Appendix 3G)

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Seismic loads used for the structural design are obtained from seismic soil-structure interaction (SSI) analyses using a lumped mass-stick model, as described in DCD Appendix 3A.7. Design seismic loads, which are shown in DCD Figures 3G.1-24 through 26 and Table 3G.1-9, are established from the envelopes of all analysis results from SSI cases, as described in DCD Appendix 3A.9.

Seismic member forces for each section are obtained from the NASTRAN analyses for the design seismic loads mentioned above.

Seismic loads consist of four components, i.e., shear, moment, torsion, and vertical acceleration, as shown in DCD Figures 3G.1-24 through 26 and Table 3G.1-9. In the NASTRAN analyses, shear, moment, and torsion due to horizontal seismic loads are applied as nodal forces to the nodes at the connections of seismic walls and floor slabs so as to reproduce the distributions shown in Figures 3G.1-24 through 26. For vertical seismic loads, nodal forces corresponding to the accelerations shown in Table 3G.1-9 are applied to all nodes.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Appendix 3G.1.5.2.1.13 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-23

The staff reviewed DCD Tier 2, Chapter 1 for information of potential significance to the ESBWR containment design, and identified several areas in need of additional information. The staff requests the applicant to address the following:

(1) DCD Tier 2 Section 1.2.1.2, on page 1.2-3, states that the areas above the containment slab and drywell head are flooded in a pool of water during operation, and that this is effective in scrubbing any potential containment leakage through that path. Please describe this hydrostatic loading on the adjacent pool walls, the top slab and the drywell head in greater detail, including the height of the pool, and the pressure gradient. Describe how this loading is included in the load combinations defined in DCD Section 3.8.1 and 3.8.2 and describe the external pressure loading analysis of the drywell head and the results of the analysis; and include the above requested information in DCD Section 3.8.1, Section 3.8.2, and/or Appendix 3G, as applicable.

(2) DCD Tier 2 Table 1.3-3 states that the design temperature of the drywell is 171°C (340°F). Please describe how this design temperature was utilized in defining the concrete and steel properties used in the drywell structural analyses; explain how the concrete temperature limits in ASME Section III, Subsection CC (150°F general, 200°F local) are satisfied; and include the requested information in DCD Section 3.8.1, Section 3.8.2, and/or Appendix 3G, as applicable.

GE Response

(1) The information of the depth of IC/PCCS pool is presented in DCD Tables 3G.1-3 and 4. The magnitude of pressure is proportional to the depth of pool water and considered as a part of dead loads in design.

In the analysis model, hydrostatic loading of 6.7m is considered for drywell head during operation as dead load as stated in DCD Section 3.8.1.3.1 and Tables 3G.1-3 and 4.

(2) Effects of the temperature on material properties are described in DCD Sections 3G.1.5.2.3.1 and 3G.1.5.2.3.2. ASME Section III, Subsection CC-3440 specifies the temperature limits in three conditions as follows.

(a) Long term period; 150 °F general, 200 °F local

(b) Accident or short term period; 350 °F general, 650 °F local

(c) Test; may allowed higher than given in (a) and (b)

Because the Drywell temperature of 171 °C (340 °F) is for the accident condition, it satisfies the ASME limitations.

With regard to the local areas of concrete around high energy penetrations, thermal analyses have been carried out to demonstrate that concrete temperature limits in ASME Section III, CC-3440 are satisfied. In all cases the concrete temperature is lower than 93°C (200°F) for

normal operation, and lower than 177°C (350°F) for accident condition. The sleeve length for hot penetrations is designed to meet these temperature requirements.

DCD Section 3.8.2.1.3 and Appendix 3G.1.5.2.3.1 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-25

Describe how the analysis of a typical liner plate-to-RCCV attachment is performed using the NASTRAN model results. Include this information in DCD Section 3.8.1 and/or Appendix 3G.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Rigid bar elements connect the corresponding grid points of the liner elements and concrete elements as described in DCD Appendix 3G.1.4.1. They are schematically shown in Figure 3.8-25(1). To represent the anchor, rigid bar elements are placed in the radial direction for the liners of the RCCV cylinder wall and the RPV pedestal. They are placed vertically for the basemat, the suppression pool slab, and the top slab.

Using this modeling technique, the design forces of liner plates are obtained from the analysis directly, and the anchorage design is performed in accordance with ACI 349-01 Appendix B.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

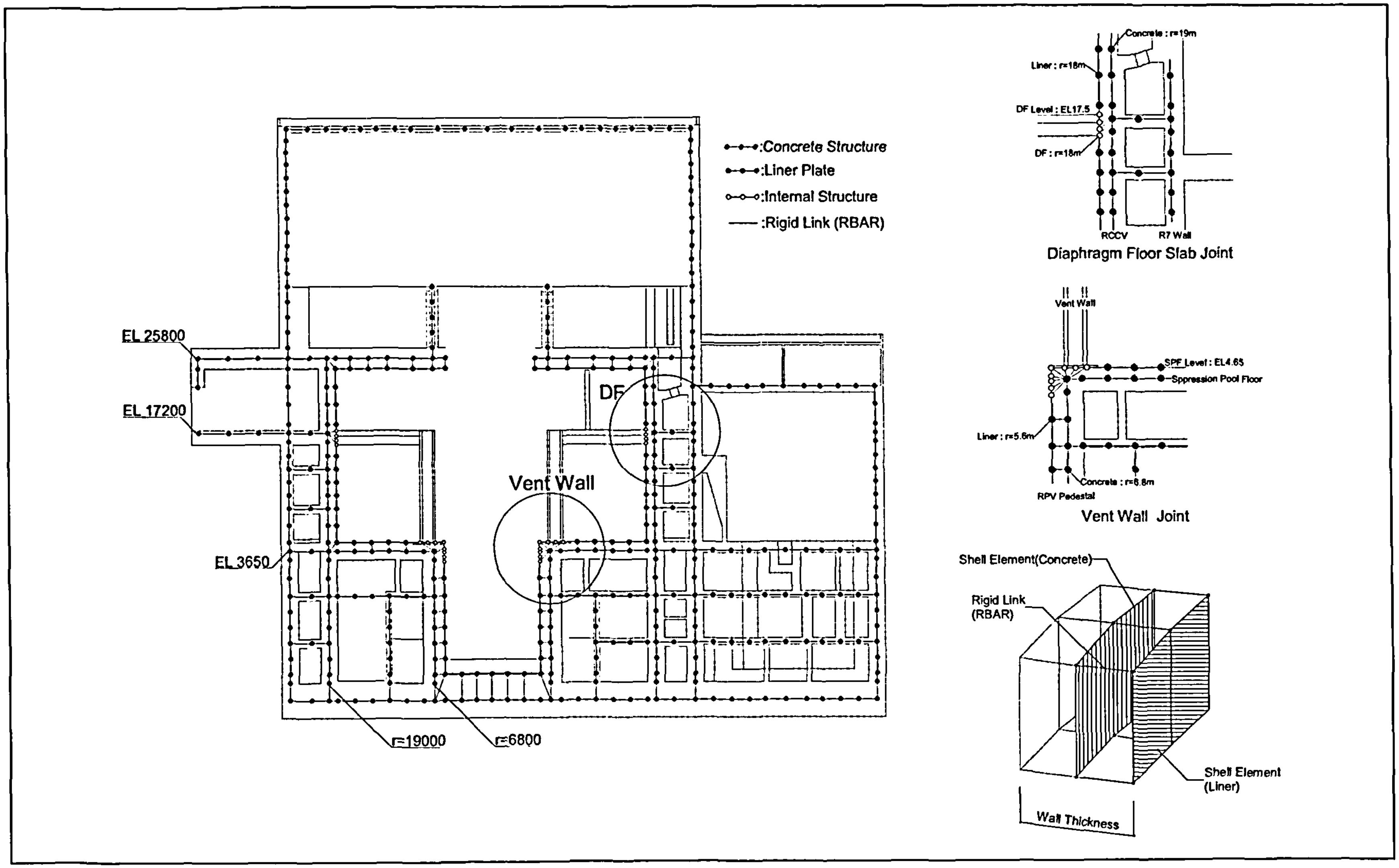

Figure 3.8-25(1) Rigid Bar Elements between Concrete and Liner

NRC RAI 3.8-26

In the NASTRAN model, is the attachment of the liner plate to the RCCV modeled in a manner that is consistent with the physical attachment scheme? Please describe the method used to attach the liner plate to concrete in the NASTRAN model, compare it to the physical attachment scheme, and discuss the adequacy of the model to predict realistic strains in the liner plate. Include this information in DCD Section 3.8.1 and/or Appendix 3G.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Liner plates, as described in the response to RAI 3.8-25, are rigidly attached to the RCCV concrete in the NASTRAN model. This modeling approach is adequate to predict overall liner strains since liners deform in conformance with the concrete, even though liner plates are physically anchored at discrete locations only. Relative movement between liner and concrete will be considered for liner anchor evaluation in the detailed design phase in accordance with the procedures outlined below.

- Displacement Evaluation of Liner Anchor

  The displacement of liner anchor is evaluated for the case that one section of liner plate between the liner anchor and adjacent one buckles. Once the buckling is occurred, the balance of the liner plate forces due to strains of the both sides of liner anchor is disrupted. The liner anchor would strain to balance forces from both sides. The liner plate strains from the integral NASTRAN model and liner anchor load-displacement relationship based on the available test results of similar anchors are used to evaluate the displacement. The evaluation is performed to meet the acceptance criteria in ASME B&PV Code Section III, Division 2, Table CC-3730-1, using the same methodology as Bechtel Topical Report BC-TOP-1, Containment Building Liner Plate Design Report, Revision 1, December 1972.

- Embedment Evaluation of Liner Anchor

  A negative pressure acts on the liner plate in the wetwell portion when hydrodynamic load, such as SRV, CO, CH and combination of them occurs in the suppression pool. Such negative pressure produces a reaction force on the liner anchors embedded in the concrete of RCCV wall. Concrete and liner anchor steel portion are evaluated based on ACI 349-01.

  Embedded portion is evaluated for concrete cone shear resistance and bearing on anchor. For the steel portion of anchor, flange bending stress and web tension stress are evaluated. The evaluation results are compared with ASME B&PV Code Sec. III, Division 2, Table CC-3730-1.

No DCD changes will be made in response to this RAI

NRC RAI 3.8-27

Provide the details of the locally thickened liner plate and additional anchorage at major structural attachments. Was this modeled in the NASTRAN analyses? If not, discuss the basis for not including it. Include this information in DCD Section 3.8.1 and/or Appendix 3G.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

See DCD Figure 3G.1-48 for thickened liner plates at the diaphragm floor (38 mm) and with pedestal (50 mm). They are modeled in NASTRAN using shell elements with the corresponding thicknesses specified. Analysis results are shown in DCD Table 3G.1-35. Regarding anchorage for them, anchorage itself is not modeled, however, the reaction forces are evaluated and the results are shown in DCD Tables 3G.1-38, 3G.1-40 and 3G.1-42.

The thickened liner plates are modeled by shell elements, so the thicknesses are input directly as NASTRAN data.

(1) The applicable detailed report/calculation that will be available for NRC audit is DC-OG-0052, Structural Design Report for Containment Metal components, Revision 1, September 2005, containing evaluation method and results for structural integrity of containment liner and drywell head.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Section 3G.1.4.1 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-40

a) *Provide information (description, plans, and sections) for several structures inside containment that are not presented in the DCD. These structures include the RPV stabilizer, quenchers, RPV insulation, and the connection of the diaphragm floor to the vent wall. The description should include the analysis and design information comparable to the other containment internal structures, including a description of how the quenchers are anchored to the suppression pool.*

b) *Provide additional design details that are not included in many of the configuration details presented in the figures of Appendix 3G.1. This applies to the RPV support bracket, vent wall, shield wall, gravity-driven cooling system (GDCS) pool, diaphragm floor, and miscellaneous platforms. Taking the RPV Support Bracket as an example, missing design information includes the thickness and dimensions of the plates; weld types, sizes, and lengths; and length of anchor bars embedded in the containment that connect to the RPV support bracket.*

Include this information in DCD Section 3.8.3 and/or Appendix 3G.

GE Response

a) The RPV stabilizer, quenchers and RPV insulation are not in the main load path of the containment internal structures, hence they are not included in the global structural analysis. The RPV stabilizer is part of the RPV assembly as shown in DCD Figure 5.3-3. It is supported by the reactor shield wall (RSW) and its supporting effects (such as reactions) are considered in the RSW design. The quenchers for the SRV discharge lines, shown in DCD Figure 6.2-1, are similar to those in the existing BWR plants except they are anchored to the elevated suppression pool slab. The detail design will be done in the next design phase. The RPV insulation does not perform structural functions and the details will be developed in the detailed design phase. The connection of the diaphragm floor to the vent wall is a welded joint.

b) All thickness and dimensions of the steel plates for RPV support bracket, vent wall, shield wall, GDCS pool wall, and diaphragm floor are shown in DCD Figures 3G.1-56 through 3G.1-59. Other information such as weld sizes/lengths and anchorage into the containment are considered to be local design details and will be determined in the detail design phase. Similarly the design of miscellaneous platforms will be performed in the detail design phase.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-41

DCD Sections 3.8.3.1.1 and 3.8.3.1.4 indicate that the diaphragm floor (DF) and vent wall (VW) are constructed from steel plates filled with concrete. Section 3G.1.4.1 of Appendix 3G indicates that the infill concrete is conservatively neglected in the analysis model. Neglecting the mass and stiffness of the concrete may not be conservative. Therefore, provide more information which explains how the infill concrete is considered in the analysis and design of these structures. Describe how the mass, stiffness, and strength are considered when analyzing the DF and VW structures for each applicable loading condition. For analysis of thermal transients, how was the infill concrete modeled in heat transfer analyses, and how was the constraint to thermal growth/contraction of the steel plates considered in the thermal stress analyses?

Include this information in DCD Section 3.8.3 and/or Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Concrete strength and stiffness are conservatively neglected in both the structural analysis model and the seismic analysis model. The mass of concrete is considered in the seismic analysis model and in the structural analysis model.

For the linear thermal analysis, concrete strength and stiffness are neglected and thus the constraint to thermal expansion or contraction of the steel plates from the infill concrete is not considered. However, for the non linear analyses, the infill concrete in VW and DF is explicitly included as brick elements with strain compatibility between the steel and concrete interfaces and using the respective values for the coefficient of thermal expansion for concrete and steel. This modeling includes the effect of the constraint to thermal expansion or contraction to both the concrete and steel components. Note that concrete cracking is also included, and this would relieve some of the thermal induced stress. The effect of this infill concrete on thermal constraint from the nonlinear model is then transferred to the linear thermal-stress design model through scaling via thermal ratios. Concrete cracking effects due to thermal loads are obtained by a nonlinear, concrete cracking analysis using ABAQUS/ANACAP program as described in DCD Appendix 3C.

Thermal transients in the heat transfer analysis done to determine temperature distribution, the heat transfer coefficient of concrete is neglected in the DF and WW for the linear analysis but concrete is included in the non linear model. Through the use of the thermal ratios to account for the thermal stresses, the effect of infill concrete on the heat transfer is implicitly addressed in the linear analysis.

Therefore, for the non-thermal and non-seismic loads, neglecting the strength of the infill concrete in the design of the VW and DF structures is conservative, because the steel sections must then resist all these type of loads (under the bending of the VW or DF, the concrete could resist significant load in compression, if not neglected). For seismic load, neglecting the strength

and stiffness of the concrete but including the mass is conservative because the mass can add significant dynamic load without the benefit of any stiffness or strength to resist this load. For the thermal loads, the stiffness, strength, and associated constraint due to thermal expansion or contraction of the infill concrete is included in the nonlinear modeling. In addition, concrete cracking due to thermal induced stress and the associated reduction and redistribution of thermal load is also included. The effect of concrete expansion or contraction and cracking of the infill concrete in the steel composite structures (VW, DF) associated with thermal loads is incorporated into the design through the use of thermal ratios that scale results of the design basis model that use linear thermal stress analysis neglecting the infill concrete.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6625, Cracking Analysis of Containment Structure for DBA Thermal Loads, Revision 1, October 2005. This report documents the non-linear analyses for the thermal loads taking into account of concrete cracking and the redistribution of section forces due to concrete cracking.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-46

a) *DCD Table 3.8-7 presents the load combinations and acceptance criteria for steel structures inside containment. This table identifies loads P_I and P_s, which are not attributed to any load combinations. Explain what these loads represent and what load factors would be applicable.*

b) *Provide a description of the different subcategories for SRV discharge (e.g., single valve, two valve, ADS, and all valves) and for LOCA (large, intermediate, and small) if applicable, and how they are treated in the load combinations. Also, provide a description and the basis for the method used to combine the various dynamic loads that can occur simultaneously. Include in the description the cyclic loading (i.e., number of events and number of cycles per event) for pressure and temperature loads applicable to the various containment internal structures and how the number of cycles were considered in the design.*

c) *For the SRV and LOCA loads, in addition to the direct pressure loads acting on the boundary of the suppression pool walls and floor, provide a description of the other loads associated with these hydrodynamic loads (e.g., jet loads and drag loads on structural members and quenchers), if applicable. Include a discussion of the analysis method and design approach used to evaluate the effects of these loads on the structural members.*

d) *DCD Table 3.8-7 identifies LOCA loads as condensation oscillation (CO), chugging (CHUG), vent line clearing (VLC), and pool swell (PS); and indicates that the sequence of occurrence is given in Appendix 3B. A description of VLC loads is not provided in Appendix 3B and the sequence of VLC with respect to the other loads is omitted in Figure 3B-3 of Appendix 3B. Therefore, provide a description and sequence for the VLC loads.*

e) *Some containment internal structures are subjected to annulus pressurization (AP) loads. However, it is not clear from DCD table 3.8-7 where AP loads are specified. Therefore, indicate where is the load combination and acceptance criteria for AP loads in DCD Table 3.8-7.*

Include this information in DCD Section 3.8.3, Appendix 3B, and/or Appendix 3G, as applicable. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

a) LOCA (large, intermediate, and small break) are described in Containment Load Definition (CLD) report (NEDE-33261P).

   The drywell pressure associated with Intermediate Break Accident (IBA) is labeled as Pi, while the drywell pressure associated with Small Break Accident (SBA) is labeled as Ps.

The bounding pressure and temperature values are used as LOCA loads in the load combinations for design.

