3.8 Design of Category I Structures

This design of Category I structures section provides information on the Seismic Category I structures of the U.S. EPR, including the Reactor Containment Building (RCB), Reactor Building (RB) internal structures, other Seismic Category I structures, and their foundations. Figure 3B-1 illustrates key dimensions of the Nuclear Island (NI) Common Basemat Structure and other Seismic Category I structures.

The RB is located in the central portion of the NI Common Basemat Structure and houses the reactor coolant system (RCS). The RB consists of two concrete shell structures, which are the inner RCB and the outer Reactor Shield Building (RSB). The NI Common Basemat Structure foundation basemat supports both structures. The RCB houses the RB internal structures. These structures are Seismic Category I.

The RB is surrounded by Safeguard Buildings (SB) 1, 2, 3, and 4, the Fuel Building (FB), and four stair towers (included with the SB). The NI Common Basemat Structure foundation basemat supports each of these buildings, which are safety-related Seismic Category I structures. The main steam system and main feedwater system valve stations are located within SBs 1 and 4. The vent stack is a non-safety-related structure supported on the south-east stair tower roof. It is a Seismic Category II structure because it is located adjacent to the safety-related NI Common Basemat Structure.

Two Emergency Power Generation Buildings (EPGB) are located separately from the NI Common Basemat Structure. Each EPGB contains two emergency diesel generators and supporting equipment, and has its own independent foundation basemat. These structures are Seismic Category I.

Four Essential Service Water Buildings (ESWB), which house Essential Service Water Cooling Towers (ESWCT) and Essential Service Water Pump Buildings (ESWPB) are located separately from the NI Common Basemat Structure and are supported by independent foundation basemats. These structures are Seismic Category I.

Safety-related buried conduit, duct banks, pipes and pipe ducts are installed Seismic Category I to support and protect safety-related distribution systems outside of the NI Common Basemat Structure.

The dimensional arrangement drawings for Seismic Category I structures are provided in Appendix 3B.

3.8.1 Concrete Containment

The RCB is part of the RB system as illustrated in Figure 3B-1. The RCB controls the release of airborne radioactivity following postulated design basis accidents (DBA) and provides radiation shielding for the reactor core and the RCS. The RCB is a post-tensioned concrete pressure vessel and is located inside the reinforced concrete RSB described in Section 3.8.4. This section addresses the concrete elements of the RCB. Section 3.8.2 addresses steel sub-elements of the RCB (e.g., the equipment hatch and other penetrations). Section 6.2 describes the functional aspects of the containment system (e.g., heat removal, containment isolation, combustible gas control and leakage testing).

3.8.1.1 Description of the Containment

Figures 3.8-1—Reactor Building Plan at Elevation - 50 Feet, 3.8-2—Reactor Building Plan at Elevation - 20 Feet, 3.8-3—Reactor Building Plan at Elevation -8 Feet, 3.8-4—Reactor Building Plan at Elevation +5 Feet, 3.8-5—Reactor Building Plan at Elevation +17 Feet, 3.8-6—Reactor Building Plan at Elevation +29 Feet, 3.8-7—Reactor Building Plan at Elevation +45 Feet, 3.8-8—Reactor Building Plan at Elevation +64 Feet, 3.8-9—Reactor Building Plan at Elevation +79 Feet, 3.8-10—Reactor Building Plan at Elevation +94 Feet, 3.8-11—Reactor Building Section A-A, 3.8-12—Reactor Building Section B-B, and 3.8-13—Reactor Building Section C-C show plan and section views of the RCB. See Sections 3.8.3 and 3.8.4 for additional figures showing structures adjacent to the RCB.

The RCB is located inside the reinforced concrete RSB. The RSB protects the containment structure from external hazards (e.g., wind loads, tornado loads, aircraft hazard, explosion pressure wave and missiles). An annular space, designated as the RB annulus, is provided between the RCB and the RSB to prevent interaction of the two structures when subjected to extreme postulated design basis and beyond design basis loading conditions.

The RCB houses the RB internal structures. To prevent adverse interactions inside the RCB, the RB internal structures are physically independent of the RCB, except at the supporting foundation basemat. No structural connections are provided between the RCB and the RB internal structures. The RCB also provides structural support for the polar crane.

The NI Common Basemat Structure foundation basemat supports the RCB, and provides the only physical contact of the RCB with other structures. See Section 3.8.5 for a description of the NI Common Basemat Structure foundation basemat.

The RCB is a Seismic Category I, post-tensioned reinforced concrete shell structure consisting of an upright cylinder capped with a spherical dome. The dimensions of the RCB are approximately 162 feet outside diameter, by 153 feet inside diameter, by 218 feet high. The RCB is concentric with, and completely enclosed by, the RSB. No soil loadings are applied to the containment structure, and waterproofing materials are not required around the exterior surface of containment. A leak-tight steel liner plate covers the entire inner surface of the RCB, including the basemat (GDC 16).

The RCB is a concrete containment structure with a steel liner designed in accordance with the ASME BPV Code 2004 Edition, Section III, Division 2 (Reference 1) (GDC 16). The RCB accommodates the calculated pressure and temperature conditions resulting from a loss of coolant accident (LOCA) without exceeding the design leakage rate and with sufficient margin (GDC 50). The RCB is designed for an internal pressure of 62 psig and a maximum temperature of 309.2°F. The RCB is also designed for a negative internal pressure of -3 psig.

The equipment hatch and two airlocks provide access to the RB. A third opening provides access to the lower containment during construction. Section 3.8.2 provides a description of these sub-assemblies. The equipment hatch [ ] is located at [ ] and opens to the operating level of the RB internal structures. A personnel airlock is located at [ ] at the heavy load operating floor level and connects to a secure stair tower that serves various levels of the RCB. A construction access is located at [ ] An emergency airlock is located at [ ] and opens to the operating floor level from [ ]

The equipment hatch allows the entry of heavy components (e.g., the reactor pressure vessel, steam generators, reactor coolant pumps, and pressurizer) into the RB. The size of the hatch accommodates the entry of the reactor pressure vessel during construction and the entry of a replacement steam generator or pressurizer in one piece.

The steel liner plate is part of the concrete containment system and is designed in accordance with ASME BPV Code, Section III, Division 2 (Reference 1). The liner plate serves as a leak-tight membrane to prevent the uncontrolled release of radioactive materials to the environment (GDC 16). The steel liner plate is approximately 0.25 inch thick.

RCB penetrations are described in Section 3.8.2.1.

3.8.1.1.1 Concrete Wall and Dome Shells and Connection to Foundation

The RCB wall is 4 feet, 3 inches thick, and the dome is 3 feet, 3 $^{3}/_{8}$ inches thick. The NI Common Basemat Structure foundation basemat supporting the containment structure is approximately 10 feet thick under the liner plate. Additional concrete is provided over the liner plate inside of containment to support the RB internal structures.

The wall and dome shells of the RCB are post-tensioned with hoop, vertical, and dome tendons. Reinforcing steel bars are provided in the concrete containment walls and dome for crack control and strength to accommodate seismic and other loads.

Three buttresses run vertically and project outward from the outside surface of the cylindrical containment wall. These buttresses serve as the anchorage locations for terminating the horizontal hoop tendons. The anchorage surfaces of the buttresses are normal to the tangent line of the anchored hoop tendons. The buttresses are located at azimuths 0°, 112°, and 230°. Appendix 3E provides details of the design and reinforcement for the containment cylinder wall and buttresses.

A tendon gallery is provided under the circumference of the cylindrical containment wall below the NI Common Basemat Structure foundation basemat. This gallery provides access for installing and maintaining the lower terminations of the vertical wall tendons. Appendix 3E provides details of the design and reinforcement where the RCB wall intersects with the NI Common Basemat Structure foundation basemat.

A ring girder is provided around the top perimeter of the cylindrical containment wall where it transitions into the spherical dome. The ring girder is a thickened area of concrete that stiffens the containment vessel at the transition area. This serves as the termination point for the upper end of vertical tendons and the ends of the horizontal dome tendons.

The concrete shell is thickened around the equipment hatch opening to provide a reinforced area where the concrete is removed for the opening. Appendix 3E provides details of the design and reinforcement in the equipment hatch area. Horizontal and vertical tendons are routed around penetrations through the containment wall. The two airlocks and the construction opening are located in the thickened buttresses.

Structural anchorages embedded in the containment wall support the polar crane. Structural members are welded to these embedments for supporting the polar crane rails.