Pi and Ps will be deleted from DCD Table 3.8-7.

b) LOCA (large, intermediate, and small break) and SRV discharges (single valve first actuation, single valve subsequent actuation, and multiple valves) are discussed in CLD (NEDE-33261P). The bounding pressure and temperature values are used as design as LOCA loads in load combinations for design. The SRV pressure values for these three limiting conditions (single valve first actuation, single valve subsequent actuation, and multiple valves) are furnished in NEDE-33261P. The multiple valves case bounds ADS. The SRV pressure values for these three limiting conditions cover the different subcategories of SRV discharge (e.g., single valve, two valve, ADS, and all valves). The bounding values of these three limiting conditions are shown in DCD Figure 3B-1 and are considered as SRV loads in DCD Section 3.8.1.3 and in the DCD load combination Tables 3.8-4 and 3.8-7. The SRV pressure loads are applied throughout the entire suppression pool as axisymmetrical SRV (DCD Section 3.8.1.4.1.1.2), which represents the all (or multiple) valves case. The SRV pressure loads are applied on half of the entire suppression pool as non-axisymmetrical SRV (DCD Section 3.8.1.4.1.1.1), which represents the single valve or two-valve case. Because the total load for the axisymmetrical SRV load case is greater than those for the non-axisymmetrical cases, only the former is considered in the RCCV and vent wall design. The SRV pressure time history and other related information are presented in DCD Appendix 3B.

   LOCA pressure, temperature, SRV, PS, CO or CHUG are combined in accordance with the loading combinations shown in DCD Table 3.8-2 for RCCV or DCD Table 3.8-7 for steel structures inside the containment. Regarding the concurrence of these loads, the combination is based on the time relationship shown in DCD Figure 3B-3.

   Total number of cycles based on the number of events and number of cycles per event for cyclic loadings such as SSE, SRV, CO, CHUG will be considered for fatigue evaluation in the detailed design phase for the steel components of the RCCV according to the requirements of NE-3200. Fatigue consideration is not included in the design of steel structures inside containment. A check will be made in the detailed design phase.

c) For the SRV and LOCA loads, the suppression pool walls and floor slab including liners are subjected to direct pressure loads (including hydrostatic pressure) only. Other associated loads such as jet loads and drag loads are applicable to submerged structures only. Submerged Structure Loads are discussed in CLD (NEDE-33261P). Design of quenchers will be conducted in the detailed design phase.

d) Vent Line Clearing (VLC) is very short duration and prior to Pool Swell (PS). Because there are no structures in the pool directly opposite the vent exits, the water jets created during VLC have no impact. In addition, the VLC pressure response in the pool is bounded by the peak PS pressure. For these reasons, VLC has not traditionally been considered in containment load responses, and it is neither provided in DCD Appendix 3B nor CLR (NEDE-33261P).

   VLC will be deleted from DCD Section 3.8.1.3.5, Tables 3.8-2, 3.8-4 and 3.8-7.

e) A statement shown below will be added at the end of item #3 of DCD Table 3.8-7.

"LOCA includes AP loads."

(1) The applicable detailed reports/calculations that will be available for NRC audit are

- 26A6650, RCCV Structural Design Report, Revision 1, November 2005, containing the structural design details of the RCCV,
- DC-OG-0052, Structural Design Report for Containment Metal Components, Revision 1, September 2005, containing evaluation method and results for structural integrity of containment liner and drywell head,
- DC-OG-0053, Structural Design Report for Containment Internal Structures, Revision 2, October 2005, containing evaluation method and results for structural integrity of containment internal structures.
- NEDE-33261P, Containment Load Definition, Revision 1, May 2006, containing description of hydrodynamic loads.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Tables 3.8-2, 3.8-4, 3.8-7 and Section 3.8.1.3.5 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-47

DCD Section 3.8.3.3.1 seems to single out the reactor shield wall for consideration of the Annulus Pressurization (AP) loads, which the DCD states are loads and pressures directly on the reactor shield wall caused by a rupture of a pipe within the reactor vessel shield wall annulus region. Confirm that the loads and effects of the annulus pressurization are considered not only for the reactor vessel shield wall, but for all applicable containment internal structures such as the RPV support bracket, RPV stabilizer, and RPV insulation. Also explain whether the AP loads generate building dynamic spectral loads and displacements (similar to the other hydrodynamic loads) which need to be considered in the analysis and design of other SSCs.

Include this information in DCD Section 3.83 and/or Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

AP loads and effects are considered not only for the reactor shield wall (RSW), but also for the RPV support bracket, diaphragm floor (DF) and vent wall (VW) structure. The RPV stabilizers are not a part of Steel Internal Structures of Containment, but the reactions are considered in the RSW design. RPV insulation is not a part of Steel Internal Structures of Containment.

Response Spectra and displacements generated by AP loads and other hydrodynamic loads such as SRV, CO, and CH are to be used for the analysis and design of structures, systems and components (SSCs) located inside of RCCV. Dynamic analyses and the results are documented in DCD Appendix 3F. Building dynamic spectral loads and displacements generated by the AP loads are considered in the design.

(1) The applicable detailed reports/calculations that will be available for NRC audit are:

- DC-OG-0053, Structural Design Report for Containment Internal Structures, Revision 0, October 2005, containing evaluation method and results for structural integrity of containment internal structures
- 092-134-F-C-00008, SRVD, LOCA & AP Dynamic Responses in RPV and RSW, Issue 1, June 8 , 2006, containing analysis and results for the response of the RPV, and the RSW to CO, CH, HVL, LCO and SRV in the SP, as well as AP in the RSW and the RPV, and the associated nozzle jet, jet impingement and pipe whip restraint loads..

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-48

DCD Section 3.8.3.4 indicates that the containment internal structures are included in the NASTRAN finite element model described in DCD Subsection 3.8.1.4.1.1. The finite element model described in DCD Subsection 3.8.1.4.1.1 includes the containment, containment internal structures (CIS), reactor building (RB), and fuel building (FB). This subsection also indicates that for LOCA and SRV loadings, the hydrodynamic pressures, as described in Appendix 3B, are applied as equivalent static pressures equal to the dynamic peak value times a dynamic load factor.

Appendix 3F "RESPONSE OF STRCTURES TO CONTAINMENT LOADS" states that this appendix specifies the design for safety-related structures, systems, and components as applicable due to dynamic excitations originating in the primary containment in the event of operational transients and LOCA. The input containment loads are described in Appendix 3B.

The containment loads considered for structural dynamic response analysis are (1) Hydrodynamic Loads which are Condensation Oscillation(CO), Pool Chugging (CH), Horizontal Vent Chugging (HVL), Local Condensation Oscillation (LCO) and Safety Relief valve discharge (SRV) in the Suppression Pool (SP), and (2) Pipe break Loads which consist of Annulus Pressurization (AP) in the annulus between the Reactor Shield Wall (RSW) and Reactor Pressure Vessel (RPV), nozzle jet, jet impingement and pipe whip restraint loads.

The staff notes that Appendix 3F is not reference anywhere in DCD Section 3.8 or Appendix 3G. Therefore, the staff requires additional information to clarify how the dynamic effects of the hydrodynamic loadings were analyzed and how the results were included in the design calculations for the affected structures.

(a) What computer code was used for the hydrodynamic analyses described in Appendix 3F?

(b) Provide detailed information on how the symmetric and asymmetric hydrodynamic loads are applied in the time history analysis.

(c) In Appendix 3F, horizontal and vertical floor response spectra are presented for 4 locations. What is the significance of these 4 locations, compared to any other location? Were response spectra generated at additional locations for future use in subsystem analyses?

(d) From the response spectral plots, it appears that the zero period acceleration (ZPA) frequency is above 100 Hz for several of the loadings; however, the plot is truncated at 100 Hz. Please explain this.

(e) Describe how the hydrodynamic response spectra were/will be utilized in the ESBWR detailed design.

(f) Describe how the structure responses to the hydrodynamic loadings were incorporated into the design evaluation of the affected structures, for load combinations that include hydrodynamic loads.

Include this information in DCD Section 3.8 and/or Appendix 3G, as applicable. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

a) ANSYS software is used for the hydrodynamic load analysis. DCD Section 3C.6 addresses ANSYS documentation.

b) Symmetric loads have an axisymmetric pressure distribution on the SP walls and floors. Asymmetric loads have cosine pressure distribution on the SP walls and floor.

c) The 4 locations for floor response spectra included in DCD Appendix 3F are intended to be representative. Response floor response spectra are generated at all locations of interest for use in the subsystem analysis.

d) The Fourier spectra (amplitude) have been obtained for loads that contain high frequencies (CO and CH loads). The spectra obtained show a rapid reduction of amplitude with frequency. The energy content of the wave at a given frequency is a function of the square of the Fourier amplitude. For CH loads at 100 Hz, the energy content is 36 times less than at frequencies < 10 Hz and 20 times less than for frequencies < 20 Hz. For CO loads, the factors are even higher. Consequently, the truncation at 100 Hz in response spectra is conservative since the actual ZPA values are at higher frequencies.

e) The use of hydrodynamic and AP load response spectra in combination with others loads will be included in the system and equipment design specifications in the detailed design.

f) The design evaluation of the affected structures for hydrodynamic loads was performed using equivalent static pressure input equal to a dynamic load factor (DLF) of two times the peak dynamic pressure. The resulting forces or stresses were combined with those due to other loads in the most conservative manner by systematically varying the signs associated with dynamic loads.

(1) The applicable detailed report/calculation that will be available for NRC audit is 092-134-F-C-00006, Dynamic Response Analysis of Containment Loads, Revision 3, June 2006, containing the RBFB dynamic analysis and results under AP, SRV and LOCA hydrodynamic loads.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

Some changes to DCD Appendix 3F have been identified. DCD Appendix 3F will be revised in the next update as noted in the attached markup. DCD Subsections 3.8.1.4.1.1.1 and 3.8.1.4.1.1.2 will also be revised to add DCD Appendix 3F reference in the next update as noted in the attached markup.

NRC RAI 3.8-49

From the finite element NASTRAN model shown in various figures in Appendix 3G, it is not clear how the RPV has been represented in the model. Therefore, provide a description how the RPV is included in the model. If it is not modeled discretely as a separate structure/component, then discuss how its mass and stiffness have been represented in the overall NASTRAN model.

Include this information in DCD Section 3.8.3 and/or Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

The RPV is not explicitly included in the NASTRAN model. In NASTRAN analysis the RPV reaction forces are applied to the interface locations as nodal forces. The RPV reaction forces, obtained from coupled building-RPV dynamic analysis for seismic and hydrodynamic loads, include the mass and stiffness effects of the RPV.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6558, General Civil Design Criteria, Revision 0, August 2005, containing design criteria for ESBWR structures.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-51

From the information presented in DCD 3.8.3.4 and Appendix 3G, it is not clear how the individual member forces from thermal, seismic, hydrodynamic, and other loads are obtained from the finite element model.

a) Provide a description of what type of analyses (static, response spectra, time history, etc.) are used with the finite element model for each of the applicable loads in order to obtain individual member forces for design.

b) For thermal loading consideration, define the transient and steady state thermal loads, nonlinear temperature distributions, analysis approach, model, and design approach utilized for the major containment internal structures.

Include this information in DCD Section 3.8.3 and/or Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

a) The type of analyses for various loads considered for the containment internal structures, such as Diaphragm Floor (DF), Vent Wall (VW), RPV Support Bracket (RPVSB), Reactor Shield Wall (RSW) and GDCS Pool (GDCSP) are:

(i) Dead Load

Static analysis was performed for the dead load to all containment internal structures. Hydrostatic loads of pool water were also applied statically to VW and GDCSP.

(ii) Pressure load

Static analysis was performed for the pressure load (Po and Pa) applied to DF and VW.

(iii) Thermal load

Static analysis was performed for the thermal load (To and Ta) to all internal structures.

(iv) Seismic load

Static analysis was performed for the seismic load on DF, VW, RPVSB and RSW in the integral NASTRAN model, while response spectra analysis was performed for GDCSP local model.

In this response spectra analysis, it is assumed that all pool water mass is distributed uniformly on the GDCDP wall and RCCV wall. This is considered as a conservative assumption, therefore sloshing was not considered in GDCSP local model. For integral NASTRAN model, however, sloshing load was considered as

the static pressure load on DF upper surface and static reaction load from GDCSP wall. The results from integral NASTRAN model due to these loads were used for the structural integrity evaluation of the structures other than GDCSP, while the results from GDCSP local model were used for evaluation of GDCSP itself.

(v) Hydrodynamic load

Static analysis was performed for the hydrodynamic load (CO, CH and SRV) on VW taking DLF = 2 into account.

(vi) Pipe Break loads consist of Annulus Pressurization (AP) load, jet impingement and pipe-whip restraint loads

(vii) These loads acting on the RSW were first analyzed for dynamic response using the NASTRAN beam model. The resulting maximum values of bending moment and shear force were then applied to the integral NASTRAN static analysis model.

b) All steel temperature is the same as atmospheric temperature. The temperature of the intermediate node of VW rib plate is the average value of outer and inner plate ones. Further discussion of thermal analysis is described in the response to RAI 3.8-41.

(1) The applicable detailed report/calculation that will be available for NRC audit is DC-OG-0053, Structural Design Report for Containment Internal Structures, Revision 2, October 2005, containing evaluation method and results for structural integrity of containment internal structures.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Section 3G.1.5.4.2 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-56

DCD Section 3.8.3.4.1 describes the analysis and design of the diaphragm floor and DCD figure 3G.1-55 provides a drawing of the diaphragm floor. From this information it is not clear whether the diaphragm floor is attached to the radial support beams in a manner that makes them respond as an integral member. Provide a description in DCD Section 3.8.3.4.1 and show in DCD Figure 3g.1-55 how the diaphragm floor and radial support beams are connected.

GE Response

The radial support beams are welded to the diaphragm floor, so they form an integral structure.

DCD Section 3.8.3.4.1 and DCD Figure 3G.1-55 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-63

It is the staff's understanding that the CB is supported on a foundation mat that is independent of the RB and FB. Provide plan and section views showing the relationship of the CB and RB/FB foundation mats and superstructures and confirm that these structures are independent of each other.

Include this information in DCD Section 3.8.4 and/or Appendix 3G.

GE Response

DCD Figures 1.2-2, 1.2-3, 1.2-4, 1.2-5, and 1.2-11 show the relationship of the CB and RB/FB foundation mats and superstructures. These structures are independent of each other.

DCD Section 3.8.4.1.2 and Appendix 3G.2.3 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-64

DCD Section 3.8.4.1.2 states that the CB frame members such as beams or columns are designed to resist vertical loads and to accommodate deformations of the walls in case of earthquake conditions. A similar statement appears in Section 3.8.4.1.3 for the Fuel building and Section 3.8.4.1.4 for the Emergency Breathing Air system (EBAS) Building. Provide the structural design criteria, including the deformation limits, used to design these frame members.

Include this information in DCD Section 3.8.4 and/or Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Frame members are explicitly included in the 3D NASTRAN model. As a result, the interaction with building walls and slabs are automatically accounted for in the analysis. The criterion of frame members is presented in DCD Section 3.8.4.5 Structural Acceptance Criteria.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6655, FB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Fuel Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-82

DCD Section 3G.1.5.2.2.4 states that based on previous experience, critical load combinations are selected for the Reactor Building design. The selected load combinations are shown in Table 3G.1-11. Explain why Load Combination 7 from Table 3.8-15, which includes the effects of tornado loads, is not included as a critical load combination in Table 3G.1-11. It would appear that tornado loads would have a significant effect on the design of the exterior walls of the Reactor Building. Also explain why load Combination 4 in Table 3G.1-11 is considered to be a more critical load combination than Load Combination 3 in Table 3.8-15.

Also clarify whether in the final design of all Seismic Category I Structures, all required load combinations were checked by the design engineer.

Include this information in DCD Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff and (2) reference this report/calculation in the DCD.

GE Response

Design calculations were performed for all load combinations in DCD Table 3.8-15, excluding those which are obviously not critical or whose loads are negligibly small. Among the combinations, the ones which are controlling in critical sections were selected, and their results are described in the DCD. Design calculations for the load combinations including tornado loads were performed, but were found to be less critical than other combinations, like (LOCA + SSE). Therefore, the results are not described in the DCD.

Temperature loads in winter are one of the most severe loads for the exterior wall design. Load Combination 4 in DCD Table 3G.1-11 includes the temperature load, while Load Combination 3 in DCD Table 3.8-15 does not. Therefore, the former is more critical than the latter.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-83

Explain why DCD Section 3G.1.5.3 does not include the load combinations for wind (W) and tornado loads (Wt), as defined in Table 3.8-14.

Include this information in DCD Appendix 3G.

GE Response

Because the impact on the stability by seismic load is larger than wind and tornado, the load combinations for W and Wt are excluded in DCD Section 3G.1.5.3. Only the controlling combinations are reported.

DCD Appendix 3G.1.5.3 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-87

Section 3.8.5.4 indicates that the design of the RB/FB foundation mat involves determining shear and bending moments of the substructure, including interaction of the basemat with the underlying foundation materials. However, DCD Section 3.7 indicates that dynamic analyses are performed using simplified frequency-independent impedance functions, which implies that the dynamic analyses are performed using rigid base assumptions. DCD Section 3.8.5 or Appendix 3G needs to describe the procedures that are employed to determine the bending moments induced in the basemat under applied seismic loads.

Include this information in DCD Section 3.8.3 and/or Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Bending moments induced in the foundation mat are calculated by 3D-NASTRAN static analyses for all design loads including seismic loads.

In the NASTRAN model, the foundation mat is modeled using thick shell elements as described in the response to the RAI 3.8-100, and soil springs corresponding to soft soil are attached to the foundation mat in order to represent the stiffness of underlying foundation soil, as described in DCD Appendix 3G.1.4.2. Figure 3.8-87(1) shows the detail of the basemat portion of the NASTRAN model.

Under seismic loads, the foundation mat resists out-of-plane forces applied from superstructures and foundation soil. Bending moments in the foundation mat are evaluated for the resultant out-of-plane forces.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Section 3.8.5.4 will be revised in the next update as noted in the attached markup.