3.8.1.1.2 Post-Tensioning System

Tendons are provided both horizontally and vertically in the cylindrical portion of the RCB. Tendons are provided in two orthogonal directions in the plan view of the containment dome. Layouts of the tendons vary to accommodate penetrations through the RCB wall.

The Freyssinet C-range post-tensioning system is the tendon system used for post-tensioning the concrete RCB. The Freyssinet 55C15 tendon system is made up of 55 seven-wire strands in each tendon. Section 3.8.1.6.3 describes the material properties of the tendon system. The tendons are grouted in place after tensioning.

A total of 119 horizontal hoop tendons are provided around the cylindrical shell of the RCB. The tendons terminate at the three vertical buttresses provided around the outside of the containment wall. Terminations alternate so that each buttress has a horizontal tendon terminating every third hoop (i.e., each hoop tendon extends the full circumference of the building).

A total of 47 vertical tendons are provided around the cylindrical shell of the RCB. The vertical tendons terminate at the top of the ring girder that is provided at the transition of the wall to the spherical dome roof. A total of 104 gamma tendons are also provided vertically up through the containment wall where they then wrap over the dome and terminate at the ring girder on the opposite side of the wall. The gamma tendons are separated into two groups that are placed 90° apart in the RBC dome. The bottom of both the vertical tendons and the gamma tendons terminate at the tendon gallery.

Additional information on layout and design of the tendons is provided in Appendix 3E for the RCB cylindrical wall, and buttress areas. The minimum required post tensioning force to offset the structural integrity test (SIT) pressure loading is 801k/ft hoop force, 401k/ft vertical force, and 548k/ft in both directions for the dome.

Figure 3.8-18—Finite Element Model of Reactor Containment Building Tendon Layout in Cylindrical Wall and Figure 3.8-19—Finite Element Model of Reactor Containment Building Tendon Layout in Dome show the finite element model of the tendon layout.

3.8.1.1.3 Liner Plate System

A carbon steel liner plate covers the entire inside surface of the RCB, excluding penetrations. The steel liner is 0.25 inch thick and is thickened locally around penetrations, large brackets, and at major attachments. Except for the bottom horizontal surface, headed studs anchor the liner plate to the concrete containment structure. The in-containment refueling water storage tank (IRWST), including the containment sumps, are lined with 0.25 inch thick stainless steel liner plates that serve as additional corrosion protection for the underlying carbon steel liner. See Section 3.8.3 for a description of the IRWST.

Steel shapes reinforce the plate both longitudinally and laterally to provide rigidity during prefabrication, erection, and concrete placement. Headed studs are welded to the liner plate and are fully embedded in the concrete along with the stiffeners to provide a rigid connection to the inside surface of the RCB concrete. The concrete foundation of the RB internal structures is poured on top of the liner plate at the basemat surface, embedding the lower region of the liner plate in the foundation. The liner plate is not used as a strength element to carry design basis loads; however, the liner supports the weight of wet concrete during the construction of the RCB.

Section 3.8.2 contains a description of the penetrations through the containment liner, including the equipment hatch, airlocks, piping penetration sleeves, electrical penetration sleeves, and the fuel transfer tube penetration sleeve.

No load transfer attachments are used at the bottom portion of the liner plate to transfer loads from the concrete RB internal structures into the lower portion of the NI Common Basemat Structure foundation basemat. RB internal structure lateral reaction loads are transferred through the liner plate. This is achieved by lateral bearing on the haunch wall at the bottom of the RB internal structures foundation where it is embedded in concrete above the NI Common Basemat Structure foundation basemat.

Structural attachments to the containment walls and dome include various pipe, HVAC, electrical, and equipment support brackets, as well as the polar crane rail supports. The liner plate is continuously welded to embedded plate areas and areas with thickened plates so that a continuous leak-tight barrier is maintained.

3.8.1.2 Applicable Codes, Standards, and Specifications

The following codes, standards, specifications, design criteria, regulations, and regulatory guides are used in the design, fabrication, construction, testing, and in-service inspection of the RCB (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50).

3.8.1.2.1 Codes

- ACI 117-90/117R-90, Specification for Tolerances for Concrete Construction and Materials (Reference 6).
- ACI 301-05, Specifications for Structural Concrete for Buildings (Reference 7).
- ACI 304R-00, Guide for Measuring, Mixing, Transporting, and Placing Concrete (Reference 8).
- ACI 305.1-06, Specification for Hot-Weather Concreting (Reference 9).
- ACI 306.1-90, Standard Specification for Cold-Weather Concreting (Reference 10).
- ACI 347-04, Guide to Form Work for Concrete (Reference 11).
- ACI 349-01, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary (exception described in Sections 3.8.4.4 and 3.8.4.5) (Reference 12).
- ACI SP-2 (99), Manual of Concrete Inspection (Reference 13).

- ANSI/AISC N690-1994 (R2004), Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2 (Reference 14).

- ASCE Standard 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary (Reference 15).

- ASCE/SEI Standard 7-05, Minimum Design Loads for Buildings and Other Structures (Reference 16).

- ASCE/SEI Standard 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities (Reference 17).

- ANSI/AWS D1.1/D1.1M-2006, Structural Welding Code – Steel (Reference 18).

- ANSI/AWS D1.4-2005, Structural Welding Code - Reinforcing Steel (Reference 19).

- ANSI/AWS D1.6 - 1999, Structural Welding Code – Stainless Steel (Reference 20).

- ASME BPV Code - 2004 Edition.

  – Section II - Material Specifications.

  – Section III, Division 2 - Code for Concrete Reactor Vessels and Containments.

  – Section V - Nondestructive Examination.

  – Section VIII - Pressure Vessels.

  – Section IX - Welding and Brazing Qualifications.

  – Section XI – Rules for Inservice Inspection of Nuclear Power Plant Components.

- Acceptable ASME BPV Code cases per RG 1.84, Revision 33, August 2005.

- ASME NOG-1-04, Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder) (Reference 21).

- SEI/ASCE Standard 37-02, Design Loads on Structures During Construction (Reference 2).

3.8.1.2.2 Standards and Specifications

Industry standards (e.g., those published by the ASTM) are used to specify material properties, testing procedures, fabrication, and construction methods. Section 3.8.1.6 lists the applicable standards used.

Structural specifications cover the areas related to the design of the RCB. These specifications emphasize the important points of the industry standards for the RCB and reduce the options that would otherwise be permitted by the industry standards. These specifications cover the following areas:

- Concrete material properties.
- Mixing, placing, and curing of concrete.
- Reinforcing steel and splices.
- Post-tensioning system.
- Liner plate system.

3.8.1.2.3 Design Criteria

The design of pressure retaining components of the RCB complies with:

- Article CC-2000 of the ASME BPV Code, 2004 Edition, Section III, Division 2.
- Article CC-3000 of the ASME BPV Code, 2004 Edition, Section III, Division 2 (GDC 1, GDC 2, and GDC 16).
- ASME BPV Code 2004 Edition, Section XI, Subsection IWL, Requirements for Class CC Concrete Components of Light-Water Cooled Plants.
- ASME BPV Code 2004 Edition, Section XI, Subsection IWE, Requirements for Class MC and Metallic Liners of Class CC Concrete Components of Light-Water Cooled Power Plants.

3.8.1.2.4 Regulations

- 10 CFR Part 50 – Licensing of Production and Utilization Facilities.
- 10 CFR Part 50, Appendix A – General Design Criteria for Nuclear Power Plants (GDC 1, 2, 4, 16, and 50).
- 10 CFR Part 50, Appendix J – Primary Reactor Containment Leakage Testing for Water Cooled Power Reactors.
- 10 CFR Part 100 – Reactor Site Criteria.

3.8.1.2.5 NRC Regulatory Guides

Regulatory Guides applicable to the design and construction of the RCB:

- RG 1.7, Revision 3.
- RG 1.84, Revision 33.

- RG 1.90, Revision 1 (exception described in 3.8.1.7).
- RG 1.94, Revision 1.
- RG 1.107, Revision 1.
- RG 1.136, Revision 3 (exception described in 3.8.1.3).
- RG 1.199, November 2003.

3.8.1.3 Loads and Load Combinations

The U.S. EPR standard plant design loads envelope includes the expected loads over a broad range of site conditions. Loads and load combinations for the RCB are in accordance with the requirements of Article CC-3000 of the ASME BPV Code, Section III, Division 2, Code for Concrete Containments and ACI Standard 359, and RG 1.136 (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50). RG 1.136 endorses the 2001 Edition of the ASME BPV Code with the 2003 addenda (including exceptions taken in RG 1.136). The U.S. EPR standard plant design is based on the 2004 Edition of the Code, inclusive of the exceptions taken in RG 1.136. Design loads and loading combinations for the concrete RCB are described in Sections 3.8.1.3.1 and 3.8.1.3.2.