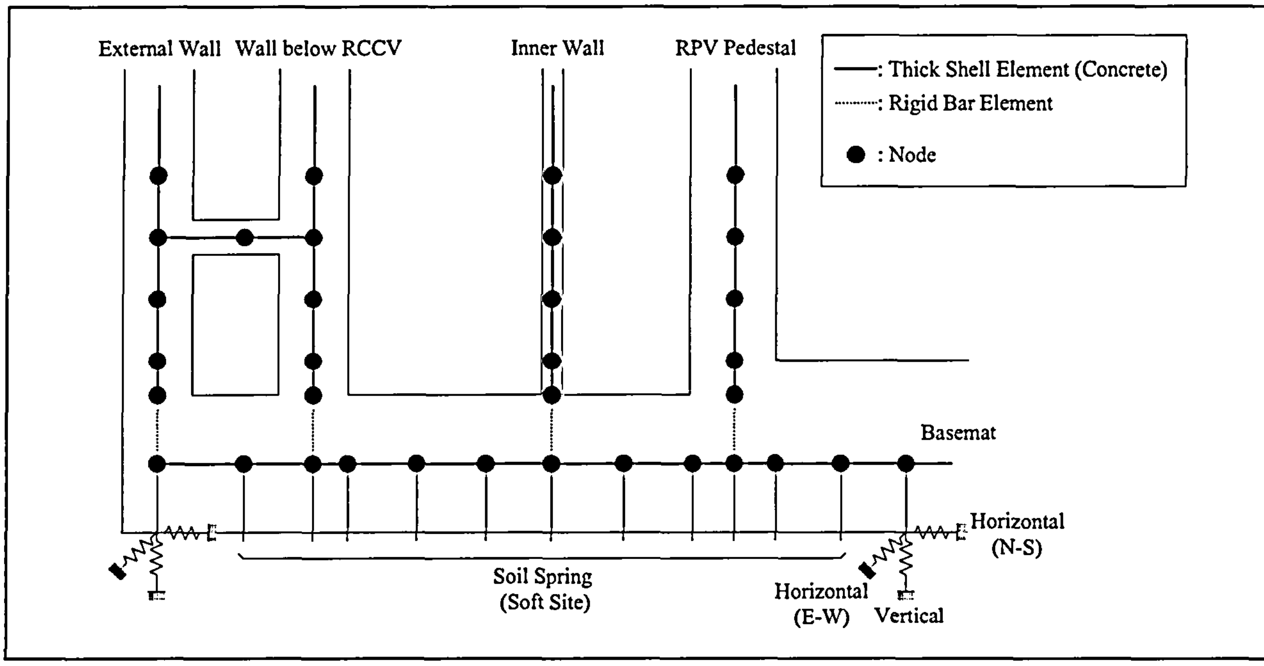

Figure 3.8-87(1) Details of the Basemat Portion of the NASTRAN Model

NRC RAI 3.8-90

DCD Section 3.8.5.4 indicates that the foundations are evaluated for the worst resulting forces from the superstructure, but does not indicate how the worst-case scenario is to be determined. DCD Section 3.8.5.4 needs to indicate the procedures being used to evaluate the worst conditions.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

The worst-case scenario for foundation basemat design is the soft soil since it is subject to largest deformation. From the NASTRAN analysis the results are scanned for the worst loads in the mat sections and are selected for checking the section. This enveloping of most severe loading is done for all loading considered in the analysis.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Section 3.8.5.4 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-91

DCD Section 3.8.5.4 states that the foundations are analyzed using "well-established methods". Identify the references for and describe the "well-established methods" used to analyze the foundations. Demonstrate conformance of these methods with the requirements of SRP 3.8.5. Include this information in DCD Section 3.8.5.4.

In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

As described in DCD Section 3.8.1.4.1.1, the linear elastic finite element (FE) model is used for the analyses of the building structures including the foundation mat, and the foundation soil is modeled with elastic springs in the FE model. The modeling method is the same as the ABWR standard design which was reviewed and approved by the NRC; hence it is considered to be a well-established method.

SRP 3.8.5 II 4.a. requires that the soil-structure interaction be considered in the seismic Category I foundation design, and the method mentioned above satisfies this SRP requirement.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Section 3.8.5.4 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-100

DCD Figure 3G.1-9 shows the finite element (FE) Model of RB/FB Foundation Mat. Describe the type of finite elements used to model the foundation mat. Are they classical thin plate/shell type elements that have only membrane and bending behavior, or are they "thick shell" elements that also account for shear deformation also? How is the transition between the 5.1 meters and the 4 meters portions of the mat modeled? Given the thickness of the foundation mat identified in Table 3.8-13 (5.1 and 4 meters), provide the technical basis for using plate/shell type elements.

Include this information in DCD Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

The type of finite elements used to model the foundation mat is the thick shell type of elements which account for out-of-plane shear deformation also.

In the NASTRAN model and in the section design calculations, the thickness of basemat shell elements is set to 4.0 m uniformly. At the central portion of the mat where the thickness is 5.1 m, the extra 1.1 m is neglected for conservatism because this region is fully constrained by the RPV pedestal and is limited in size as compared to the total mat. Furthermore, this extra thickness is treated as a non-load carrying element. However, the thickened region of the mat is considered in the temperature distribution analysis to evaluate the design temperature of the central portion of the basemat.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

DCD Section 3.8.5.4 will be revised in the next update as noted in the attached markup.

NRC RAI 3.8-104

Given the large disparity of element sizes in the NASTRAN model, how was the numerical stability of the solution checked and verified? In addition, a number of triangular elements around penetrations have large height-to-base aspect ratios, and likely produce less accurate results. Discuss any limitations on the use of the numerical results for these elements.

Include this information in DCD Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

The large disparity of element sizes and triangular elements which have large height-to-base aspect ratios are mainly found in the areas around the RCCV openings in the NASTRAN model. However, the RCCV wall around large penetrations is designed using refined local FEM models to consider stress concentrations. In the local models, large disparity of element sizes is eliminated and elements with smaller aspect ratios are used.

In addition, stresses of triangular elements of large aspect ratios in other locations are compared with those of rectangular elements around the triangular elements to check the reasonableness of the results.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-105

Why is the desirable mesh shown in Figure 3G.1-13 for the suppression pool slab not duplicated for the top slab shown in Figure 3G.1-12? Why is the mesh un-symmetrical with respect to the 90-270 plane?

Include this information in DCD Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

The suppression pool slab is annular in shape. It is convenient to map the mesh in the polar coordinates. As for the top slab, although an annular plate by itself, it is connected to pool girders and pool walls for which the polar coordinates are difficult to apply. NASTRAN model needs to be established considering connections with these walls. This is the reason why the mesh for the top slab is different from that of the suppression pool slab.

The pool girders running along 0°-180° direction and location of pool walls are not symmetrical with respect to 90°-270° plane. Therefore, an un-symmetrical mesh with respect to the 90°-270° plane is developed.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

NRC RAI 3.8-106

Explain why there is movement in the -x direction under dead load in Figure 3G.1-30, movement in the +x direction under drywell unit pressure in Figure 3G.1-31, and a slight rotation about y under vertical seismic load in Figure 3G.1-38.

Include this information in DCD Appendix 3G. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

Because of the weight unbalance between RB and FB, i.e., the RB is heavier than the FB, the basemat slightly rotates about Y axis under the dead load and vertical seismic load. This basemat rotation causes the movement in the -x direction under dead load.

In case of drywell unit pressure, if the model is symmetric, both ends of the basemat would tend to equally deform upwards. However, the RB/FB foundation mat is not symmetric with respect to 90° -270° plane, therefore, the soil springs underneath the mat restrain this deformation of the basemat at the FB side. As a result, the basemat slightly rotates about the Y axis, and the movement in the +x direction is generated.

(1) The applicable detailed report/calculation that will be available for NRC audit is 26A6651, RB Structural Design Report, Revision 1, November 2005, containing the structural design details of the Reactor Building.

(2) Since this information exists as part of GE internal tracking system, it is not necessary to add it to the DCD submittal to the NRC.

No DCD changes will be made in response to this RAI.

3.8.1.3 Loads and Load Combinations

The containment is analyzed and designed for all credible conditions of loading, including normal loads, preoperational testing loads, loads during severe environmental conditions, loads during extreme environmental conditions and loads during abnormal plant conditions.

3.8.1.3.1 Normal Loads

(1) D — Dead load of the structure and equipment plus any other permanent loads, including vertical and lateral pressures of liquids.

(2) L — Live loads, including any moveable equipment loads and other loads that vary in intensity and occurrence, such as forces exerted by the lateral pressure of soil. Live load for structures inside the containment is 9.6 kPa during outages and laydown operations. The loads are applied to the containment interior floors, except the suppression pool floor slab.

(3) T_o — Thermal effects and loads during normal operating, startup or shutdown conditions, including liner plate expansion, equipment and pipe reactions, and thermal gradients based on the most critical transient or steady- state thermal gradient.

(4) R_o — Pipe reactions during normal operating or shutdown conditions based on the most critical transient or steady-state conditions.

(5) P_o — Pressure loads resulting from the pressure difference between the interior and exterior of the containment, considering both interior pressure changes because of heating or cooling and exterior atmospheric pressure variations.

(6) Construction Loads — Loads that are applied to the containment from start to completion of construction. The definitions for D, L and T_o given above are applicable, but are based on actual construction methods and/or conditions.

(7) SRV — Safety/relief valve loads. Oscillatory dynamic pressure loadings resulting from discharge of safety/relief valves (SRVs) into the suppression pool.

3.8.1.3.2 Preoperational Testing Loads

(1) P_t — Test loads are loads which are applied during the Structural Integrity Test (SIT).

(2) T_t — Thermal effects and loads during the SIT.

3.8.1.3.3 Severe Environmental Loads

W —Loads indirectly transmitted by the design wind specified for the plant site as defined in Section 3.3.

3.8.1.3.4 Extreme Environmental Loads

(1) E'— Safe shutdown earthquake (SSE) loads as defined in Section 3.7 including pool sloshing loads.

(2) W' —Loads indirectly transmitted by the tornado specified in Section 3.3.

3.8.1.3.5 Abnormal Plant Loads

(1) Ra — Pipe reactions (including Ro) from thermal conditions generated by a LOCA.

(2) T_a — Thermal effects (including T_o) and loads generated by a LOCA.

(3) P_a — Design accident pressure load within the containment generated by a LOCA, based upon the calculated peak pressure with an appropriate margin.

(4) Y — Local effects on the containment due to a LOCA. The local effects include the following:

   a. Y_r — Load on the containment generated by the reaction of a ruptured high-energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of Y_r.

   b. Y_j — Load on the containment generated by the jet impingement from a ruptured high-energy pipe during the postulated event of the DBA. The time-dependent nature of the load and the ability of the containment to deform beyond yield shall be considered in establishing the structural capacity necessary to resist the effects of Y_j.

   c. Y_m — The load on the containment resulting from the impact of a ruptured high-energy pipe during the DBA. The type of impact (e.g., example plastic or elastic), together with the ability of the containment to deform beyond yield, shall be considered in establishing the structural capacity necessary to resist the impact.

(5) CO — An oscillatory dynamic loading (condensation oscillation) on the suppression pool boundary due to steam condensation at the vent exits during the period of high steam mass flow through the vents following a LOCA.

(6) CHUG — An oscillatory dynamic loading (chugging) in the top vent and on the suppression pool boundary due to steam condensation inside the top vent or at the top vent exit during the period of low steam mass flow in the top vent following a LOCA.

(7) PS — Pool swell bubble pressure on the suppression pool boundary due to a LOCA.

3.8.1.3.6 Load Combinations for the Containment Structure and Liner Plate

The containment structure is designed using the loads, load combinations, and load factors listed in Table 3.8-2. Table 3.8-2 complies with Table CC-3230-1 of the ASME Code Section III Division 2 Subsection CC.

Loads and load combinations listed in Table 3.8-2 are used for the design of the steel liner and liner anchors, but the load factor for all loads in the load combinations is 1.0.

As for seismic loads, the maximum co-directional responses to each of the excitation components are combined by the 100/40/40 method in accordance with ASCE 4-98.

3.8.1.4 Design and Analysis Procedures

This section describes the analytical and design procedures used in designing the containment.

3.8.1.4.1 Containment Cylindrical Wall, Top Slab, and Foundation Mat

3.8.1.4.1.1 Analytical Methods

The containment structure is analyzed by the use of the linear elastic finite element (FE) computer program NASTRAN described in Appendix 3C. The containment, RB and FB layout utilizes an integrated structural system. The structure is idealized as a three-dimensional assemblage of beam elements, and isoparametric membrane-bending plate elements.

The FE analysis model of the containment, RB and FB includes the whole structure. The details of the global FE model are described in Appendix 3G Subsection 3G.1.4.1.

The foundation soil is simulated by a set of horizontal and vertical springs. The soil spring constraints are calculated based on the properties of the soil spring used in the soil–structure interaction (SSI) analysis model, which is described in Appendix 3A. The constraints by soil surrounding the RB and FB are neglected in the FE model.

3.8.1.4.1.1.1 Nonaxisymmetrical Loads

Nonaxisymmetrical loads imposed on the containment and its connected structures, each of which may bear different kinds of loadings, include the following as defined in Subsection 3.8.1.3:

(1) Tornado wind (indirect)

(2) Design wind (indirect)

(3) Safe shutdown earthquake

(4) Local pipe rupture forces, including local compartmental pressures from ruptured pipes in compartments inside or outside the containment

(5) LOCA hydrodynamic pressures in the suppression pool

(6) SRV actuation in the suppression pool

(7) Loadings from embedded steel brackets in the wall and top slab

The containment wall is shielded from the design wind and tornado by the Reactor Building, which completely encloses the structure. Forces from the design wind and tornado are transmitted directly to the containment wall through the RB connections.

The LOCA and SRV hydrodynamic pressures in the suppression pool boundaries as described in Appendix 3B are applied as equivalent static pressures equal to the dynamic peak value times dynamic load factor. The LOCA and SRV dynamic analyses are described in Appendix 3F.

3.8.1.4.1.1.2 Axisymmetrical Loads

Axisymmetrical loads imposed on the containment and its connected structures include the following, and are as defined in Subsection 3.8.1.3:

(1) Structure dead load

(2) Surcharge loads from adjacent structures

(3) Hydrostatic load from probable maximum flood

(4) Hydrostatic load from normal site water table

(5) Local dead and live loads from embedded brackets, treated as axisymmetrical loads for overall structural response

(6) Dead and live loads from internal structures imposed on the suppression pool slab

(7) Normal operating thermal gradients

(8) Abnormal plant thermal gradients

(9) Preoperational test pressure

(10) Abnormal plant pressure loads (including those from high energy line breaks)

(11) Normal external pressure load

(12) SRV actuation in suppression pool

(13) LOCA hydrodynamic pressures in the suppression pool

The LOCA and SRV hydrodynamic pressures in the suppression pool boundaries as described in Appendix 3B are applied as equivalent static pressures equal to the dynamic peak value times dynamic load factor. The LOCA and SRV dynamic analyses are described in Appendix 3F.

3.8.1.4.1.1.3 Major Penetrations

The major penetrations in the concrete containment include: (1) the drywell head, (2) the upper drywell equipment and personnel hatches, (3) the lower drywell equipment and personnel hatches, (4) the suppression chamber access hatch, and (5) the main steam and feedwater pipe penetrations. The global model includes all major penetrations. The state of stress and behavior of the containment around these openings is determined by the use of analytical numerical techniques. The penetrations are included in the global FE model integrating the containment, RB and FB, described in Subsection 3.8.1.4.1.1.

3.8.1.4.1.1.4 Variation of Physical Material Properties

In the design analysis of the containment, the physical properties of materials are based on the values specified in applicable codes and standards. Reconciliation evaluation is performed when the as-built properties becomes available.

3.8.1.4.1.2 Design Methods

The design of the containment structure is based on the membrane forces, shear forces and bending moments for the load combinations defined in Subsection 3.8.1.3.6. The membrane forces, shear forces and bending moments in selected sections are obtained from the analysis done using the computer program NASTRAN, as described in Subsection 3.8.1.4.1.1. The global analysis considers the major structural configurations, including RCCV with the internal steel components, the Reactor Building with floor connections to the RCCV, and the basemat, using plate element modeling and linear material assumptions. The selected sections from the global model used for the section sizing design calculations are described in Appendix 3G Subsection 3G.1.5.4.

The SSDP-2D program module, described in Appendix 3C, is used to determine the extent of concrete cracking at these sections and the resulting concrete and rebar stresses. The SSDP-2D

The equipment hatches and covers are entirely supported by the RCCV.

3.8.2.1.3 Penetrations

In addition to the personnel airlocks, equipment hatches and drywell head, other steel components of the concrete containment vessel include piping and electrical penetrations. The major piping penetrations are associated with main steam and feedwater lines. Electrical penetrations are described in Subsection 8.3.3.7. A summary of various containment penetrations is given in Section 6.2. The state of stress and behavior of the containment wall around these openings is determined by the use of analytical numerical techniques. The analysis of the area around the penetrations consists of a three-dimensional finite element analysis with boundaries extending to a region where the discontinuity effects of the opening are negligible.

The RCCV penetrations are categorized into two basic types. These types differ with respect to whether the penetration is subjected to a hot or cold operational environment.

The cold penetrations pass through the RCCV wall and are embedded directly in it. The hot penetrations do not come in direct contact with the RCCV wall but are provided with a thermal sleeve, which is attached to the RCCV wall. The thermal sleeve is attached to the process pipe at distance from the RCCV wall to minimize conductive heat transfer to the RCCV wall. With regard to the local areas of concrete around high energy penetrations, thermal analyses have been carried out to demonstrate that concrete temperature limits in ASME Section III, CC-3440 are satisfied. In all cases the concrete temperature is lower than 93°C (200°F) for normal operation, and lower than 177°C (350°F) for accident condition. The sleeve length for hot penetrations is designed to meet these temperature requirements.

3.8.2.1.4 Drywell Head

A 10,400 mm diameter opening in the RCCV upper drywell top slab over the RPV is covered with a removable steel torispherical drywell head, which is part of the pressure boundary. This structure is shown in the general arrangement drawings in Appendix 3G Subsection 3G.1.5.4.1.4. The drywell head is designed for removal during reactor refueling and for replacement prior to reactor operation using the Reactor Building crane. One pair of mating flanges is anchored in the drywell top slab and the other is welded integrally with the drywell head. Provisions are made for testing the flange seals without pressurizing the drywell.

3.8.2.2 Applicable Codes, Standards, and Specifications

3.8.2.2.1 Codes and Standards

In addition to the codes and standards specified in Subsection 3.8.1.2.2, the following codes and standards apply:

(1) American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, Division 1, Nuclear Power Plant Components, Subsection NE, Class MC and Code Case N-284.

(2) ANSI/AISC-N690-1994s2 (2004) Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities

Anchorage of steel internal structures complies with Regulatory Guide 1.199.

3.8.3.3 Loads and Load Combinations

3.8.3.3.1 Load Definitions

The loads and applicable load combinations for which a containment internal structure is designed depend on the conditions to which the particular structure is subjected.

The containment internal structures are designed in accordance with the loads described in Subsection 3.8.1.3. These loads and the effects of these loads are considered in the design of all internal structures as applicable. The reactor shield wall is also designed to the Annulus Pressurization (AP) loads, which are loads and pressures directly on the reactor shield wall caused by a rupture of a pipe within the reactor vessel shield wall annulus region.

3.8.3.3.2 Load Combination

The load combinations and associated acceptance criteria for steel internal structures of the containment are listed in Table 3.8-7.

3.8.3.4 Design and Analysis Procedures

The design of steel internal structures is performed in accordance with the general practice of the AISC-N690. The effects of concrete cracking of the containment structure on the accidental thermal stresses in the containment internal structures are accounted for in the form of thermal ratios as described in Subsection 3.8.1.4.1.3.

3.8.3.4.1 Diaphragm Floor

The diaphragm is included in the finite-element model described in Subsection 3.8.1.4.1.1. The design and analysis is based on the elastic method. All loads are resisted by the integral action of the top plate, bottom plate and support beams. The radial support beams are welded to the diaphragm floor, so they form an integral structure.

3.8.3.4.2 RPV Support Bracket

The RPV support bracket is included in the finite-element model described in Subsection 3.8.1.4.1.1.

The design and analysis is based on the elastic method. All loads from RPV support and RSW are resisted by the integral action of eight (8) separate brackets located separately. RPV feet can slide radially, and therefore there are no thermal expansion loads from the RPV support acts on RPV support bracket.

3.8.3.4.3 Reactor Shield Wall

The reactor shield wall is included in the finite-element model described in Subsection 3.8.1.4.1.1. The design and analysis is based on the elastic method. All loads including those from the RPV stabilizer are resisted by the thick steel cylinder supported by the RPV support bracket.

The summary report for the RB is in Appendix 3G Subsection 3G.1. This report contains a description of the RB, the loads, load combinations, reinforcement stresses, and concrete reinforcement details for the basemat, seismic walls, and floors.

3.8.4.1.2 Control Building

The Control Building (CB) is adjacent to but structurally independent of the Reactor Building (see Figures 1.2-2 through 1.2-5 and Figure 1.2-11). The key dimensions of the CB are summarized in Table 3.8-8.

The CB houses the essential electrical, control and instrumentation equipment, the control room for the Reactor and Turbine Buildings and the CB HVAC equipment. Structure below grade in the CB is a Seismic Category I structure that houses control equipment and operation personnel. Structure above grade is a Seismic Category II structure.

The CB is a reinforced concrete box type shear wall structure consisting of walls and slabs and is supported on a foundation mat. Steel framing is composite with concrete slab and is used to support the slabs for vertical loads. The CB is a shear wall structure designed to accommodate all seismic loads with its walls and connected floors. Therefore, frame members such as beams or columns are designed to resist vertical loads and to accommodate deformations of the walls in case of earthquake conditions.

The summary report for the CB is in Appendix 3G Subsection 3G.2. This report contains a description of the CB, the loads, load combinations, reinforcement stresses, and concrete reinforcement details for the basemat, seismic walls, and floors.

3.8.4.1.3 Fuel Building

The Fuel Building (FB) is integrated with the RB, sharing a common wall between the RB and the FB and a large common foundation mat (see Section 1.2). The key dimensions of the FB are summarized in Table 3.8-8.

The FB houses the spent fuel pool facilities and their supporting system and HVAC equipment. The FB is a Seismic Category I structure except for the penthouse that houses HVAC equipment. The penthouse is a Seismic Category II structure.

The FB is a reinforced concrete box type shear wall structure consisting of walls and slabs and is supported on a foundation mat. Concrete and/or steel framing is composite with a concrete slab and is used to support the slabs for vertical loads. The FB is a shear wall structure designed to accommodate all seismic loads with its walls and connected floors. Therefore, frame members such as beams or columns are designed to resist vertical loads and to accommodate deformations of the walls in case of earthquake conditions.

The summary stress report for the FB is in Appendix 3G Subsection 3G.3. This report contains a description of the FB, the loads, load combinations, reinforcement stresses, and concrete reinforcement details for the basemat, seismic walls, and floors.

3.8.4.1.4 Emergency Breathing Air System (EBAS) Building

The Emergency Breathing Air System (EBAS) building is a stand-alone structure, on its own foundation mat, adjacent to the control building (see Section 1.2).

Fuel Building foundation is in Appendix 3G Subsection 3G.3. The summary stress report contains a section detailing safety factors against sliding, over turning, and floatation.

3.8.5.2 Applicable Codes, Standards and Specifications

The applicable codes, standards, specifications and regulations are discussed in Subsection 3.8.1.2 for the containment foundation and in Subsection 3.8.4.2 for the other Seismic Category I foundations.

3.8.5.3 Loads and Load Combinations

The loads and load combinations for the containment foundation mat are given in Subsection 3.8.1.3. The loads and load combinations for the other Seismic Category I structure foundations are given in Subsection 3.8.4.3.

The loads and load combinations for all Seismic Category I foundations examined to check against sliding and overturning due to earthquakes, winds and tornados, and against flotation due to floods are listed in Table 3.8-14.

3.8.5.4 Design and Analysis Procedures

The foundations of Seismic Category I structures are analyzed using well-established methods where the transfer of loads from the foundation mat to the supporting foundation media is determined by elastic methods.

Bearing walls and columns carry all the vertical loads from the structure to the foundation mat. Lateral loads are transferred to shear walls by the roof and floor diaphragms. The shear walls then transmit the loads to the foundation mat.

The design of the mat foundations for the structures of the plant involves primarily determining shear and moments in the reinforced concrete and determining the interaction of the substructure with the underlying foundation medium. For a mat foundation supported on soil or rock, the main objectives of the design are (1) to maintain the bearing pressures within allowable limits, particularly due to overturning forces, and (2) to ensure that there is adequate frictional and passive resistance to prevent sliding of the structure when subjected to lateral loads.

The foundation mat is analyzed using the linear elastic finite element (FE) computer program NASTRAN as described in Sections 3.8.1.4.1.1 and 3.8.4.4.1. The type of finite elements used to model the foundation mat is the thick shell type of elements which account for out-of-plane shear deformation also. The foundation mat resists out-of-plane forces applied from superstructures and foundation soil. Bending moments in the foundation mat are evaluated for the resultant out-of-plane forces. The foundation soil is modeled with elastic springs and connected to the foundation mat elements in the FE model. By means of using this method, the soil-structure interaction (SSI) is considered in the foundation design, and the requirement of SRP 3.8.5 II 4.a is satisfied.

The design loads considered in analysis of the foundations are the worst resulting forces from the superstructures and loads directly applied to the foundation mat due to static and dynamic load combinations.

The worst case scenario for foundation base mat design is the soft soil since it is subject to largest deformation. From the NASTRAN analysis the results are scanned for the worst loads in the mat sections and are selected for checking the section. This enveloping of most severe loading is done for all loading considered in the analysis.

The capability of the foundation to transfer shear with waterproofing is a COL item. See Subsection 3.8.6.1 for COL information.

The site-specific allowable bearing capacities are no less than the calculated static and dynamic bearing pressures. See Subsection 3.7.5.1 for COL information.

The standard ESBWR design is developed using a range of soil conditions as detailed in Appendix 3A. COL Applicant shall determine the physical properties of the site-specific subgrade materials (Subsection 3.8.6.2). Settlement of the foundations, and differential settlement between foundations for the site-specific foundations medium, is calculated, and safety-related systems (i.e., piping, conduit, etc.) designed for the calculated settlement of the foundations. The effect of the site-specific subgrade stiffness and calculated settlement on the design of the Seismic Category I structures and foundations is evaluated. See Subsection 3.8.6.2 for COL information.

A detailed description of the analytical and design methods for the foundations of the RB including the containment, the CB and the FB is included in Appendix 3G.

3.8.5.5 Structural Acceptance Criteria

The main structural criteria for the containment portion of the foundation are to provide adequate strength to resist loads and sufficient stiffness to protect the containment liner from excessive strain. The acceptance criteria for the containment portion of the foundation mat are presented in Subsection 3.8.1.5. The structural acceptance criteria for the RB, CB and FB foundations are described in Subsection 3.8.4.5.

The allowable factors of safety of the ESBWR structures for overturning, sliding, and flotation are included in Table 3.8-14. The calculated factors of safety are shown in Appendix 3G for each foundation mat evaluated according to the following procedures.

The factor of safety against overturning due to earthquake loading is determined by the energy approach described in Subsection 3.7.2.14.

The factor of safety against sliding is defined as:

$$FS = (F_s + F_p)/(F_d + F_h)$$

where F_s and F_p are the shearing and sliding resistance, and passive soil pressure resistance, respectively. F_d is the maximum lateral seismic force including any dynamic active earth pressure, and F_h is the maximum lateral force due to loads other than seismic loads.

The factor of safety against flotation is defined as:

$$FS = F_{DL}/F_B$$

where F_{DL} is the downward force due to dead load and F_B is the upward force due to buoyancy.

Table 3.8-2

Load Combinations, Load Factors and Acceptance Criteria for the Reinforced Concrete Containment[*1,*2,*3]

Load Conditions																		Acceptance Criteria[*6]
Description	No.	D	L	P_t	P_o	P_a	T_t	T_o	T_a	E'	W	W'	R_o	R_a	Y*4	SRV	LOCA	
Service																		
Test	1	1.0	1.0	1.0			1.0											S
Construction	2	1.0	1.0					1.0			1.0							S
Normal	3	1.0	1.0		1.0			1.0					1.0			1.0		S
Factored																		
Severe Environmental	4	1.0	1.3		1.0			1.0			1.5		1.0			1.0		U
Extreme	5	1.0	1.0		1.0			1.0		1.0			1.0			1.0		U
Environmental	6	1.0	1.0		1.0			1.0				1.0	1.0			1.0		U
Abnormal	7	1.0	1.0			1.5			1.0					1.0		1.0	Note*5	U
	8	1.0	1.0			1.0			1.0					1.25		1.0	Note*5	U
	9	1.0	1.0			1.25			1.0					1.0		1.25	Note*5	U
Abnormal/Severe Environmental	10	1.0	1.0			1.25			1.0		1.25			1.0		1.0	Note*5	U
Abnormal/ Extreme Environmental	11	1.0	1.0			1.0			1.0	1.0				1.0	1.0	1.0	Note*5	U

*1: The loads are described in Subsection 3.8.1.3 and acceptance criteria in Subsection 3.8.1.5.

*2: For any load combination, if the effect of any load component (other than D) reduces the combined load, then the load component is deleted from the load combination.

*3: Because Pa, Ta, SRV and LOCA are time-dependent loads, their effects are superimposed accordingly.

*4: Y includes Y_j, Y_m and Y_r.

*5: LOCA loads, CO, CHUG and PS are time-dependant loads for which DLF may be used. The sequence of occurrence is given in Appendix 3B. The load factor for LOCA loads shall be the same as the corresponding pressure load P_a.

*6: S = Allowable Stress as in ASME Section III, Div. 2, Subsection CC-3430 for Service Load Combination. U = Allowable Stress as in ASME Section III, Div. 2, Subsection CC-3420 for Factored Load Combination.

Table 3.8-4

Load Combination, Load Factors and Acceptance Criteria for Steel Containment Components of the RCCV (1), (2), (3)

Service Level	No	Load Combination (1)																Acceptance Criteria			
		D	L	P_t	P_o	P_a	T_t	T_o	T_a	E'	W	W'	R_o	R_a	Y (4)	SRV	LOCA (5)	P_m	P_L	P_L+P_b (8)	P_L+P_b+Q
Test Condition	1	1.0	1.0	1.0			1.0											0.75 S_y	1.15Sy	1.15Sy (11)	N/A (10)
Design Condition	2	1.0	1.0			1.0			1.0					1.0				1.0 S_{mc}	1.5 S_{mc}	1.5 S_{mc}	N/A
Level A, B (9)	3	1.0	1.0		1.0			1.0					1.0					1.0 S_{mc}	1.5 S_{mc}	1.5 S_{mc}	3.0 S_{m1}
	4	1.0	1.0		1.0			1.0								1.0					
	5	1.0	1.0			1.0			1.0					1.0							
	6	1.0	1.0			1.0			1.0					1.0		1.0	1.0				
Level C (6)	7	1.0	1.0		1.0			1.0		1.0			1.0					1.2 S_{mc} or* 1.0 S_y	1.8 S_{mc} or* 1.5S_y	1.8 S_{mc} or* 1.5S_y	N/A
	8	1.0	1.0			1.0			1.0	1.0				1.0		1.0	1.0				
	9	1.0	1.0			1.0			1.0			1.0	1.0	1.0	1.0	1.0	1.0				
Level D (7)	10	1.0	1.0			1.0				1.0				1.0	1.0	1.0	1.0	S_f	1.5S_f	1.5S_f	N/A

Notes:

(1) The loads are described in Section 3.8.1.3

(2) For any load combination, if the effects of any load component (other than D) reduces the combined load, then the load component is deleted from the load combination.

(3) P_a, T_a, SRV and LOCA are time-dependent loads. The sequence of occurrence is given in Appendix 3B.

(4) Y includes Y_j, Y_m and Y_r.

(5) LOCA loads include CO, CHUG and PS. They are time-dependent loads. The sequence of occurrence is given in Appendix 3B.

(6) Limits identified by (*) indicate a choice of the larger of the two.

(7) S_f is 85% of the general primary membrane allowable permitted in Appendix F, ASME B&PV Code, Section III. In the application of Appendix F, S_{mt}, if applicable, shall be as specified in Section II, Part D, Subpart 1, Tables 2A and 2B of ASME B&PV Code, which is the same as S_m.

(8) Values shown are for a rectangular section. See NE-3221.3(d) for other than a solid rectangular section.

(9) The allowable stress intensity S_{m1} shall be the S_m listed in Section II, Part D, Subpart 1, Tables 2A and 2B and the allowable stress intensity S_{mc} shall be 1.1 times the S_m listed in Section II, Part D, Subpart 1, Tables 1A and 1B, except S_{mc} shall not exceed 90% of the material's yield strength at temperature shown in Section II, Part D, Subpart 1, Tables Y-1 of the ASME B&PV Code

(10) N/A = No evaluation required

(11) Bending and General Membrane P_m+P_b.

Table 3.8-7

Load Combination, Load Factors and Acceptance Criteria for Steel Structures Inside the Containment [*1, *2]

Category	No.	Load Combination D	L	P_o	P_a	T_o	T_a	E'	W	W'	R_o	R_a	Y[*4]	SRV	LOCA	Acceptance Criteria[*5]
Normal	1	1.0	1.0	1.0												S
	2	1.0	1.0	1.0		1.0					1.0					S(a)
Severe Environmental	3	1.0	1.0	1.0					1.0					1.0		S
	4	1.0	1.0	1.0				1.0						1.0		S
	5	1.0	1.0	1.0		1.0			1.0		1.0			1.0		S(a)
	6	1.0	1.0	1.0		1.0		1.0			1.0			1.0		S(a)
Extreme Environmental	7	1.0	1.0	1.0		1.0				1.0	1.0			1.0		1.6S(b)(c)
	8	1.0	1.0	1.0		1.0		1.0			1.0			1.0		1.6S(b)(c)
Abnormal	9	1.0	1.0		1.0		1.0					1.0		1.0	Note[*3]	1.6S(b)(c)
	9a	1.0	1.0		1.0		1.0							1.0	Note[*3]	1.6S(b)(c)
Abnormal/Severe Environmental	10	1.0	1.0		1.0		1.0					1.0	1.0	1.0	Note[*3]	1.6S(b)(c)
Abnormal/Extreme Environmental	11	1.0	1.0		1.0		1.0	1.0				1.0	1.0	1.0	Note[*3]	1.7S(b)(c)

*1 The loads are described in Subsection 3.8.4.3.1.1 and acceptance criteria in Subsection 3.8.4.5.1.

*2 For any load combination, where any load reduces the effects of other loads, the corresponding coefficient for that load shall be taken as 0.9 if it can be demonstrated that the load is always present or occur simultaneously with the other loads. Otherwise, the coefficient for that load shall be taken as zero.

*3 LOCA loads, such us CO, CHUG and PS are time-dependant loads. The sequence of occurrence is given in Appendix 3B. The loads factor for LOCA loads shall be the same as the corresponding Pressure Load P_a. The maximum values of P_a, T_a, R_a, Y including an appropriate Dynamic Load Factor (DLF) shall be used, unless an appropriate time history analysis is performed to justify otherwise. LOCA includes AP loads and effects

*4 Y includes Y_j, Y_m and Y_r.

*5 Allowable elastic working stress (S) is the allowable stress limit specified in Part 1 of ANSI/AISC N-690-1994-s2 (2004).

(a) For primary plus secondary stress, the allowable limits are increased by a factor of 1.5.

(b) Stress limit coefficient in shear shall not exceed 1.4 in members and bolts.

(c) The Stress limit coefficient where axial compression exceeds 20% of normal allowable, shall be 1.5 for load combinations 7, 8, 9, 9a and 10, and be 1.6 for load combination 11.

a. If $(fs)_h > f_2$ then use f_2

b. If $f_1 < (fs)_h < f_2$ then use $(fs)_h$

c. If $f_1 > (fs)_h$ then use f_1

In symmetric load case, three vertical frequencies of 5 Hz (SRV-V1), 6.06 Hz (SRV-V2) and 12 Hz (SRV-V3) are selected. In asymmetric load case, 3 horizontal frequencies, 5 Hz (SRV-H1), 8.83 Hz (SRV-H2) and 12 Hz (SRV-H3), of the structure satisfying the above selection criteria are adopted as bubble frequencies.

(3) HVL Load

Both symmetric and non-symmetric upward loads are considered on the ventwall structure due to chugging in the top horizontal vents.

(4) Chugging, Condensation Oscillation Loads

Sixteen critical pressure time histories for CH and 5 CO are selected for dynamic analysis. Furthermore, one local spike load is added in CO response study.

3F.2.4 Analysis Method

(1) Pipe Break Load Analysis

For these analyses, multi-input excitation time history analyses are performed using a full transient analysis. The α mass matrix and β stiffness matrix multipliers are used for the damping matrix.