A COL applicant that references the U.S. EPR design certification will confirm that site-specific loads lie within the standard plant design envelope for the RCB, or perform additional analyses to verify structural adequacy.

3.8.1.3.1 Design Loads

The concrete RCB is designed for the following loads:

Service Loads

- Normal Loads – Normal loads are those loads encountered during normal plant operation and shutdown (GDC 4). This load category includes:
  - Dead Loads (D) – Dead loads include the weight of the structure and any permanent equipment or material weights. Dead load effects also refer to internal moments and forces due to dead loads.
  - Live Loads (L) – Live loads include any normal loads that vary with intensity or point of application, including moveable equipment. Live load effects also refer to internal moments and forces due to live loads. Live loads are applied, removed, or shifted in location to obtain the worst-case loading conditions. Impact forces due to moving loads are applied as appropriate for the loading condition.
  - Soil Loads or Lateral Earth Pressure (H) – There are no soil or lateral earth pressure loads on the RCB because it is surrounded by other Seismic Category I structures that shield it from these loads.

– Hydrostatic Loads (F) – Hydrostatic loads due to water stored in pools and tanks are considered in the design of RB internal structures that exert reaction loads on the RCB and NI Common Basemat Structure foundation basemat. Hydrodynamic loads resulting from seismic excitation of fluids are included as a component of the safe shutdown earthquake (SSE) load. There are no hydrostatic loads from groundwater or external floods on the RCB because it is surrounded by other Seismic Category I structures that subsequently provide a shield. Buoyancy loads are addressed in Section 3.8.5 for foundation design.

– Thermal Loads (T_o) – Thermal loads consist of thermally induced forces and moments resulting from normal plant operation and environmental conditions. Thermal loads and their effect are based on the critical transient or steady-state condition. Thermal expansion loads due to axial restraint, as well as loads resulting from thermal gradients, are considered.

  The ambient air temperatures listed below are for normal operation. Normal operation temperatures are given as a maximum value during summer and a minimum value during winter.

  RB internal ambient temperatures:

  - During normal operation:
    Equipment Area: 131°F (maximum), 59°F (minimum).
    Service Area: 86°F (maximum), 59°F (minimum).

  - During normal shutdown: 86°F (maximum), 59°F (minimum).

  RB annulus internal ambient temperatures:

  - During normal operation: 113°F (maximum), 45°F (minimum).

– Pipe Reactions (R_o) – Pipe reactions are those loads applied by piping system supports during normal operating or shutdown conditions based on the critical transient or steady state conditions. The dead weight of the piping and its contents are included. Appropriate dynamic load factors are used when applying transient loads, such as water hammers.

– Post-Tension Loads (J) – Post-tension loads are those loads developed from applying strain on the containment tendons.

– Relief Valve Loads (G) – Relief valve loads are those loads resulting from the actuation of a relief valve or other high-energy device.

– Pressure Variant Loads (P_v) – Pressure variant loads are those external pressure loads resulting from pressure variation either from inside or outside of containment.

– Construction Loads – Construction loads are those loads to which the structure may be subjected during construction of the plant. Construction loads will be applied to evaluate partially completed structures, temporary structures, and their respective individual members. Design load requirements during construction for buildings and other structures will be developed in accordance with Table CC-3230-1 of the Section III, Division 2, of the ASME BPV Code and with SEI/ASCE 37-02. The magnitude and location of construction loads will be applied to generate the maximum load effects of dead, live, construction, environmental, and lateral earth pressure loads. Consideration will be given to the loads and load effects of construction methods, equipment operation, and sequence of construction.

– Test Loads – Test loads are those loads that are applied during structural integrity testing or leak-rate testing. This load category includes:

  - Test Pressure Loads (P_t) – Test pressure loads are those loads resulting from the pressure exerted on the RCB during the SIT at 1.15 times the design pressure and during the leak-rate test at 1.0 times the DBA pressure.

  - Test Thermal Loads (T_t) – Test thermal loads include thermal effects and loads experienced by the RCB during the structural integrity and leak-rate tests.

Factored Loads

- Severe Environmental Loads – Severe environmental loads are those loads that could be encountered infrequently during the life of the plant (GDC 2). This load category includes:

  – Wind Loads (W) – There are no wind loads applicable on the RCB because it is surrounded by other Seismic Category I structures that subsequently provide a shield.

  – There are no operating basis earthquake (OBE) loads applicable to the overall RCB design for the U.S. EPR because an OBE level of one-third the SSE has been selected. See Section 3.7.1 for a description of the OBE.

- Extreme Environmental Loads – Extreme environmental loads are those that are credible but are highly improbable (GDC 2). This load category includes:

  – SSE (E’) – SSE loads are those loads generated by an earthquake with a peak horizontal ground acceleration of 0.30g. Seismic loads in the vertical direction and two orthogonal horizontal directions are considered to act simultaneous. Section 3.7 provides a description of how SSE loads are determined and combined. SSE loads are considered due to applied inertia loads, including dead loads, live loads, and hydrodynamic loads (i.e., water in storage pools and tanks).

  – Tornado Loads (W_t) – Loads generated by the design basis tornado are described in Section 3.3 and Section 3.5. This load category includes:

    - Tornado Wind Pressure (W_w) – Tornado wind pressure is not applicable because the RCB is protected from wind forces by the RSB.

  - Tornado Created Differential Pressure (W_p) – The RSB is designed as an enclosed, unvented structure, which does not allow tornado differential pressure forces to affect the RCB.

  - Tornado Generated Missiles (W_m) – Tornado-generated missile loads are not applicable because the RSB serves as a barrier to protect the RCB from missile strikes.

- Abnormal Loads – Abnormal loads are those loads generated by a postulated high-energy pipe break accident. This event is classified as a DBA (GDC 4 and GDC 50). These loadings include an appropriate dynamic load factor to account for the dynamic nature of the load, unless a time-history analysis is performed to justify otherwise. Abnormal loads include the following loads:

  – Internal Flooding Loads (F_a) – Loads resulting from the internal flooding of containment during or following a postulated DBA.

  – Buoyant Force (F_b) – Fluid forces acting vertically on a partially or fully submerged body as a result of the design basis maximum flood. Section 3.8.5 describes application of buoyant force loads to the NI Common Basemat Structure foundation basemat.

  – Pressure Load (P_a) – Pressure equivalent static load within or across a compartment or building generated by a postulated pipe break.

  – Thermal Load (T_a) – Thermal loads generated by the postulated pipe break (including thermal load T_o).

  – Accident Pipe Reactions (R_a) – Pipe reactions generated by the postulated pipe break (including pipe reaction load R_o).

  – Pipe Break Loads (R_r) – Local loads following a postulated pipe break. Unless a time-history analysis is performed to justify otherwise, these loadings include an appropriate dynamic load factor to account for the dynamic nature of the load. This load category includes:

    - Pipe Break Reaction Loads (R_{rr}) – R_{rr} is defined as the equivalent static load on the structure generated by the reaction of the high-energy pipe during the postulated break.

    - Pipe Break Jet Impingement Loads (R_{rj}) – R_{rj} is defined as the jet impingement equivalent static load on the structure generated by the postulated break.

    - Pipe Break Missile Impact Loads (R_{rm}) – R_{rm} is defined as the missile impact equivalent static load on the structure generated by or during the postulated break, such as pipe whipping.

Other Loads

Other loads refer to postulated events or conditions that are not included in the design basis (GDC 4). These loading conditions and effects are evaluated without regard to the bounding conditions under which SSC are required to perform design basis functions. This load category includes:

- Aircraft Hazard (A) – Aircraft hazard refers to loads on a structure resulting from the impact of an aircraft. The evaluation of this loading condition is considered as part of the plant safeguards and security measures. Aircraft hazard loads are not applicable on the RCB because it is surrounded by other Seismic Category I structures that provide a shield.

- Explosion Pressure Wave (B) – Explosion pressure wave refers to loads on a structure resulting from an explosion in the vicinity of the structure. The evaluation of this loading condition is considered as part of the plant safeguard and security measures. Explosion pressure wave loads are not applicable on the RCB because it is surrounded by other Seismic Category I structures that provide a shield.