(2) Symmetric Load Analysis

For the dynamic response analyses of SRV and LOCA cases, the full harmonic analysis solution method is used. The input time history is first transformed into harmonic loads. Each harmonic loading is analyzed individually for Fourier n=0 spatial distribution in the frequency domain. Responses to each harmonic loading are transformed back to the time domain and then superimposed, on a time consistent basis, to obtain the total responses. The constant (frequency-independent) stiffness for each material is used. The damping matrix is obtained as follows:

$$[C] = \sum_{j=1}^{Nm} \frac{2}{\Omega} \beta_j [K_j] \qquad (3F\text{-}3)$$

where:

N_m = Number of materials

Ω = circular excitation frequency

$[K_j]$ = structural stiffness matrix

$[C]$ = structural damping matrix

β_j = constant damping stiffness matrix coefficient

Table 3F-1

Maximum Accelerations for AP Loadings (g)

Location	Node	MS	RWCU	FW
Top of Vent wall	701	0.0275	0.0644	0.0143
Top of pedestal	706	0.015	0.0224	0.0153
Upper pool slab	208	0.0047	0.0147	0.0082

Table 3F-2

Maximum Accelerations for Hydrodynamic Loads (g)

Location	Direction	Node	SRV	HVL	CH	CO	LCO
Top of vent wall	Horizontal Vertical	1104 1104	0.12 0.21	0.01 0.14	0.024 0.68	0.02 0.53	0.01 0.35
SP Floor	Horizontal Vertical	1254 1254	0.14 0.31	0.000 0.040	0.14 1.325	0.32 1.66	0.04 0.31
RCCV Top slab side	Horizontal Vertical	1119 1119	0.08 0.09	0.000 0.000	0.30 0.13	0.08 0.19	0.01 0.06
RCCV Top slab center	Horizontal Vertical	1159 1159	0.08 0.14	0.000 0.000	0.24 1.25	0.06 0.40	0.01 0.03

Table 3F-3

Maximum Displacements for AP Loadings (mm)

Location	Node	MS	RWCU	FW
VW Top	701	0.0166	0.047	0.0317
Top of Pedestal	706	0.0099	0.019	0.0131
Upper pool slab	208	0.0103	0.017	0.0112

Table 3F-4

Maximum Displacements for Hydrodynamic Loads (mm)

Location	Direction	Node	SRV	HV	CH	CO	LCO
VW Top	Horizontal Vertical	1104 1104	0.17 1.57	0.0 0.01	0.054 0.11	0.01 8.30	0.0 0.18
SP Floor	Horizontal Vertical	1254 1254	0.27 1.11	0.0 0.0	0.039 0.229	0.05 7.72	0.0 0.14
RCCV Top slab side	Horizontal Vertical	1119 1119	0.20 0.94	0.0 0.0	0.07 0.033	0.02 7.33	0.0 0.12
RCCV Top slab center	Horizontal Vertical	1159 1159	0.20 1.38	0.0 0.01	0.05 0.21	0.01 8.52	0.0 0.20