- Combustible Gas (C) – Combustible gas loads are those pressure loads that result from a fuel-clad metal-water reaction, an uncontrolled hydrogen burn, and a postaccident condition for the containment inerted by carbon dioxide. RG 1.136, Regulatory Position C.5 provides the loads and load combinations acceptable for analysis and design of containment when exposed to the loading conditions associated with combustible gas. The principal combustible gas for the U.S. EPR is hydrogen. There is no inerting gas system in the U.S. EPR. The containment design pressure is 62 psig based on DBA conditions. RG 1.136, Regulatory Position C.5 and RG 1.7 specify a pressure of 45 psig combined with dead load (D) as a minimum design condition. Therefore, the strains and stresses for the RCB calculated using the U.S. EPR design pressure in the load combinations in Table CC-3230-1 of the ASME BPV Code bounds the results of the pressure specified in RG 1.136 and RG 1.7. See Section 6.2.5 for a description of combustible gas loads.

Missile Loads other Than Wind- or Tornado-Generated Missiles

There are no missile loads on the RCB resulting from activities of nearby military installations, turbine failures, or other causes. The RCB is surrounded by other Seismic Category I structures that shield it from missiles.

3.8.1.3.2 Design Load Combinations

Loading combinations used for the design of the RCB, including its steel liner plate, are in accordance with guidance provided in NUREG-0800, Standard Review Plan, Section 3.8.1 (Reference 3) (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50). The following guidance is used for applying load combinations for design of the RCB:

- The live load (L) is applicable after construction of containment. Construction loadings, temporary or otherwise, may also be considered as live loads and included within appropriate loading combinations.

- Twenty five percent of the design live load is considered with tornado load combinations. The full potential live load is used for local analysis of structural members.

- Unless a time-history analysis is performed to justify otherwise, the maximum values of load combinations including the loads P_a, T_a, R_a, R_{rr}, R_{rj}, R_{rm}, or G are used, including an appropriate dynamic load factor.

- For concrete members, U_S is defined as the required section strength for service loads based on the allowable stresses defined in Subarticle CC-3430 of the ASME BPV Code, Section III, Division 2, with additional guidance provided by NUREG-0800.

- For concrete members, U_F is defined as the required section strength for factored loads based on the allowable stresses defined in Subarticle CC-3420 of the ASME BPV Code, Section III, Division 2, with additional guidance provided by NUREG-0800.

- The following requirements are met for the design of concrete components for factored load conditions:

  – Primary forces must not bring the local section to a general yield state with respect to any component of section membrane strain or section flexural curvature. General yield state is the point beyond which additional section deformation occurs without an increase in section forces.

  – Under combined primary and secondary forces on a section, the development of a general yield state with respect to those membrane strains or flexural curvatures that correspond to secondary stress components is acceptable, and is subject to rebar strain limits specified in Subarticle CC 3420 of the ASME BPV Code, Section III, Division 2. The concept of a general yield state is not applicable to strains associated with radial shear stress.

- Primary and secondary forces are as defined in Subarticle CC-3130 of the ASME BPV Code, Section III, Division 2.

- Limitations on maximum concrete temperatures as defined in Subarticle CC-3440 of the ASME BPV Code, Section III, Division 2 are observed.

- Loads and loading combinations encompass the soil cases described in Section 3.7.1, using the design criteria described in Section 3.7.1 and Section 3.7.2.

The following load combinations define the design limits for the Seismic Category I concrete RCB. These load combinations define the design limits for the Seismic Category I steel liner plate for the RCB, except that load factors are considered to be 1.0.

- Service load combinations (test loads).

  $U_S = D + L + J + P_t + T_t$

- Service load combinations (construction loads).

  $U_S = D + L + J + T_o + W$

- Service load combinations (normal loads).

  $U_S = D + L + J + G + T_o + R_o + P_v$

- Factored load combinations (severe environmental loads).

  $U_F = D + 1.3L + J + G + T_o + R_o + P_v$

  $U_F = D + 1.3L + J + G + T_o + R_o + P_v + 1.5W$

- Factored load combinations (extreme environmental loads).

  $U_F = D + L + J + G + T_o + R_o + P_v + E'$

  $U_F = D + L + J + G + T_o + R_o + P_v + W_t$

- Factored load combinations (abnormal loads).

  $U_F = D + L + J + G + 1.5P_a + T_a + R_a$

  $U_F = D + L + J + G + P_a + T_a + 1.25R_a$

  $U_F = D + L + J + 1.25G + 1.25P_a + T_a + R_a$

- Factored load combinations (abnormal or severe environmental loads).

  $U_F = D + L + J + G + 1.25P_a + T_a + R_a + 1.25W$

  $U_F = D + L + J + G + T_o + F_a$

  $U_F = D + L + J + G + T_o + F_a + W$

  $U_F = D + L + J + F_a$

- Factored load combinations (abnormal or extreme environmental loads).

  $U_F = D + L + J + G + P_a + T_a + R_a + R_r + E'$

3.8.1.4 Design and Analysis Procedures

The analysis and design of the post-tensioned RCB comply with the requirements of Article CC-3300 of the ASME BPV Code, Section III, Division 2 and RG 1.136 (GDC 1 and GDC 16).

Computer programs perform many of the computations required for the RCB analysis and design. In many cases, classical methods and manual techniques are also used for the analysis of localized areas of the containment structure and its subassemblies. Manual calculations are generally used for:

- Initial proportioning of the dome, wall, and base slab and determining tendon layout.
- Evaluation of the effects of locally applied loads, such as crane loads and pipe reaction loads.
- Preparation of input for the computer analyses.
- Design of the liner plate and its anchorage to the concrete containment shell.

The analysis and design methods incorporate several phases. Overall analysis and design are performed for structures using computer models of the NI Common Basemat Structure, Seismic Category I structures. Then, localized design evaluations account for local loadings and discontinuities in structures (e.g., openings and local changes in member cross-sections). Results from the local analyses are combined with the overall global analysis results to produce the final design.

An ultimate capacity analysis is performed, as described in Section 3.8.1.4.11, to determine the ultimate internal pressure load capability of the containment for use in probabilistic risk assessment and severe accident analyses. The ultimate capacity analysis evaluates the concrete containment structure (including the liner plate), as well as large containment penetrations, such as the equipment hatch and airlocks.

Gaps are provided between the RCB and adjoining interior and exterior structures to accommodate deformation during pressurization and as a result of seismic movements.

Appendix 3E provides details of the design and reinforcement for the containment wall to foundation connection.

Appendix 3E provides details of the design and reinforcement for the containment cylinder wall and buttresses.

The following sections provide details of design and analysis of the RCB.

3.8.1.4.1 Computer Programs

The containment structure is included in an overall model developed for analysis of the NI Common Basemat Structure, which includes the RCB with the RB internal structures, the RSB, the SBs, the FB, and the NI Common Basemat Structure foundation basemat. The RCB is modeled and analyzed using the ANSYS computer program. ANSYS is a validated and verified, quality-controlled computer program that has been used for a number of years in the nuclear power industry. Refer to Chapter 17 for a description of the quality assurance program for the U.S. EPR design certification.

The ANSYS model is used to analyze the RCB for the loads defined in Section 3.8.1.3.1. The results from these load case analyses are combined and factored using the loading combinations defined in Section 3.8.1.3.2. The design of the RCB shell wall and dome is generally controlled by load combinations containing the +62/-3 psig design internal pressure load and SSE seismic loads.

The overall NI Common Basemat Structure analysis is performed using the ANSYS finite element computer program. The RCB is modeled in combination with the other structures of the NI Common Basemat Structure and basemat using a mesh of finite elements. The element mesh for the RCB consists of the dome and cylindrical shell wall, which interconnects with the overall NI Common Basemat Structure foundation basemat. No other structures physically connect to the containment structure; therefore, the foundation basemat is the only interfacing structure in the model. Section 3.8.5 describes the modeling of the NI Common Basemat Structure foundation basemat.

ANSYS SOLID45 solid elements are primarily used to model the RCB concrete dome and cylindrical shell wall. SOLID45 is a three-dimensional, four-node brick element that is suitable for moderately thick shell structures. It can also provide out-of-plane shear forces and has an elastic-plastic capability. Five layers of SOLID45 elements are used to model through the thickness of the cylindrical shell wall and dome. ANSYS SOLID95, a twenty node brick element, and ANSYS SOLID92, a ten node tetrahedral element, are also used to model the RCB. The buttresses, ring girder, and thickened areas around the base of the containment structure are included in the ANSYS model. Soft elements are used to represent the large openings for the equipment hatch, two airlocks, and construction opening.

Post-tensioning tendon forces are included in the RCB structural analysis. Forces for each post-tensioning tendon in the RCB shell and dome are calculated along their routing lengths for the appropriate nodal locations in the RCB model. This is accomplished by using a second ANSYS model developed for this task. The tendons are modeled using ANSYS LINK8 type elements, which are two-node three-dimensional truss type elements. These elements follow the routings used in the structure and are given the material properties of the tendons. Forces are applied to these links by imposing strains along the lengths of the modeled tendons, tensioning losses are explicitly included in these calculations. The calculated reactions forces from the tendon model are then applied as forces to the RCB model. ANSYS BEAM44 elements, which are two-node three dimensional beam type elements, are used to model the end anchorages for the tendons.

The steel liner causes discontinuity between the NI foundation basemat and the base of the RCB interior structure. This transition is modeled using multi-point constraints to allow sub-modeling of the interior structure and interface, as needed. For static modeling considerations, the individual companion nodes are coupled together. The strength of the liner is not relied upon to carry structural loadings.

The finite element model used for analysis of the RCB is shown in Figure 3.8-14—Finite Element Model of Reactor Containment Building, Figure 3.8-15—Finite Element Model of Reactor Containment Building Dome Concrete, Figure 3.8-16—Finite Element Model of Reactor Containment Building Basemat Concrete, Figure 3.8-17—Finite Element Model of Reactor Containment Building Interface with Concrete Interior Structures, Figure 3.8-18, and Figure 3.8-19. The finite element model is based on the layout and dimensions shown in the figures listed in Section 3.8.1.1.

Additional descriptions of the RCB computer model are provided in Appendix 3E.

3.8.1.4.2 Assumptions on Boundary Conditions

The RCB is modeled integral with the NI Common Basemat Structure foundation basemat in the overall ANSYS model. Section 3.8.5 provides information on the design of the NI Common Basemat Structure foundation basemat and interface conditions between the soil and foundation. Soil spring parameters are described in Section 3.8.5 and the soil conditions are described in Section 2.5.

3.8.1.4.3 Axisymmetric and Nonaxisymmetric Loads

The RCB is modeled in its entirety as a three-dimensional structure. The loads described in Section 3.8.1.3.1 are applied in the locations and directions appropriate for each load. Overall pressure is applied uniformly to the interior surface of the containment structure. Pressure variant loads potentially present in the annulus are applied uniformly to the exterior surface of the structure.

Localized loads, such as penetration dead loads, hydrostatic pool water loads, live loads, and pipe rupture loads are applied to specific portions of the structural model as appropriate. Post-tension loads are applied to each tendon in its specific location. Seismic loads are applied in each possible direction and combination for the two horizontal and one vertical load directions using the methodology described in Section 3.7.

3.8.1.4.4 Transient and Localized Loads

Thermal and pressure loads resulting from a LOCA are applied to the RCB model as a non-linear load condition. The LOCA temperature peaks rapidly at the surface of the internal liner plate and builds up over time through the thickness of the concrete containment vessel. Accident pressure and temperature curves used in the analysis are presented in Figures 3.8-20—Accident Temperature versus Time - Reactor Containment Building and 3.8-21—Accident Pressure versus Time - Reactor Containment Building.

A heat transfer analysis was performed for the RCB accident temperature using the ANSYS computer code. Temperature gradients through the wall and dome were calculated with respect to time using the curve, and annulus temperature of 79°F (26°C) and the thermal properties in Table 3.8-1—Thermal Properties for Heat Transfer Analysis-Reactor Containment Building.

Structural forces were computed, with time, based on the heat transfer analysis using the ANSYS computer code. Figure 3.8-22—Temperature Gradient Through Cylinder Wall, Figure 3.8-23—Temperature Gradient Through Dome, and Figure 3.8-24—Temperature Gradient Through Basemat provide the generic results of this analysis. These results and those of the accident pressure analysis were reviewed in detail to establish critical time points for the development of load cases to be used in the structural analysis. Forces and moments at times 0.33 hour, 2 hours, 24 hours, and 110 hours were selected as critical for cylinder, dome, and basemat forces and moments. Additional internal pressure was added to the RCB due to the heating of the liner plate.

The RCB, including the steel liner, is designed to resist the effects of impulse loads and dynamic effects. Structural members designed to resist impulse loads and dynamic effects in the abnormal, extreme environmental, and abnormal and extreme environmental categories are allowed to exceed yield strain and displacement values. The allowable stresses applicable to the determination of section strength are as specified in Subsections CC-3400 and CC-3700 of the ASME BPV Code, Section III, Division 2. In determining tensile yield strength of reinforcing steel (i.e., f_y) the dynamic effect of the loading may be considered. The applicable design assumptions in Subsection CC-3930 of the ASME BPV Code, Section III, Division 2 are used in calculating the effects of impact or impulse.

The ductility limits used in design for impact load do not exceed two-thirds the ductility determined at failure. The ductility limits used in design for impulse load do not exceed one-third the ductility determined at failure. See Section 3.5.3 for a description of additional requirements for missile barrier design and ductility requirements applicable to the design of the RCB.

3.8.1.4.5 Creep, Shrinkage, and Cracking of Concrete

Conservative values of concrete creep and shrinkage based on past experience are used in the design of the RCB. Moments, forces, and shears are obtained on the basis of uncracked section properties in the static analysis. However, in sizing the reinforcing steel required, the concrete is not relied upon for resisting tension. Thermal moments are modified by cracked-section analysis using analytical techniques. The ANSYS computer code and the RCB model thermal stress evaluation, based on results from the heat transfer analysis, were used to evaluate cracking due to accident thermal loading. The material properties, specifically E (Young's modulus), for the finite elements, were redefined as bilinear. This approximation allows the moment of inertia of a wall section to reduce in proportion to the amount of cracking developed due to the thermal loading. The threshold tensile value for cracking, maximum tension in the concrete, is taken as $4\sqrt{f'_c}$. Elements are not allowed to heal once cracked. Results from this analysis are used to factor the thermal moments from the RCB static analysis for the design of concrete sections.

Section 3.8.1.6.1 describes methods used to confirm that concrete properties satisfy design requirements.

3.8.1.4.6 Dynamic Soil Pressure

Soil loads are not applicable to the design of the RCB because the building is completely surrounded by other structures above the NI Common Basemat Structure foundation basemat.

3.8.1.4.7 Tangential Shear

The design and analysis procedures for tangential shear are in accordance with the ASME BPV Code Section III, Division 2 and RG 1.136.

Tangential shear is resisted by the vertical reinforcement and the horizontal hoop reinforcement in the RCB wall.

3.8.1.4.8 Variation in Physical Material Properties

In the design and analysis of the RCB, consideration is given to the effects of possible variations in the physical properties of materials on the analytical results. The properties used for analysis purposes were established based on past engineering experience with similar construction and materials. Values used are delineated in Tables 3.8-2—Material Properties – Reactor Containment Building, 3.8-3—Tendon Frictional Losses, and 3.8-4—Thermal Properties – Reactor Containment Building. Additional reviews of materials and their effects on the analysis and design of the RCB will be included in design specification development and materials selection.

Losses due to elastic shortening, concrete creep and shrinkage, and relaxation of the post-tensioning cables were accounted for in the analysis. Table 3.8-5—Tendon Losses and Effective Forces with Time summarizes the losses and delineates the final wire stresses.

When designing the structure under full service and factored load conditions, allowable stress levels are used based on the minimum strength of the concrete and reinforcing materials used in construction of the containment to account for variations in physical properties. The containment is designed for the range of soil properties described in Section 3.7.1.

3.8.1.4.9 Penetrations

Large penetrations through the concrete RCB include the equipment hatch, two airlocks, and a construction opening, which are described in Section 3.8.1.1. The two airlocks are located in the containment buttresses, with one positioned at azimuth 0° and one positioned at azimuth 230°. The construction opening, which is a temporary opening permanently sealed using a metal pressure closure cap after construction, is also located at azimuth 230°. The equipment hatch is located in the cylindrical shell portion of containment at azimuth 150° between the buttress locations. The containment shell is thickened in the region surrounding the equipment hatch.