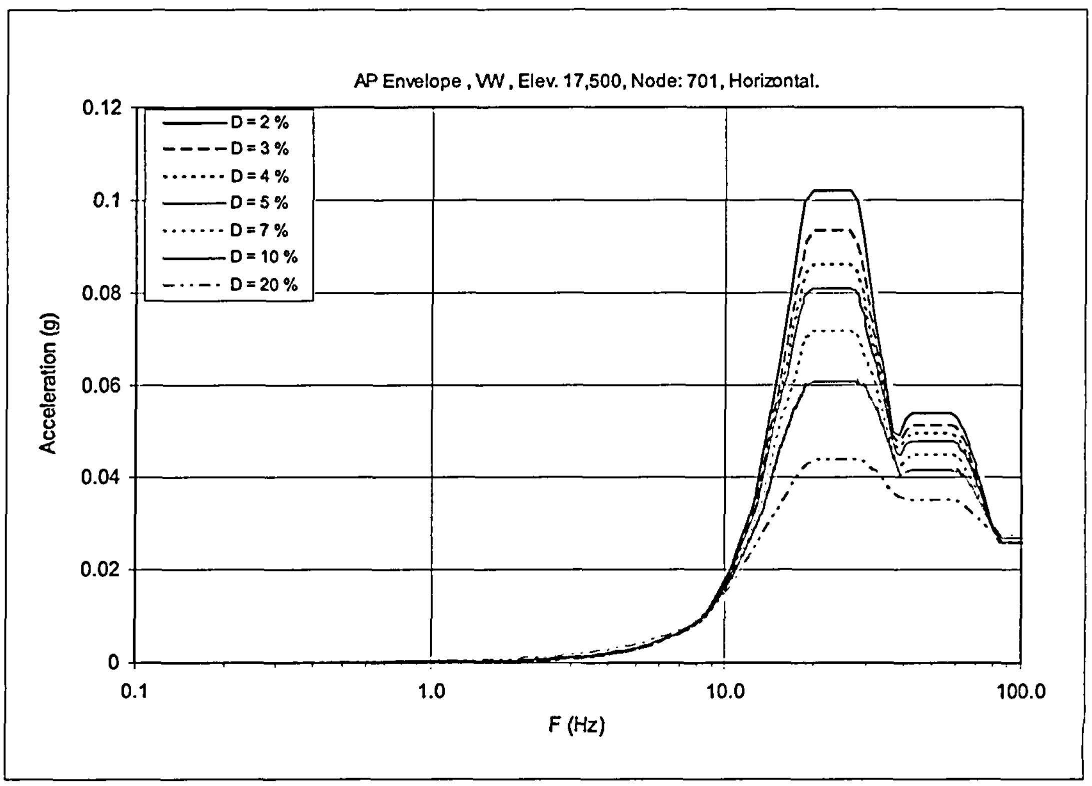

Figure 3F-4. Floor Response Spectrum—AP Envelope, Node: 701, Horizontal

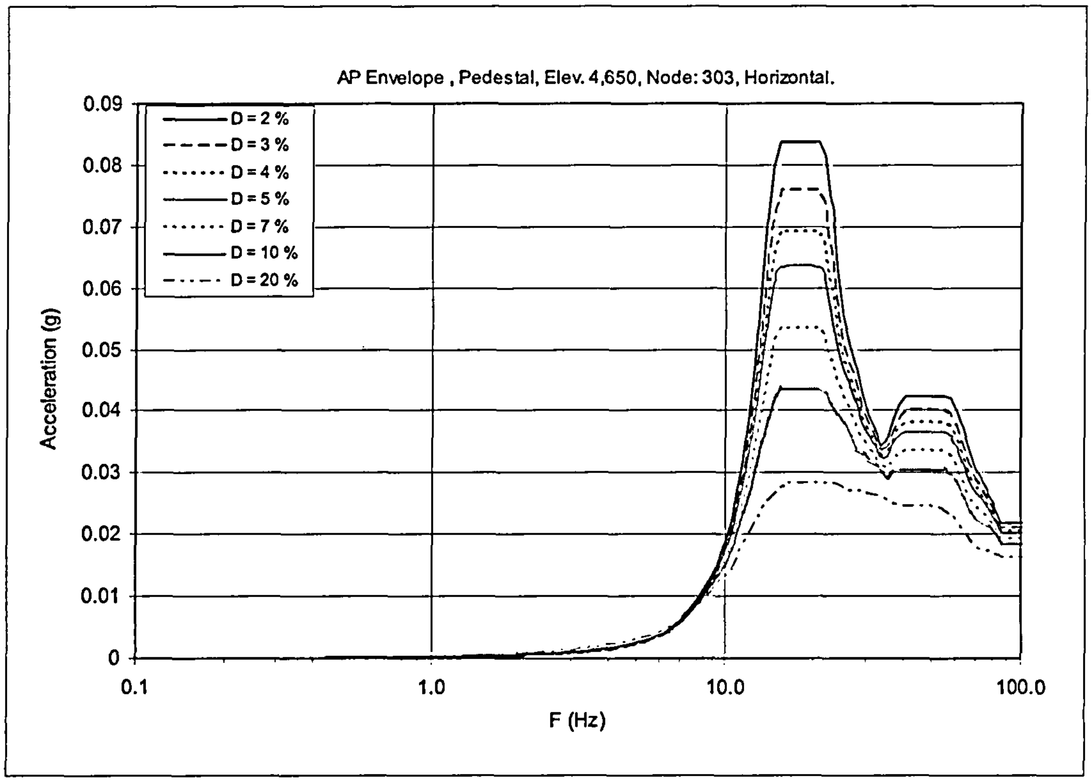

Figure 3F-5. Floor Response Spectrum—AP Envelope, Node: 706/303, Horizontal

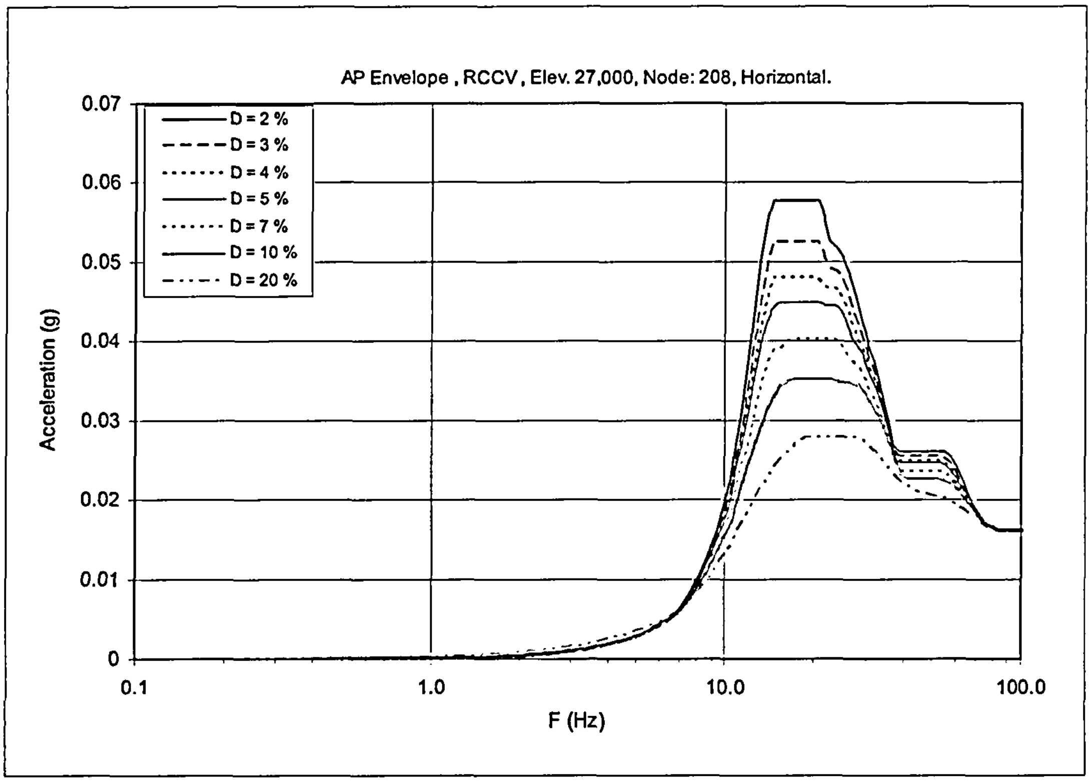

Figure 3F-6. Floor Response Spectrum—AP Envelope, Node: 208, Horizontal

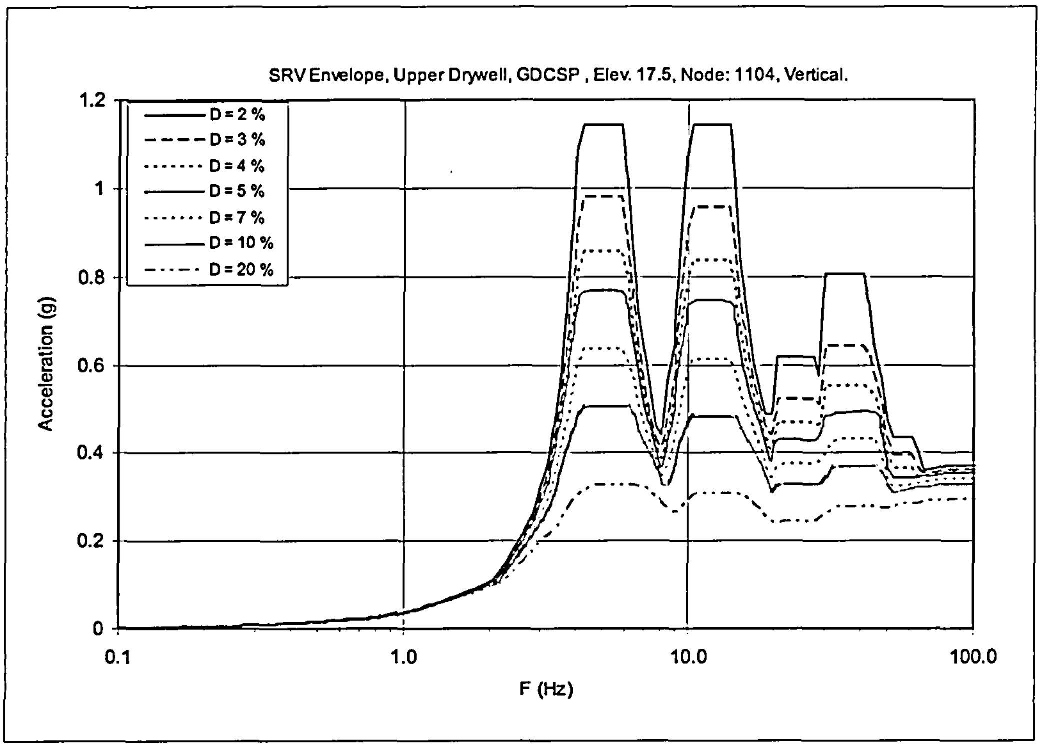

Figure 3F-7. Floor Response Spectrum—SRV Envelope, Node: 1104, Vertical

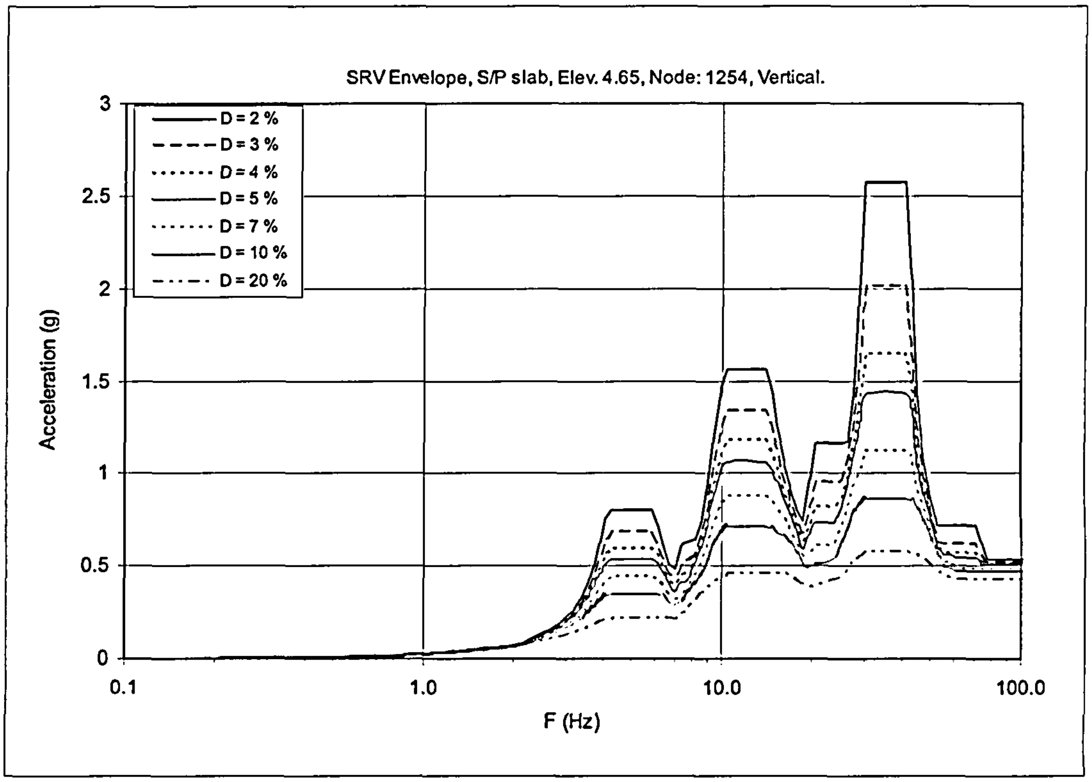

Figure 3F-8. Floor Response Spectrum—SRV Envelope, Node: 1254, Vertical

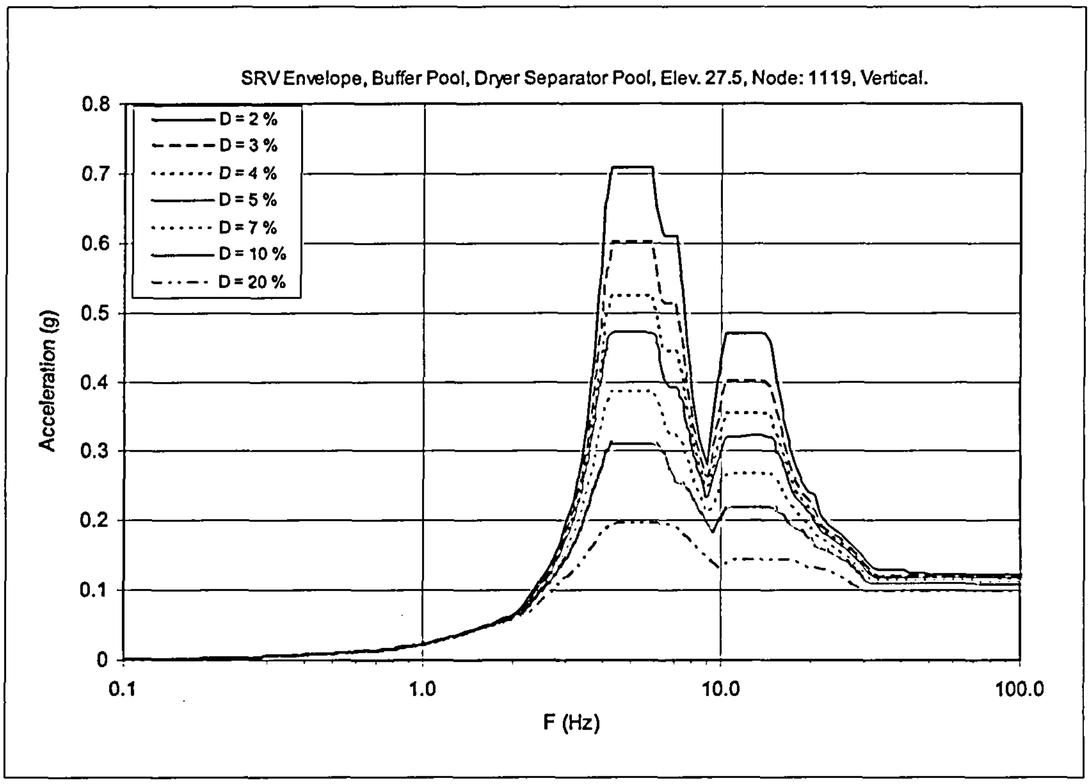

Figure 3F-9. Floor Response Spectrum—SRV Envelope, Node: 1119, Vertical

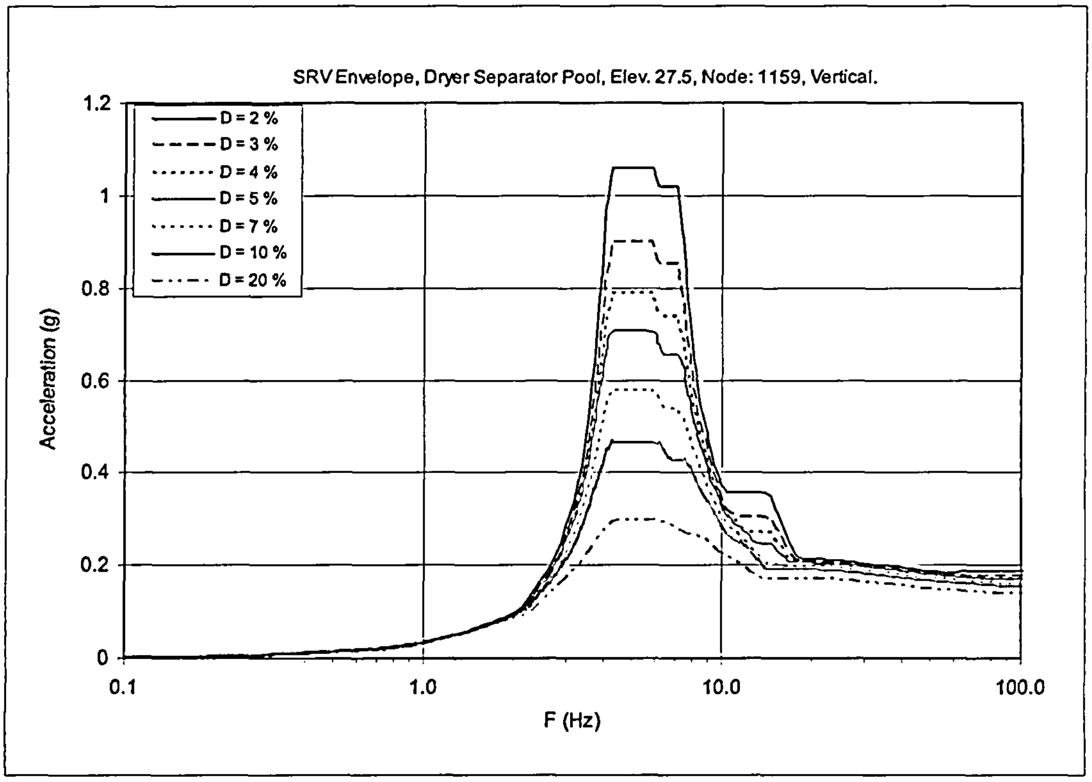

Figure 3F-10. Floor Response Spectrum—SRV Envelope, Node: 1159, Vertical

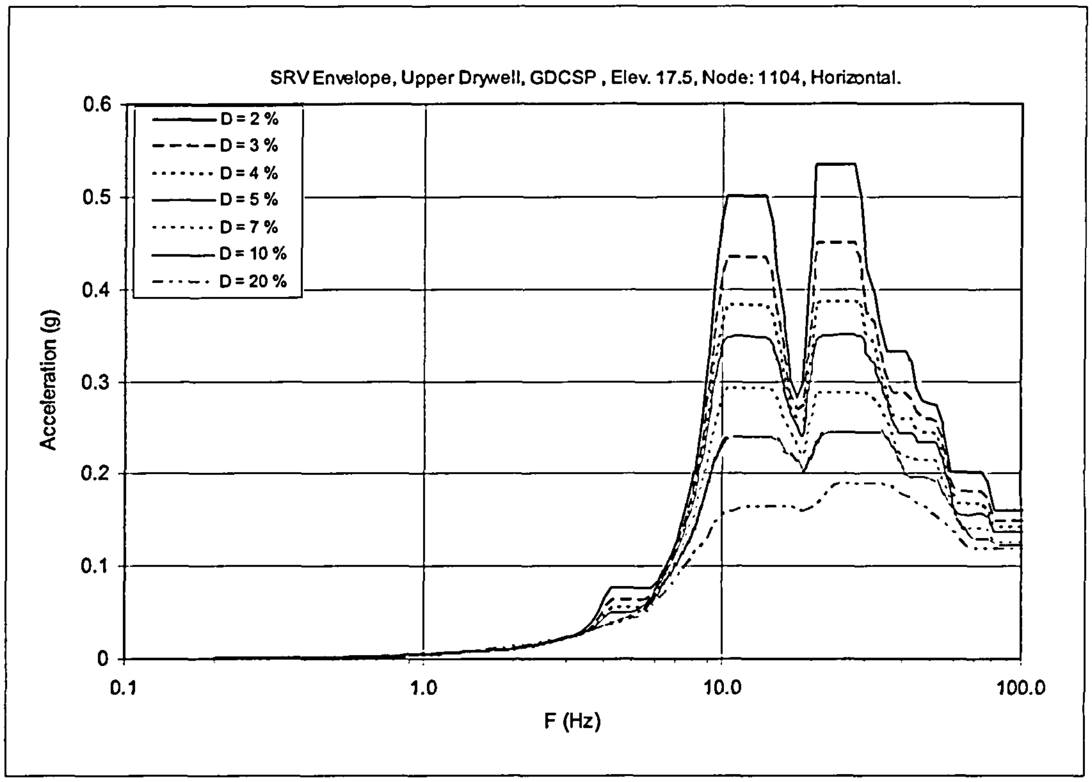

Figure 3F-11. Floor Response Spectrum—SRV Envelope, Node: 1104, Horizontal

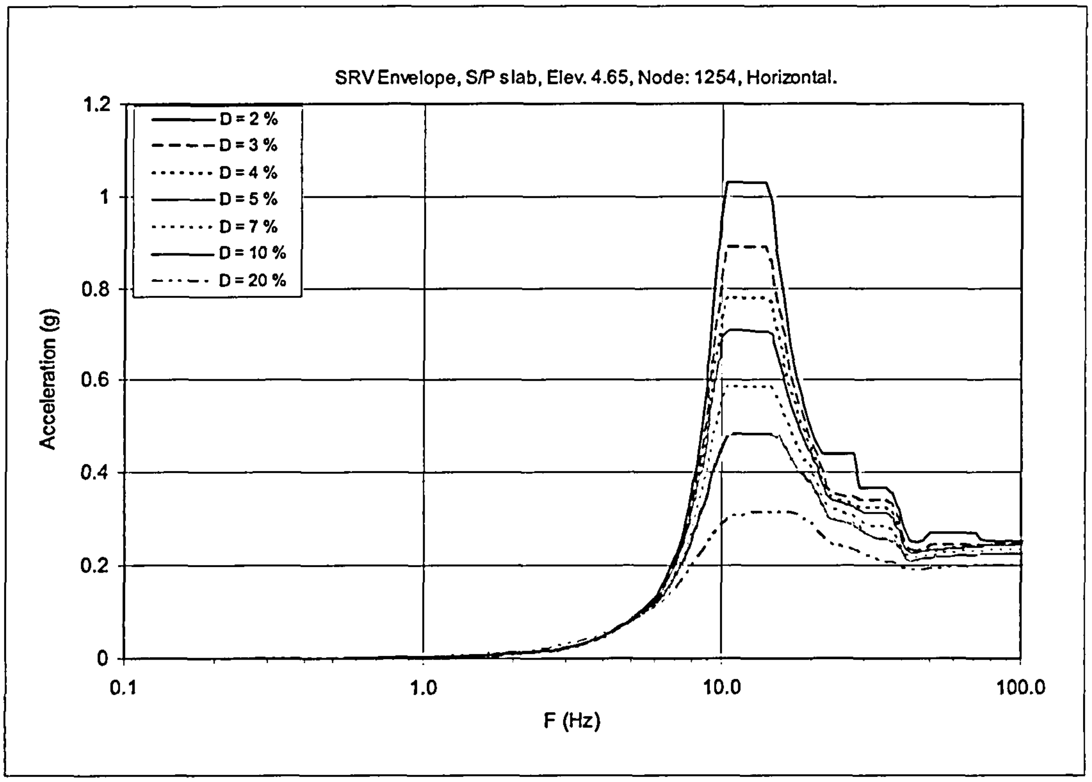

Figure 3F-12. Floor Response Spectrum—SRV Envelope, Node: 1254, Horizontal

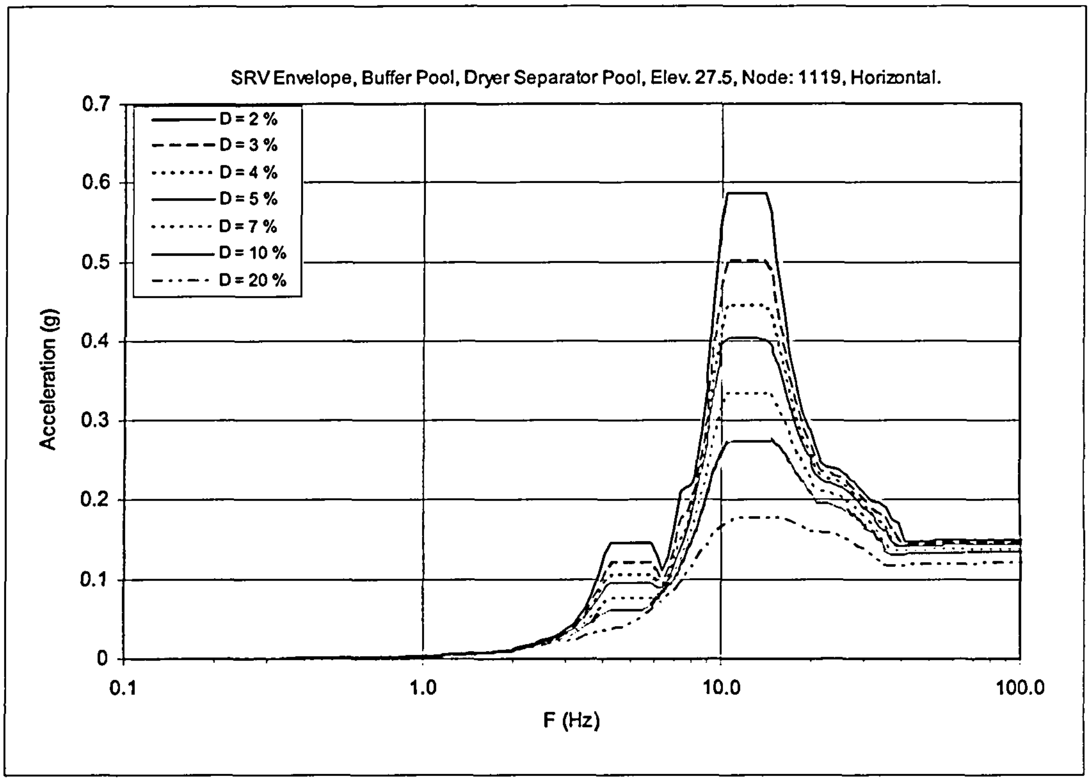

Figure 3F-13. Floor Response Spectrum—SRV Envelope, Node: 1119, Horizontal

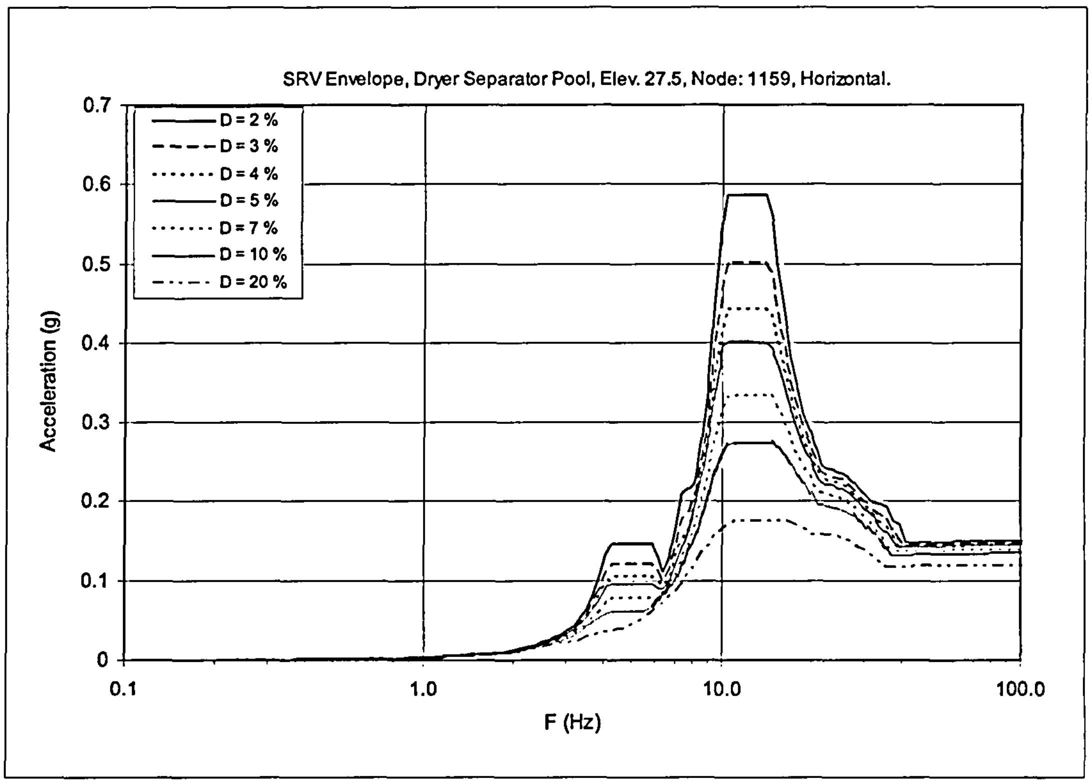

Figure 3F-14. Floor Response Spectrum—SRV Envelope, Node: 1159, Horizontal

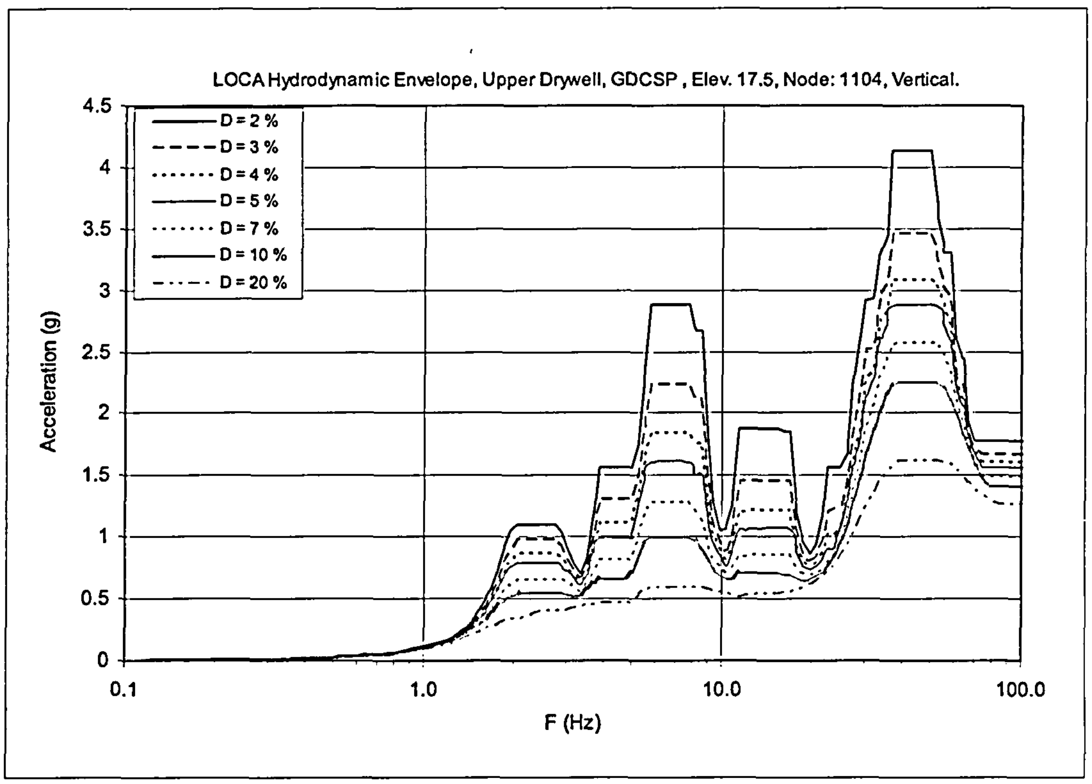

Figure 3F-15. Floor Response Spectrum—CH & CO Envelope, Node: 1104, Vertical

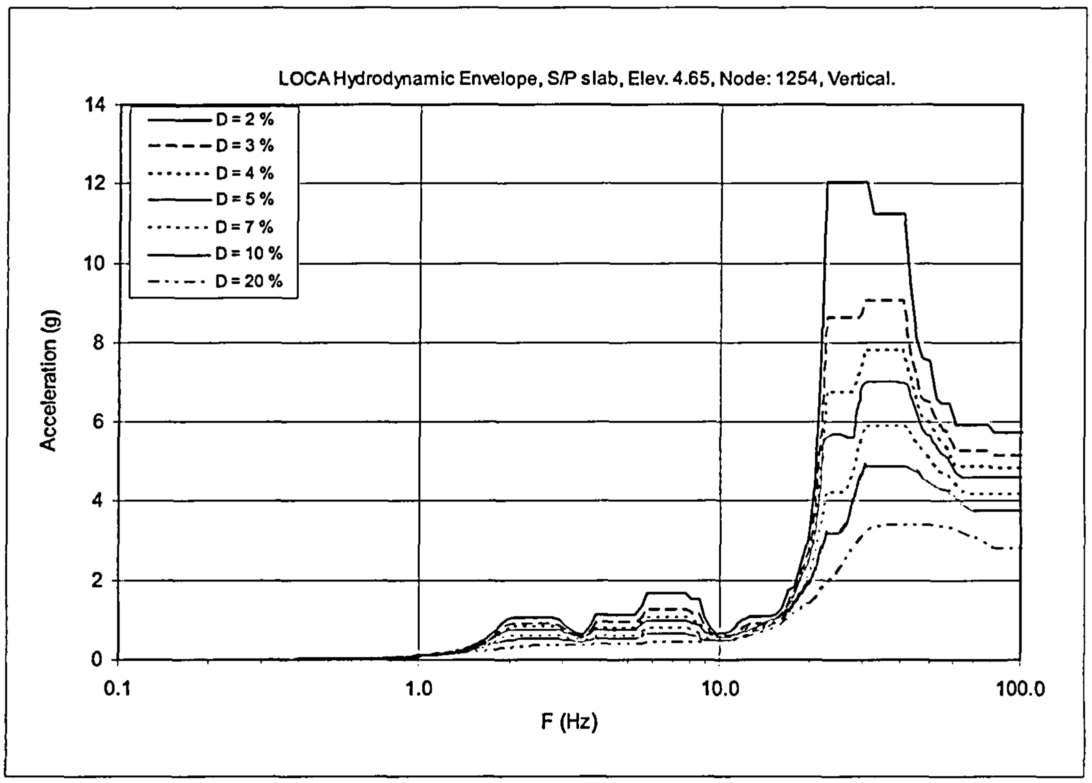

Figure 3F-16. Floor Response Spectrum—CH & CO Envelope, Node: 1254, Vertical

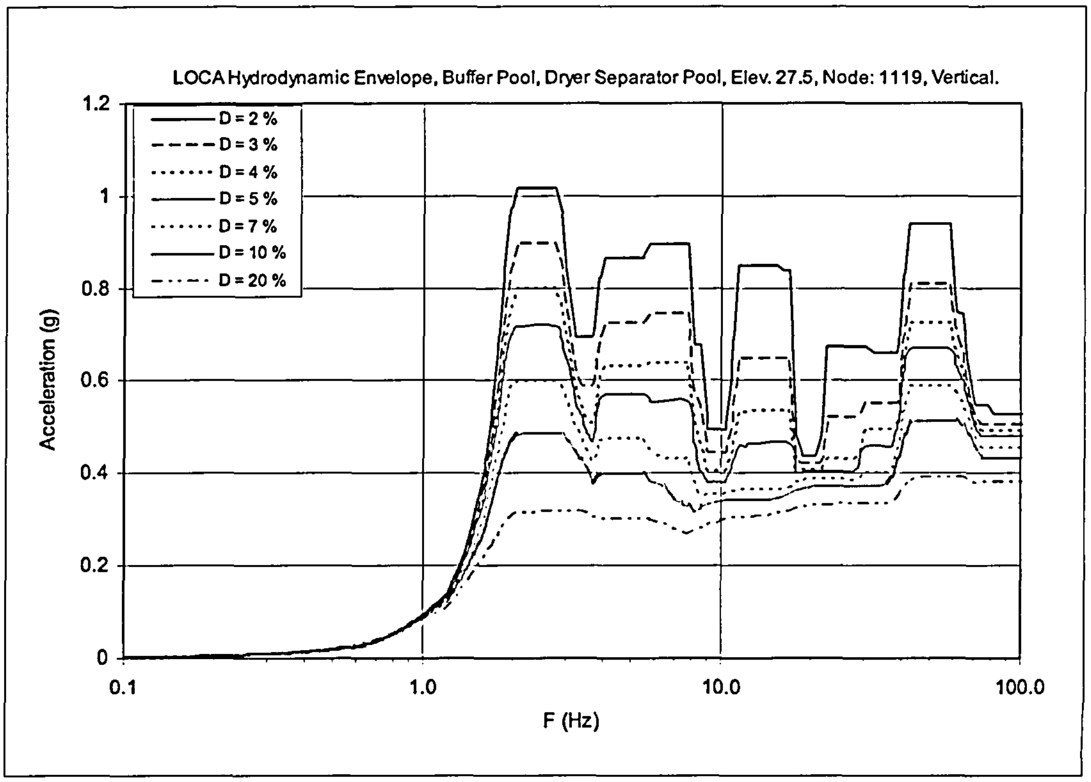

Figure 3F-17. Floor Response Spectrum—CH & CO Envelope, Node: 1119, Vertical

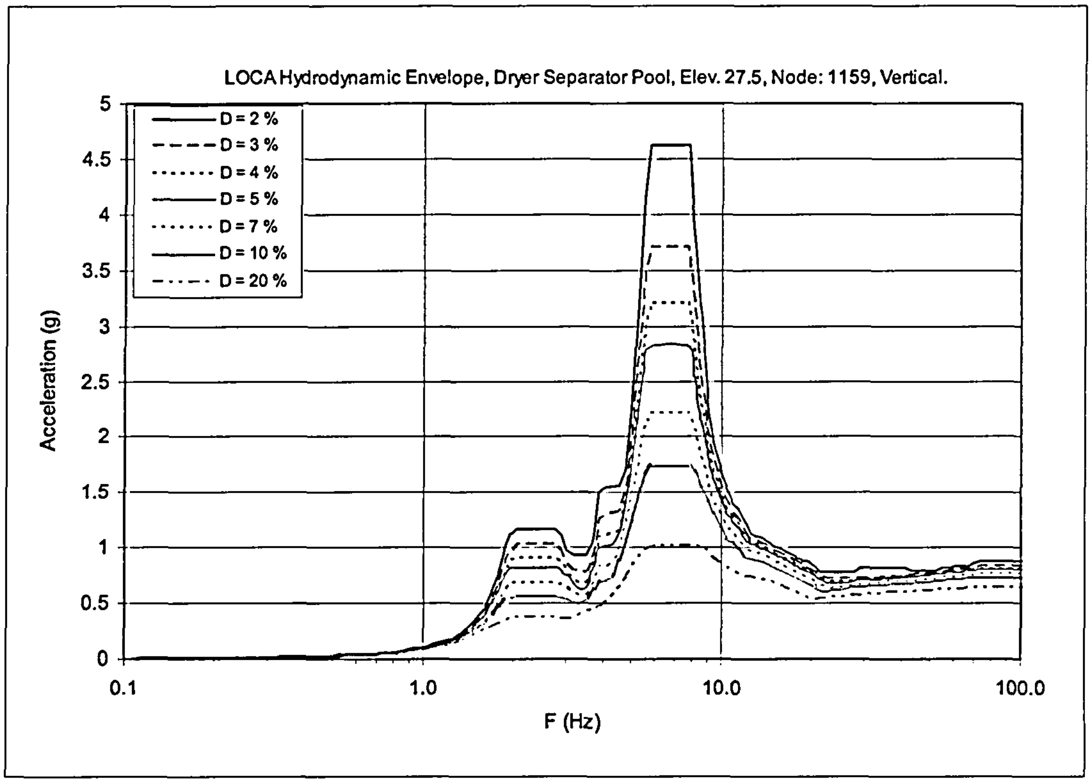

Figure 3F-18. Floor Response Spectrum—CH & CO Envelope, Node: 1159, Vertical

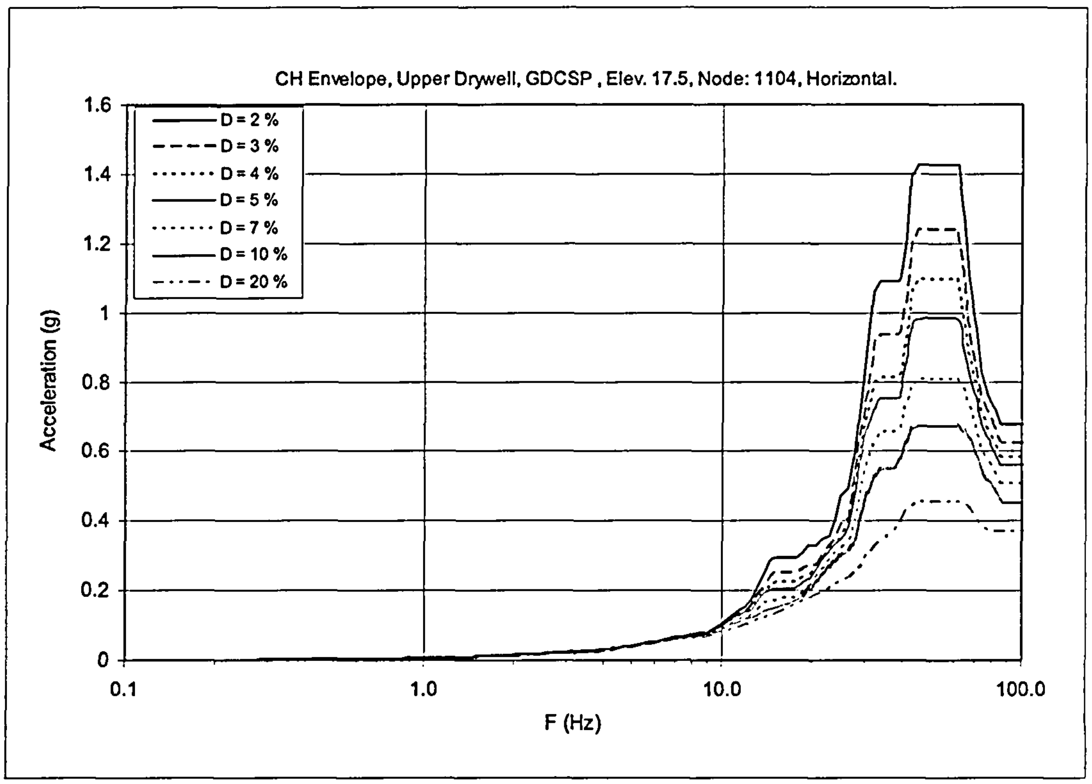

Figure 3F-19. Floor Response Spectrum—CH Envelope, Node: 1104, Horizontal

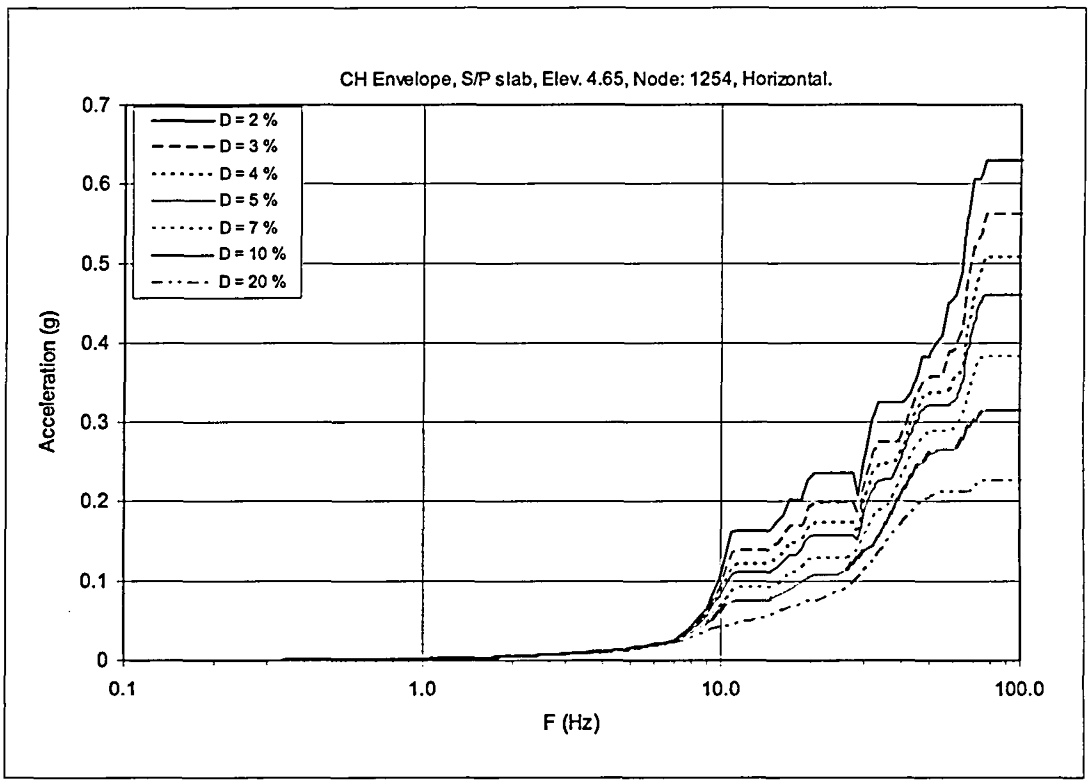

Figure 3F-20. Floor Response Spectrum—CH Envelope, Node: 1254, Horizontal

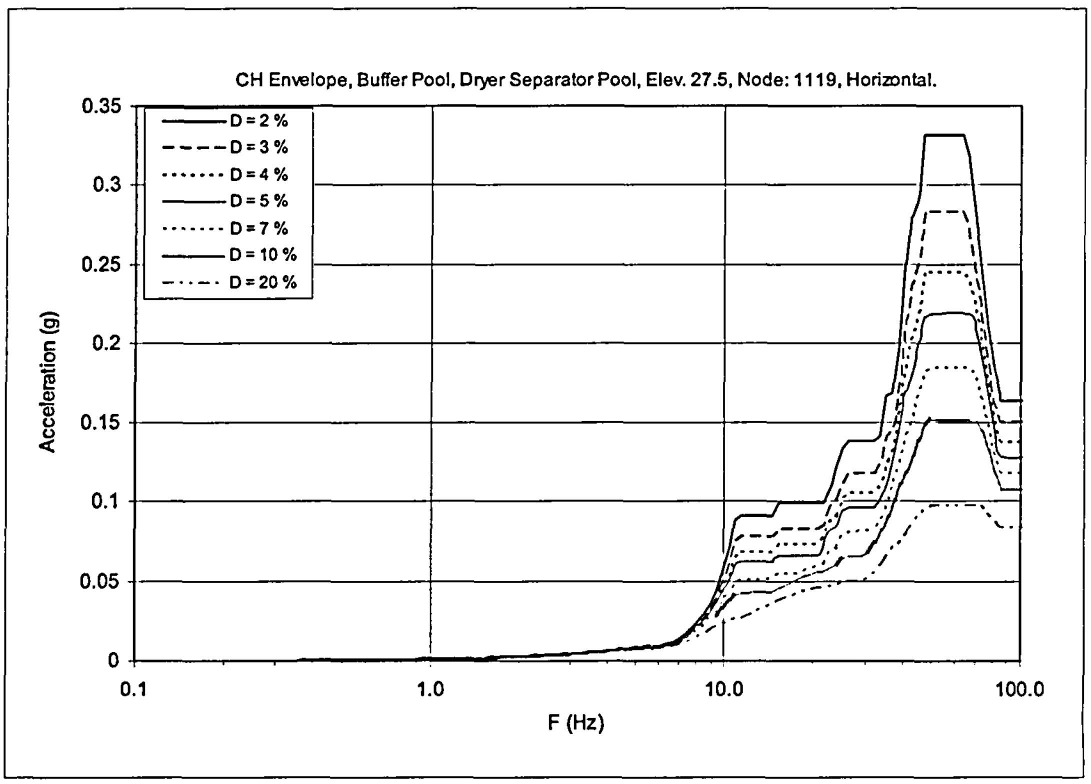

Figure 3F-21. Floor Response Spectrum—CH Envelope, Node: 1119, Horizontal

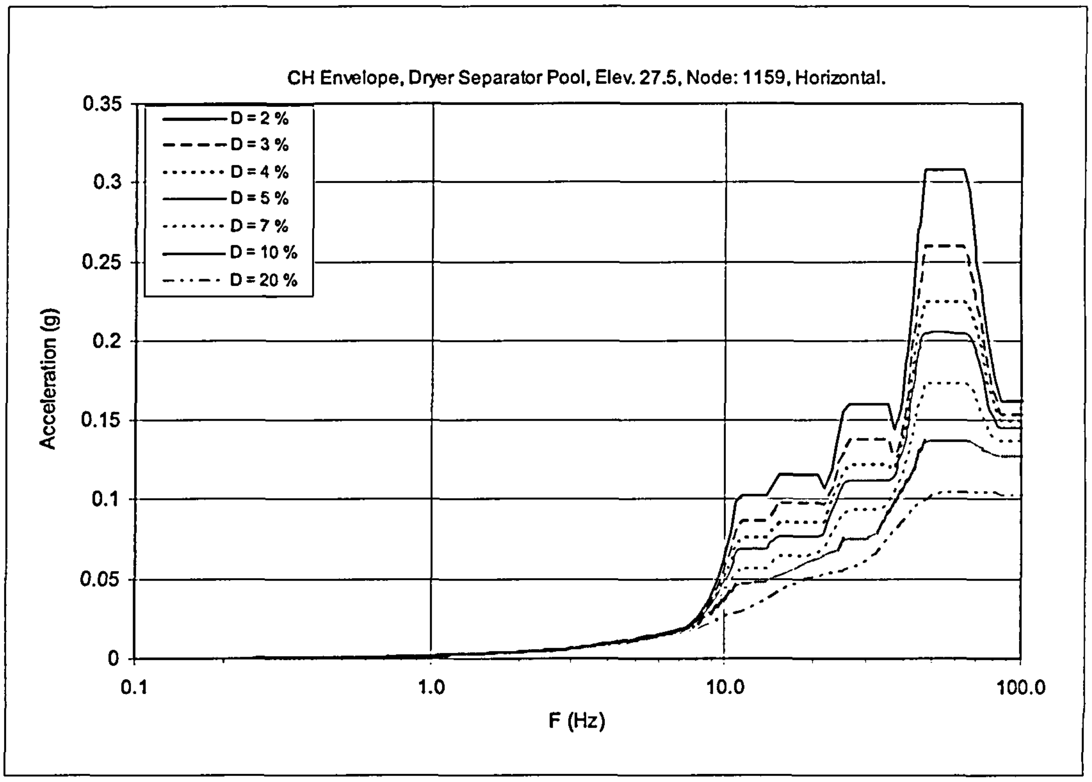

Figure 3F-22. Floor Response Spectrum—CH Envelope, Node: 1159, Horizontal

the vent wall at its inner periphery. The diaphragm floor slab is a concrete-filled steel structure. The space between the floor slab top and bottom plates is filled with concrete. The slab is supported by a system of radial beams spaced evenly all around and spanning between the vent wall structure and the reinforced concrete containment wall.

The vent wall structure is also a concrete–filled steel design consisting of two concentric carbon steel cylinders connected together by vertical web plates evenly spaced all around. The vent wall structure is anchored at the bottom into the RPV pedestal and is restrained at the top by the diaphragm floor slab. The cylindrical annulus carries 12 vent pipes and 12 safety relief valve downcomer pipes with sleeves, from the drywell into the suppression pool. The space in the cylindrical annulus is filled with concrete.