Submodels with refined element meshes and tendon configurations are used to analyze the containment vessel in the areas around the equipment hatch and in the buttress at azimuth 230° that contains the penetrations for an airlock and the construction opening. Displacements and loadings obtained from the full containment model are applied to the equipment hatch and buttress at azimuth 230° submodel to more accurately represent results in the regions around the large openings for the various loading conditions. The modulus of elasticity of the solid elements at the openings in the full containment model is reduced to one percent to consider the effect of the openings; however, the openings are explicitly included in the submodel. The modification of material properties at those solid elements was done based on the satisfactory match of displacement and stress contours between the full containment model and the equipment hatch and buttress sub-models.

Small penetration openings through the concrete RCB are defined as those having a diameter of less than approximately 6 feet. These are not considered to have a specific effect on the overall design of the RCB and are not included in the overall computer model of containment.

Appendix 3E provides details of the design and reinforcement in the equipment hatch area.

Section 3.8.2 provides design details of the steel portion of containment penetrations.

3.8.1.4.10 Steel Liner Plate and Anchors

The design of the steel liner plate is in accordance with Subarticle CC-3600 of the ASME BPV Code, Section III, Division 2. The steel liner plate is not considered as a structural strength member when performing containment design basis analyses. The steel liner plate is designed to withstand the effects of imposed loads and to accommodate deformation of the concrete containment without jeopardizing leak-tight integrity (GDC 16). The steel liner plate is anchored to the concrete containment in a manner that does not preclude local flexural deformation between anchor points. Calculated strains and stresses for the steel liner plate do not exceed the values given in Table CC-3720-1 of the ASME BPV Code, Section III, Division 2. Strains associated with construction-related liner deformations may be excluded when calculating liner strains for service and factored load combinations as allowed by the code. The liner is anchored to the concrete containment around the outside perimeter of the sides of the embedded portion between elevation -25 feet, 7 inches and elevation -7 feet, 6.5 inches. Anchors are not provided on the inside surface of the liner. Overturning moments and sliding forces of the RB internal structures relative to the liner plate are resisted by the appropriate structural dead weight and lateral bearing.

The steel liner plate anchorage system is designed to accommodate design loads and deformations without loss of structural or leak-tight integrity (GDC 16). The steel liner plate anchorage system is designed so that a progressive failure of the anchorage system is prevented in the event of a defective or missing anchor. The steel liner plate is anchored to the concrete so that the liner strains do not exceed the strain allowable given in Paragraph CC-3720 of the ASME BPV Code, Section III, Division 2. The anchor size and spacing is designed so that the response of the steel liner plate is predictable for applicable loads and load combinations. The anchorage system is designed to accommodate the design in-plane shear loads and deformations exerted by the steel liner plate and normal loads applied to the liner surface. The allowable force and displacement capacity for the steel liner plate anchors does not exceed the values given in Table CC-3730-1 of the ASME BPV Code, Section III, Division 2. The load combinations specified in Section 3.8.1.3.2 are applicable to the steel liner plate anchors. Mechanical and displacement-limited loads are as defined in Subparagraph CC-3730(a) of the ASME BPV Code, Section III, Division 2. Concrete anchors are designed in accordance with ACI 349, Appendix B, with the exceptions noted in RG 1.199.

Steel liner plate penetration assemblies, including nozzles, reinforcing plates, and penetration anchors are designed to accommodate design loads and deformations without loss of structural or leak-tight integrity (GDC 16). Effects such as temperature, concrete creep, and shrinkage are considered. Temporary and permanent brackets and attachments to the steel liner plate are designed to resist the design loads without loss of the liner integrity due to excessive deformation or load from the brackets or attachments.

Design of the steel liner plate and anchorage system is based on minimum strengths for the materials that are specified for fabrication of the steel components and their interface with the concrete containment. Deviations in the geometry of the liner plate due to fabrication and erection tolerances are considered in the design.

The materials of the liner and its stiffening and anchorage components that are exposed to the internal environment of containment are selected, designed, and detailed to withstand the effects of imposed loads and thermal conditions during design basis conditions.

3.8.1.4.11 Containment Ultimate Capacity

The ultimate capacity of the RCB is determined for use in probabilistic risk assessments (see Section 19) and severe accident analyses. The ultimate capacity of the overall structure and primary sub-assemblies of containment is calculated to determine the limiting ultimate pressure. Ultimate capacity modeling of the concrete RCB is performed in accordance with RG 1.136 and guidance from NUREG/CR-6906, Appendix A (Reference 5).

Table 3.8-6—Containment Ultimate Pressure Capacity provides the results of the containment ultimate pressure capacity analysis. Hand calculations and non-linear finite element analyses were used to support this analysis.

Pressure capacities for concrete cylinder and dome sections were calculated using material specified minimum strengths as deterministic values, neglecting the liner plate strength contribution. Pressure capacities were also computed at median and 95 percent confidence levels considering variation in material yield strengths (including the liner plate) and variations in geometry. The ultimate pressure capacity reported for the cylinder and dome is taken as median pressure capacity corresponding to a 0.8 percent maximum strain in the tendons away from discontinuities.

Pressure capacities for the dome ring and gusset were evaluated using a non-linear finite element model. The dome ring section was evaluated at azimuths where there are no dome post-tension cables present in the cross-section. This occurs at corner locations of the dome tendon criss-cross pattern as presented in Figure 3.8-19. The limiting condition in the dome belt is governed primarily by a membrane failure at the transition between the torus and spherical portions of the dome. A second area of high meridional strains from flexure exist on the inside face toward the middle part of the torus. However, membrane failure at the transition region is the limiting condition. The ultimate pressure capacity reported is the median pressure capacity.

Pressure capacities were evaluated for the reinforced area around the equipment hatch opening. The evaluation considered a horizontal plane and a vertical plane section passing through the centerline of the opening. The vertical plane section, which corresponds to hoop stress direction, was the weaker of the two planes. The ultimate pressure capacity reported is the median pressure capacity for the vertical plane section.

The equipment hatch cover and cylinder, shown in Figure 3.8-25—Equipment Hatch General Assembly has a cover ultimate pressure capacity based on ASME Section II, Part D material specification minimum required strengths and an elastic, perfectly plastic stress-strain relationship at 400°F. The internal pressure from containment is applied to the convex surface of the cover and non-embedded portion of the cylinder. The ultimate pressure capacity reported corresponds to ASME Service Level C stress limits for the hatch cover and cylinder.

3.8.1.4.12 Design Report

Design information and criteria for Seismic Category I structures are provided in Sections 2.0, 2.4, 2.5, 3.3, 3.5, 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5. Design results are presented in Appendix 3E for Seismic Category I structure critical sections.

3.8.1.5 Structural Acceptance Criteria

The limits for RCB allowable stresses, strains, deformations and other design criteria are in accordance with the requirements of Subsection CC-3400 of the ASME BPV Code, Section III, Division 2 and RG 1.136 (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50). This applies to the overall containment vessel and subassemblies and appurtenances that serve a pressure retaining function, except as noted in Section 3.8.2. Specifically, allowable concrete stresses for factored loadings are in accordance with Subsection CC-3420 and those for service loads are in accordance with Subsection CC-3430.

The limits for stresses and strains in the liner plate and its anchorage components are in accordance with ASME BPV Code, Section III, Division 2, Tables CC-3720-1 and CC-3730-1.

Section 3.8.1.6 describes minimum requirements for concrete, reinforcing, post-tensioning tendons, and the liner plate system for the RCB.

A SIT is performed as described in Section 3.8.1.7.1.

The RCB is stamped to signify compliance with the ASME BPV Code Section III, Division 2.

3.8.1.6 Materials, Quality Control, and Special Construction Techniques

This section contains information relating to the materials, quality control program, and special construction techniques used in the fabrication and construction of the RCB. Materials and quality control satisfy the following requirements (GDC 1):

- ASME BPV Code – 2004 Edition, Section III, Division 2, Code for Concrete Containments/ACI Standard 359, Articles CC-2000, CC-4000, CC-5000, CC-6000, and CC-9000.
- RG 1.107, Qualifications for Cement Grouting for Prestressing Tendons in Containment Structures, Revision 1, February 1977.
- RG 1.136, Design Limits, Loading Combinations, Materials, Construction, and Testing of Concrete Containments, Revision 3, March 2007.

Concrete and reinforcement forming and placement tolerance not specifically addressed in these references are in accordance with ACI 349-01 and ACI 117-90.

3.8.1.6.1 Concrete Materials

Concrete Mix Design

The concrete mix design for the RCB conforms to the requirements specified in Subarticle CC-2230 of the ASME BPV Code, Section III, Division 2.

Structural concrete used in the construction of the RCB shell wall and dome has a minimum compressive strength (i.e., f'_c) of 7000 psi at 90 days.

Concrete mix design is determined based on field testing of trial mixtures with actual materials used. Testing evaluates:

- Ultimate concrete strength, as well as early strength in support of an aggressive construction schedule.
- Creep and shrinkage characteristics.
- Concrete workability and consistency.
- Required concrete admixtures.
- Heat of hydration and required temperature control for large or thick concrete pours.
- Special exposure requirements when identified on design drawings.

Cement

Cement used for the concrete RCB conforms to the requirements of ASTM C150 (Reference 47) (Type I, Type II, Type IV or Type V) or ASTM C595 (Reference 48) (Type IP, Type IP [MS], or Type IP [MH]).

Cement is a low-alkali cement, not containing more than 0.60 percent by weight of total alkalis ($Na_2O + 0.658K_2O$).

Aggregates

Aggregates used for the RCB meet the requirements specified in ASME BPV Code, Section III, Division 2, Paragraph CC-2222.

Aggregates conform to the requirements of ASTM C33 (Reference 22).

Admixtures

Air-entraining admixtures conform to the requirements of ASTM C260 (Reference 23).

Chemical admixtures conform to the requirements of ASTM C494 (Reference 24) or ASTM C1017 (Reference 25).

Fly ash and other pozzolanic admixtures conform to the requirements of ASTM C618 (Reference 26).

Grout fluidizers conform to the requirements of ASTM C937 (Reference 27).

Ground-granulated blast furnace slag used as an admixture is in accordance with the requirements of ASTM C989 (Reference 28).

Silica fume used as an admixture conforms to the requirements of ASTM C1240 (Reference 29).

Admixtures used in concrete mixtures in accordance with ASTM C845 (Reference 30) expansive cement is compatible with the cement and produce no deleterious effects.

Mix Water

Mix water used for the RCB is in accordance with the requirements of ASME BPV Code, Section III, Division 2, Paragraph CC-2223.

Placement

Conveying, inspection, placement, and testing of concrete are performed in accordance with the following codes and standards:

- ACI 301-05, Specifications for Structural Concrete for Buildings.
- ACI 304R-00, Recommended Practice for Measuring, Mixing, Transporting, and Placing Concrete.
- ACI 305.1-06, Specification for Hot-Weather Concreting.
- ACI 306.1-90, Standard Specification for Cold-Weather Concreting.

- ACI 347-04, Recommended Practice for Concrete Formwork.
- ACI SP-2 (99), Manual of Concrete Inspection.
- ASTM C94, Specification for Ready-Mixed Concrete (Reference 38).

3.8.1.6.2 Reinforcing Steel and Splice Materials

Materials

Conventional reinforcing is used in the concrete RCB, which conforms to ASTM A615 (Reference 31) or ASTM A706 (Reference 32), and the criteria described in the ASME BPV Code, Section III, Division 2, Subarticle CC-2330.

Welded splices and mechanical splices of reinforcing bars are used. Mechanical splices are threaded, swaged, or sleeved with ferrous filler metal. These devices are qualified and the qualifications are maintained in accordance with Subarticle CC-4333 of ASME BPV Code. These devices also meet the provisions of ACI 349-01, Section 12.14.3.

Welding of reinforcement is as specified in approved splice details and is located as shown on approved reinforcing placement drawings. Welding conforms to ASME BPV Code, Section III, Division 2, Subsection CC, as supplemented by RG 1.136, and ANSI/AWS D1.4.

Materials used for bar-to-bar sleeves for mechanical cadweld-type rebar splices in the RCB conform to ASTM A513, (Reference 33) ASTM A519 (Reference 34), or ASTM A576 (Reference 35). For bar splice sleeves attached to the liner plate or structural steel shapes, the sleeves are carbon steel in accordance with ASTM A513, ASTM A519, or ASTM A576 (Grades 1008 through 1030).

Materials for mechanical threaded, swaged, or sleeved splicing systems are established in accordance with the ASME BPV Code, Section III, Division 2, Subarticle CB-4333.

Fabrication and Placement

Fabrication and placement of reinforcing bars for the RCB are in accordance with Subarticle CC-4300 of the ASME BPV Code, Section III, Division 2.

3.8.1.6.3 Tendon System Materials

Tendons

The post-tensioning tendon system consists of load-carrying and non-load-carrying components. The load-carrying components include the post-tensioning wires that make up the tendons, and anchorage components composed of bearing plates, anchor heads, wedges, and shims. Non-load-carrying components include the tendon sheathing (including sheaths, conduits, trumpet assemblies, couplers, vent and drain nipples, and other appurtenances) and corrosion prevention materials.

Materials used for the RCB post-tensioning system (including post-tensioning steel, anchorage components, and non-load-carrying and accessory components) meet the requirements of Subarticle CC-2400 of the ASME BPV Code, Section III, Division 2.

The Freyssinet C-range post-tensioning system has the following properties:

- ASTM A416 (Reference 36), Grade 270, low-relaxation tendon material.
- Tendon ultimate strength $F_{pu} = 270$ ksi
- Tendon minimum yield strength $F_{py} = (0.9)(270) = 243$ ksi
- Modulus of elasticity of tendon material $E_{ps} = 28{,}000$ ksi
- Number of strands per tendon $N_{strands} = 55$
- Total area of each tendon $A_p = 12.76\ in^2$

The materials used for the anchorage components are compatible with the tendon system. Tendon raceways consist of corrugated metal tubing, rigid conduit, or high-density polyethylene tubing. These components are non-structural and are sealed to prevent the intrusion of concrete during construction.

Grouting of Tendons

Cement grout for the grouted tendon system in the RCB is selected based on the testing and material requirements of the ASME BPV Code, Section III, Division 2, as amended by RG 1.136, which endorses the Regulatory Positions of RG 1.107, Qualifications for Cement Grouting for Prestressing Tendons in Containment Structures.

3.8.1.6.4 Liner Plate System and Penetration Sleeve Materials

The 0.25 inch thick liner plate is ASTM A516, Grade 55 material, which conforms to Subarticle CC-2500 of the ASME BPV Code, Section III, Division 2 (GDC 16). Thickened liner plates are used at penetrations, brackets, and embedded assemblies.

Penetration assemblies and appurtenances that are either not backed by concrete or are embedded in concrete and surrounded by a compressible material to provide local flexibility conform to the material requirements of Subsection NE of the ASME BPV Code, Section III, Division 1 (GDC 16).

Welding materials conform to the requirements of ANSI/AWS D1.1 or ANSI/AWS D1.6 except as modified by ANSI/AISC N690, Sections Q1.17.1 and Q1.17.2.1. The compatibility of filler metal with base metal is specified in Table 3.1 of ANSI/AWS D1.1.

Materials used for the carbon steel liner plate, carbon steel and low alloy steel attachments, and appurtenances subject to ASME BPV Code Division 2 requirements, meet the fracture toughness requirements of Subsection CC-2520 of the ASME BPV Code, Section III, Division 2.

Materials used in ASME Division 1 attachments and appurtenances meet the fracture toughness requirements of Subsection 2300 of the ASME BPV Code, Section III, Division 1.

3.8.1.6.5 Steel Embedments

Steel embedment materials conform to the requirements of Subsection CC-2000 of the ASME BPV Code, Section III, Division 2.

3.8.1.6.6 Corrosion Retarding Compounds

Corrosion retarding compounds used for the RCB are described in Section 6.1.2.

3.8.1.6.7 Quality Control

In addition to the quality control measures addressed in Section 3.8.1.6, refer to Chapter 17 for a description of the quality assurance program for the U.S. EPR (GDC 1).

3.8.1.6.8 Special Construction Techniques

Special techniques are not used for construction of the RCB. Modular construction methods are used to the extent practical for prefabricating portions of the containment liner, equipment hatch, airlocks, penetrations, reinforcing steel, tendon conduits, and concrete formwork. Such methods have been used extensively in the construction industry. Rigging is pre-engineered for heavy lifts of modular sections. Permanent and temporary stiffeners are used on liner plate sections to satisfy code requirements for structural integrity of the modular sections during rigging operations.

3.8.1.7 Testing and Inservice Inspection Requirements

3.8.1.7.1 Structural Integrity Test

Following construction, the RCB is proof-tested at 115 percent of the design pressure. During this test, deflection measurements and concrete crack inspections are made to confirm that the actual structural response is within the limits predicted by the design analyses (GDC 1).

The SIT procedure complies with the requirements of Article CC-6000 of the ASME BPV Code, 2004 Edition, Section III, Division 2, and with Subsections IWL and IWE of Section XI of the ASME BPV Code.