There are three GDCS pools supported on top of the diaphragm floor slab. The pools on one side are contained by the reinforced concrete containment wall and on the other side by structural steel walls.

The reactor shield wall is a thick steel cylindrical structure that surrounds the RPV. It is supported by the RPV support brackets and the reactor pedestal. The function of the reactor shield wall is to attenuate radiation emanating from the RPV. In addition, the reactor shield wall provides structural support for the RPV stabilizer, the RPV insulation and miscellaneous equipment, piping and commodities. Openings are provided in the reactor shield wall to permit the routing of necessary piping to the RPV and to permit inservice inspection of the RPV and piping.

3G.1.4 Analytical Models

3G.1.4.1 Structural Models

The RB and the RCCV including its internal structures are analyzed as one integrated structure utilizing the finite element computer program NASTRAN. The finite element model consists of quadrilateral, triangular, and beam elements. The quadrilateral and triangular elements are used to represent the slabs and walls. Beam elements are used to represent columns and beams. The model is shown in Figures 3G.1-8 to 3G.1-18.

As shown in Figure 3G.1-8, the Fuel Building (FB) is also included in the model, because the FB is integrated with the RB. The model includes the whole (360°) portion of the RB including the RCCV and FB taking the application of nonaxisymmetrical loads and the asymmetric layout of the FB structure into consideration.

Liner plates of various thicknesses as shown in Figure 3G.1-48 are included in the model at locations of the pressure boundary of the containment. The liner plate nodal points are connected to the containment nodal points by rigid beams. The liner plate elements are shown in Figure 3G.1-18. Pressure loads in the containment are applied on the liner plate.

The vent wall and the diaphragm floor are concrete-filled structures consisting of steel plates and concrete. The infill concrete is neglected in analysis model conservatively. Steel plates including connecting rib plates and girders are modeled by shell elements. The GDCS pool, the reactor shield wall and the RPV support brackets are also included in the analysis model. These structures are modeled by shell elements, except the GDCS pool beams which are modeled by

$W_t = W_w + 0.5W_p + W_m$

where,

W_t = Total Tornado Load

W_w = Tornado Wind Load

W_p = Tornado Differential Pressure Load

W_m = Tornado Missile Load

3G.1.5.2.1.6 Thermal Loads

Thermal loads are evaluated for the normal operating conditions and abnormal (LOCA) conditions. Figure 3G.1-20 shows the section location for temperature distributions for various structural elements, and Table 3G.1-6 shows the magnitude of equivalent linear temperature distribution.

The evaluation method of temperature effect on the concrete design is based on ACI 349-01 Commentary Figure RA.1.

The two cases, winter and summer, are considered in the analysis.

Stress-free temperature is 15.5°C.

3G.1.5.2.1.7 Pressure Loads

Table 3G.1-7 shows the pressure loads applied to the RCCV during normal operation, structural integrity test, and the LOCA. Pressure loads in the IC/PCCS pools are provided in Table 3G.1-8.

3G.1.5.2.1.8 Condensation Oscillation (CO) and Chugging (CHUG) Loads

The condensation oscillation (CO) and chugging (CHUG) pressure loads along with Dynamic Load Factors (DLF) are provided in Figures 3G.1-21 and 3G.1-22.

3G.1.5.2.1.9 SRV Loads

The SRV loads along with DLF are provided in Figure 3G.1-23.

3G.1.5.2.1.10 Steam Tunnel Subcompartment Pressure

The design pressure in the RB main steam tunnel due to main steam line break is 76.0 kPag. Thermal loads need not be included due to short duration of the tunnel pressurization.

3G.1.5.2.1.11 Subcompartment Pressure in Other Compartments

For ESBWR, the Reactor Water Cleanup/Shutdown Cooling (RWCU/SDC) system is considered high energy during normal operation. The maximum design pressure inside the affected subcompartments from the high energy line break (HELB) of the system is 34.5 kPag. Thermal loads need not be included due to short duration of subcompartment pressurization.

3G.1.5.2.1.12 Annulus Pressurization (AP) Loads

The annulus pressurization (AP) loads due to FW and RWCU breaks are considered. AP loads contain pressure load and associated jet forces and pipe whip restraint loads.

3G.1.5.2.1.13 Design Seismic Loads

The design seismic loads are obtained by soil – structure interaction analyses, which are described in Appendix 3A. The seismic loads used for design are as follows:

- Figure 3G.1-24: design seismic shears and moments for RB and FB walls
- Figure 3G.1-25: design seismic shears and moments for RCCV
- Figure 3G.1-26: design seismic shears and moments for RPV Pedestal and Vent Wall
- Table 3G.1-9: maximum vertical acceleration

The seismic loads are composed of one vertical and two perpendicular horizontal components. The effects of the three components are combined based on the 100/40/40 method as described in Subsection 3.8.1.3.6.

Seismic lateral soil pressure for wall design is provided in Figure 3G.1-27 using the elastic procedure described in ASCE 4-98 Section 3.5.3.2.

Seismic member forces for each section are obtained directly from the NASTRAN analysis using these seismic input loads.

3G.1.5.2.2 Load Combinations and Acceptance Criteria

Load combinations and acceptance criteria for the various elements of the RB complex are discussed on the following subsections.

3G.1.5.2.2.1 Reinforced Concrete Containment Vessel (RCCV)

Table 3.8-2 gives a detailed list of various Service and Factored load combinations with acceptance criteria per ASME Section III Division 2. Based on previous experience, critical load combinations are selected for the RCCV design. They are mainly combinations including LOCA loads and seismic loads as shown in Table 3G.1-10. The acceptance criteria for the selected combinations are also included in Table 3G.1-10.

3G.1.5.2.2.2 Steel Containment Components

Table 3.8-4 gives a detailed list of various load combinations with acceptance criteria per ASME Section III Division 1, Subsection NE. For the drywell head, the loads of W, W', Ro, Ra, Y, SRV and LOCA are small and are neglected.

3G.1.5.2.2.3 Containment Internal Structures

Table 3.8-7 gives a detailed list of various load combinations with acceptance criteria per ANSI/AISC N690.

3G.1.5.2.2.4 Reactor Building (RB) Concrete Structures Including Pool Girders

Table 3.8-15 gives load combinations for the safety-related reinforced concrete structure. Based on previous experience, critical load combinations are selected for the RB design. They are mainly combinations including LOCA loads and seismic loads as shown in Table 3G.1-11. The acceptance criteria for the selected combinations are also included in Table 3G.1-11.

3G.1.5.2.3 Material Properties

3G.1.5.2.3.1 Concrete

Properties of concrete used for the design analyses are shown in Table 3G.1-12.

Concrete has a tendency to change properties when subjected to elevated temperatures. For the ESBWR design, reduction of concrete strength due to high temperature is determined based upon the average value of the following upper bound and lower bound equations excerpted from Reference 3G.1-1.

- Lower bound reduction factor
  - $\phi = 1.0 - 0.0030\,(T-21.1)$ 21.1°C (70°F) $\leq T \leq$ 121.1°C (250°F)
  - $\phi = 0.70 - 0.00083\,(T-121.1)$ 121.1°C (250°F) $\leq T$
- Upper bound reduction factor
  - $\phi = 1.0$ $T \leq$ 260.0°C (500°F)
  - $\phi = 1.0 - 0.00081\,(T-260.0)$ 260.0°C (500°F) $\leq T$

Young's modulus for concrete is also determined based upon the average value of the following upper bound and lower bound equations excerpted from Reference 3G.1-1.

- Lower bound reduction factor
  - $\phi = 1.0 - 0.0069\,(T-21.1)$ 21.1°C (70°F) $\leq T \leq$ 93.3°C (200°F)
  - $\phi = 0.50 - 0.0009\,(T-93.3)$ 93.3°C (200°F) $\leq T$
- Upper bound reduction factor
  - $\phi = 1.0 - 0.00056\,(T-21.1)$ 21.1°C (70°F) $\leq T \leq$ 204.4°C (400°F)
  - $\phi = 0.90 - 0.0015\,(T-204.4)$ 204.4°C (400°F) $\leq T$

The design temperature of the drywell is 171°C (340°F) as shown in Table 1.3-3, and it satisfies the concrete temperature limit, 350°F, for accident or short term period specified in ASME Section III, Subsection CC-3440.

3G.1.5.2.3.2 Reinforcing Steel

Reinforcing steel is deformed billet steel conforming to ASTM A-615 grade 60. Minimum yield strength, Fy, is 413.6 MPa.

Reinforcing steel also has tendency to decrease in strength at elevated temperatures. The reduction of reinforcing steel strength is based upon the following equation excerpted from Reference 3G.1-1.

- Reduction Factor

– $\phi = 1.0 - 0.000873\,(T-21.1)$ 21.1°C (70°F) ≤ T ≤ 204.4°C (400°F)

3G.1.5.2.3.3 Structural Steel

Properties of structural steel used for the design analyses are included in Table 3G.1-12.

3G.1.5.3 Stability Requirements

The RB foundations shall have the following safety factors against overturning and sliding. Because the impact on the stability by seismic load is larger than wind and tornado, the load combinations for W and Wt, which are shown in Table 3.8-14, are excluded.

Load Combination	Overturning	Sliding	Floatation
D + H + E'	1.1	1.1	
D + F'			1.1

Where

D = Dead Load, F' = Buoyant forces of design basis flood

H = Lateral soil pressure, E' = Safe Shutdown Earthquake

3G.1.5.4 Structural Design Evaluation

The evaluation of the containment structure, the containment internal structures, and the RB structures is based on the results from the load combinations indicated in Subsection 3G.1.5.2.2.

Figure 3G.1-28 shows the location of the sections that are selected for evaluation of reinforced concrete structures. They are selected, in principle, from the center and both ends of walls and slabs, where it is reasonably expected that the critical stresses appear based on engineering experience and judgment. The computer program SSDP-2D is used for the evaluation of stresses in rebar and concrete. The input to SSDP-2D consists of rebar ratios, material properties, and element geometry at the section under consideration together with the forces and moments from the NASTRAN analysis, which are shown in Tables 3G.1-13 through 3G.1-21. Element forces and moments listed in the tables are defined with relation to the element coordinate system shown in Figure 3G.1-29. Figures 3G.1-30 through 3G.1-38 indicate deformations of structures obtained by NASTRAN analyses for the loads corresponding to Table 3G.1-13 through 3G.1-21.

Figure 3G.1-39 shows a flow chart for the structural analysis and design. Figures 3G.1-40 through 3G.1-47 present the design drawings used for the evaluation of the containment and the Reactor Building structural design. Figures 3G.1-48 through 3G.1-50 show the design details of containment liner plate. Figures 3G.1-51 through 3G.1-54 show the design details of containment major penetrations. Figures 3G.1-55 through 3G.1-59 show the details of containment internal structures.

3G.1.5.4.1 Containment Structure

Tables 3G.1-22 through 3G.1-26 show the resultant combined forces and moments in accordance with the selected load combinations listed in Table 3G.1-10. Table 3G.1-27 lists the sectional

3G.1.5.4.1.3 Containment Foundation Mat

Sections 10 and 11 are evaluated for the part of the concrete containment in the foundation mat. The sections are shown in Figure 3G.1-28. The maximum rebar stress is calculated as 271.3 MPa at Section 11 just inside the RPV Pedestal and is shown in Table 3G.1-32. The maximum transverse shear stress of 1.58 MPa is found also at the Section 11 for the load combination CV-11a.

The liner plate maximum strain is found to be 0.0006 at Section 11 as shown in Table 3G.1-35.

3G.1.5.4.1.4 Drywell Head

Figure 3G.1-51 shows the design details. The highest stresses are summarized in Table 3G.1-36. The stresses except PL+Pb+Q at service Level A and B are well within the allowable stress limits. PL+Pb+Q at service Level A and B exceeds allowable, however, it meets all requirements for simplified elastic-plastic analysis stipulated in NE-3228.3 of ASME B & PV Code, Sec.III.

3G.1.5.4.2 Containment Internal Structures

Tables 3G.1-37 through 3G.1-44 show the summary of stress analysis results for containment internal structures.

The type of analyses for various loads considered for the containment internal structures, such as diaphragm floor, vent wall, RPV support bracket (RPVSB), reactor shield wall and GDCS pool are:

1. Dead load
   Static analysis is performed for the dead load to all containment internal structures. Hydrostatic loads of pool water are also applied statically to vent wall and GDCS pool.
2. Pressure load
   Static analysis is performed for the pressure load (Po and Pa) applied to diaphragm floor and vent wall.
3. Thermal load
   Static analysis is performed for the thermal load (To and Ta) to all internal structures. All steel temperature is the same as atmospheric temperature. The temperature of the intermediate node of VW rib plate is the average value of outer and inner plate ones.
4. Seismic load
   Static analysis is performed for the seismic load on diaphragm floor, vent wall, RPV support bracket and reactor shield wall in the integral NASTRAN model, while response spectra analysis is performed for GDCS pool local model.
   In this response spectra analysis, it is assumed that all pool water mass is distributed uniformly on the GDCD pool wall and RCCV wall. This is considered as a conservative assumption, therefore sloshing is not considered in GDCS pool local model. For integral NASTRAN model, however, sloshing load is considered as the static pressure load on DF upper surface and static reaction load from GDCS pool wall. The results from integral NASTRAN model due to these loads are used for the structural integrity evaluation of the structures other than GDCS pool, while the results from GDCS pool local model are used for evaluation of GDCS pool itself.
5. Hydrodynamic load

Static analysis is performed for the hydrodynamic load (CO, CH and SRV) on vent wall taking DLF = 2 into account.

6. Pipe Break loads consist of Annulus Pressurization (AP) load, jet impingement and pipe-whip restraint loads
   These loads acting on the RSW are first analyzed for dynamic response using the NASTRAN beam model. The resulting maximum values of bending moment and shear force are then applied to the integral NASTRAN static analysis model.

3G.1.5.4.2.1 Diaphragm Floor

Design of Structural Components

The design of the diaphragm floor is based on the elastic analysis results obtained from model described in Section 3G.1.4. Figure 3G.1-55 shows design details. Table 3G.1-37 summarizes the highest stresses in various structural elements of the D/F slab. All stresses are within allowable stress limits.

Design of Anchorage

Figure 3G.1-56 shows diaphragm floor anchorage into the RCCV wall. Rebars have been used for anchoring the steel plates. Threaded couplers have been used so that the anchor bars can be connected after installation of the reinforcing steel of the RCCV wall. The anchorage is designed so as to avoid interference with the RCCV reinforcing steel. Anchorage requirements for various loading combinations and the capacity of anchorage provided is shown in Table 3G.1-38.

3G.1.5.4.2.2 Vent Wall Structure

Design of Structural Components

Figure 3G.1-57 shows the design details. Highest stresses in inner cylinder, outer cylinder and the web plates are summarized in Table 3G.1-39. The stresses are shown to be within allowable stress limits.

Design of Anchorage

Figure 3G.1-57 shows vent wall anchorage into the RCCV wall. Rebars have been used for anchoring the steel plates. Threaded couplers have been used so that the anchor bars can be connected after installation of the reinforcing steel of the RCCV wall. The anchorage is designed so as to avoid interference with the RCCV reinforcing steel. Anchorage requirements for various loading combinations and the capacity of anchorage provided is shown in Table 3G.1-42.

3G.1.5.4.2.3 Reactor Shield Wall (RSW)

The reactor shield wall is designed to resist the loads and loading combinations discussed in Subsections 3G.1.5.2. Annulus pressurization (AP) loads are also considered.

Figure 3G.1-58 shows the design details. The highest stresses are summarized in Table 3G.1-40. The stresses are well within the allowable stress limits.

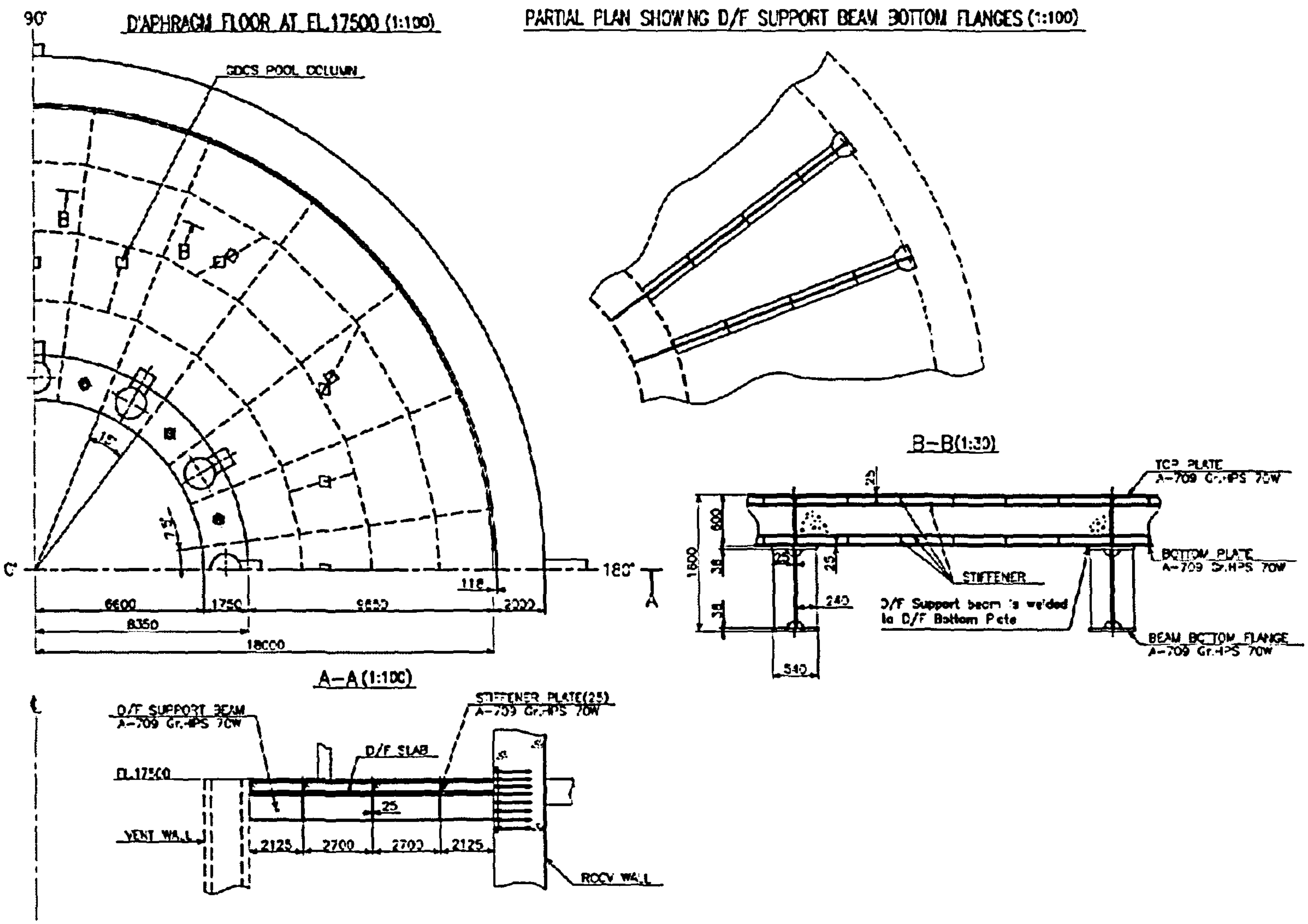

Figure 3G.1-55. Diaphragm Floor

3G.2 CONTROL BUILDING

3G.2.1 Objective and Scope

The objective of this subsection is to document the structural design details, inputs and analytical results from the analysis the Control Building (CB) of the standard ESBWR plant. The scope includes the design and analysis of the structure for normal, severe environmental, extreme environmental, and construction loads.

3G.2.2 Conclusions

The following are the major summary conclusions on the design and analysis of the CB.

- Based on the results of finite element analyses performed in accordance with the design conditions identified in Subsection 3G.2.3, stresses in concrete and reinforcement are less than the allowable stresses per the applicable regulations, codes or standards listed in Section 3.8.
- The factors of safety against floatation, sliding, and overturning of the structure under various loading combinations are higher than the required minimum.
- The thickness of the roof slabs and exterior walls are more than the minimum required to preclude penetration, perforation or spalling resulting from impact of design basis tornado missiles.

3G.2.3 Structural Description

The CB houses the essential electrical, control and instrumentation equipment, the control room for the Reactor and Turbine Buildings, and the CB HVAC equipment. Structure below grade in the CB is a Seismic Category I structure that houses control equipment and operation personnel. Structure above grade is a Seismic Category II structure.

The CB is a reinforced concrete box type shear wall structure consisting of walls and slabs and is supported by a foundation mat. Steel framing is composite with concrete slab and used to support the slabs for vertical loads. The CB is a shear wall structure designed to accommodate all seismic loads with its walls and the connected floors. Therefore, frame members such as beams or columns are designed to accommodate deformations of the walls in case of earthquake conditions. The CB is adjacent to but structurally independent of the Reactor Building (see Figures 1.2-2 through 1.2-5 and Figure 1.2-11).

The key dimensions of the CB are summarized in Table 3.8-8. Figures 3G.2-1 through 3G.2-3 show the outline drawings of the CB.

3G.2.4 Analytical Models

3G.2.4.1 Structural Model

The CB is analyzed utilizing the finite element computer program NASTRAN. The finite element model consists of quadrilateral and beam elements. The quadrilateral elements are used to represent the slabs and walls. Beam elements are used to represent columns and beams. The