3.8.1.7.2 Long-Term Surveillance

The RCB is monitored periodically throughout its service life in accordance with 10 CFR Part 50, Appendix J, to evaluate the integrity of containment over time (GDC 1 and GDC 16). As part of this monitoring program, containment deformations and exterior surface conditions are determined while the building is pressurized at the maximum calculated DBA pressure (P_a). Initial conditions, baseline measurements taken at P_a, during depressurization following the SIT are established prior to initial operation. Initial measurements and in-service inspection meet the following requirements:

- ASME BPV Code, 2004 Edition, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, Subsections IWE and IWL.
- RG 1.107, Revision 1 (February 1977).
- RG 1.90, Revision 1 (February 1977), except that:
  - Force monitoring of ungrouted tendons is not provided:
    - This exception to RG 1.90 is acceptable because all tendons used within the RCB are fully grouted.
  - Pressurization at year one uses P_a instead of P_N:
    - This exception is acceptable because the value of P_a is higher than that of P_N.
  - Pressurization at years three and seven uses P_a instead of $1.15P_D$:
    - This exception is acceptable because the structural integrity is confirmed at year zero. Additional overpressurization to $1.15P_D$ unduly fatigues the structure and interrupts the surveillance tracking of containment response to P_a.

The EPR containment uses fully grouted tendons in each location. This methodology has several advantages:

- Tendons are surrounded with a cementitious grout injected into the tendon duct; the alkaline composition of the grout mixture inhibits corrosion of the steel strands and prevents the ingress of corrosive fluids (e.g., water).

- In the event of one or more strand failures during the life of the structure, the bond of the strand with grout and the grout to the concrete wall enables the remaining portion of the post-tensioning to be transmitted to the structure.

- Grouted tendons and tendon anchorages are less vulnerable to local damage than ungrouted tendons. Therefore, if the end anchorages are damaged, for instance by fire or missile impact, the post-tensioning force will be maintained along the effective length of the tendon.

- Grouted tendons increase the overall wall tightness by filling any voids from within the structure. This reduces the risk of water or other contaminates from entering through wall cracks or tendon end caps.

- European experience has found that grouted tendons significantly improve concrete crack distribution when the containment is pressurized to a point where the tensile stress of the concrete is exceeded. Less local large tensile strains are likely to occur thus diminishing the risk of having large concrete cracks behind the containment liner. The absence of large cracks improved the safety margin of the liner with regard to air tightness.

The use of grouted tendons precludes the possibility of directly measuring the post-tension force over time by lifting off at the anchorages. The U.S. EPR mitigates this concern by extensively monitoring the movement of the RCB during 10 CFR Part 50, Appendix J, leak-rate testing at P_a. The pressure test schedule is a part of the inservice inspection program. Movements obtained from the initial test will be used to baseline a structural analysis that will be used to predict the capacity of the RCB over time. Thirty-six RCB locations will be monitored for radial displacement, 6 for vertical displacement and 13 on the dome for tri-directional displacement. Table 3.8-7—ISI Schedule for the U.S. EPR presents the ISI schedule for containment.

The RCB is fully enclosed by the RSB; therefore, the potential for corrosion of the tendon system is significantly reduced.

Section 6.2.6 contains a description of the associated leak-rate test procedure, Containment Integrated Leakage Rate Test (CILRT). Containment pressure testing will occur in conjunction with the CILRT.

Sufficient physical access is provided in the annulus between the RCB and the RSB to perform inservice inspections on the outside of the containment. Space is available inside of the RCB to perform inservice inspections of the liner plate. Gaps are provided between the liner and RB internal structures concrete structural elements, which provide space necessary to inspect the liner at wall and floor locations inside containment. Inservice inspection of the embedded portion of the containment liner and the surface of the concrete containment structure covered by the liner are exempted in accordance with Section III of the ASME BPV Code for Class CC components.

3.8.2 Steel Containment

The steel containment section describes major RCB penetrations and portions of penetrations not backed by structural concrete that are intended to resist pressure. Section 3.8.1 describes the concrete RCB.

3.8.2.1 Description of the Containment

Steel items that are part of the RCB pressure boundary and are not backed by concrete include the equipment hatch, airlocks, piping penetration sleeves, electrical penetration sleeves, and fuel transfer tube penetration sleeve. Section 3.8.1.1 describes RCB steel items that are backed by concrete, such as the liner plate.

3.8.2.1.1 Equipment Hatch, Airlocks, and Construction Opening

The equipment hatch, illustrated in Figure 3.8-25 is a welded steel assembly with a double-gasketed, flanged, and bolted cover. Provision is made for leak testing of the flange gaskets by pressurizing the annular space between the gaskets. The cover for the equipment hatch attaches to the hatch barrel from inside of the RCB. The cover seats against the sealing surface of the barrel when subjected to internal pressure inside the RCB. The equipment hatch opens into the Seismic Category I FB, which provides protection of the hatch from external environmental hazards (e.g., high wind, tornado wind and missiles, and other site proximity hazards, including aircraft hazards and blasts). The equipment hatch barrel has an inside diameter of approximately 27 feet, 3 inches.

One personnel airlock and one emergency airlock are provided for personnel to access the RCB. Figure 3.8-26—Personnel Airlock, Emergency Airlock General Overview illustrates a typical arrangement for the airlocks. Each airlock is a welded steel assembly that has two doors, each with double gaskets. The airlocks open into containment so that internal pressure inside the RCB seats the doors against their sealing surfaces. Provision is made to pressurize the annular space between the gaskets during leak testing.

The doors mechanically interlock so that one door can not be opened unless the second door is sealed during plant operation. Provisions are made for deliberately overriding the interlocks by the use of special tools and procedures for ease of access during plant maintenance. Each door is equipped with valves for equalizing the pressure across the doors. The doors are not operable unless the pressure is equalized. Pressure equalization is possible from the locations at which the associated door can be operated. The valves for the two doors interlock so that only one valve can open at a time and only when the opposite door is closed and sealed. Each door is designed to withstand and seal against design and testing pressures of the containment vessel when the other door is open. A visual indication outside each door shows whether the opposite door is open or closed. In the event that one door is accidentally left open, provisions outside each door allow remote closing and latching of the opposite door.

The personnel airlock at [ ] opens into a [ ] which is a Seismic Category I structure. The emergency airlock opens into the [ ], which is a Seismic Category I structure. Therefore, both airlocks are protected from external environmental hazards (e.g., high wind, tornado wind and missiles, and other site proximity hazards, including aircraft hazards and blasts). The personnel airlock and the emergency airlock have inside diameters of approximately 10 feet, 2 inches.

The construction opening is located at [ ] and opens to the heavy load operating floor level from [ ] This passage serves as personnel and material access into the RB during construction. Upon completion of construction work, the cavity is permanently sealed with a welded in place metal closure cap.

The equipment hatch, two airlocks, and construction opening closure cap are designated as Class MC components in compliance with Article NE-3000 of the ASME BPV Code, Section III, Division I, and are stamped pressure vessels designed and tested in accordance with this code (GDC 1 and GDC 16).

3.8.2.1.2 Piping Penetration Sleeves

Piping penetrations through the RCB pressure boundary are divided into the following three general groups:

- High-energy penetrations:

  This type of penetration is used for high-energy piping. Examples of high-energy penetrations are those provided for the safety injection or chemical and volume control lines. High-energy piping penetrations consist of the following major steel items:

  - Process pipe – Process pipes are welded or seamless and are made of carbon or stainless steel. The pipes are welded to a connecting part centrally located in the annulus between the inner containment wall and the outer shield wall. The connecting part is welded to an embedded sleeve in the inner containment wall. This acts as an anchor for the penetration. The guard pipe is also connected to the connecting part. The process pipes conform to the requirements of ASME BPV Code Section III, Subsection NC and meet the requirements of the piping system they serve as described in Sections 3.6.

  - Connecting part – Connecting parts are made from forged carbon or stainless steel and conform to ASME BPV Code Section III, Division 1, Subsection NC. The connecting process pipes and connecting part are each designed and analyzed to be capable of carrying loads in the event of failure of the process pipes as described in Sections 3.6 and 3.9.

– Pipe sleeve – Pipe sleeves are made from carbon or stainless steel and consist of the portion of the penetration that projects into the RCB and supports the connecting part. Pipe sleeves conform to ASME BPV Code Section III, Division 1, Subsection NE (GDC 1).

- Main steam and feedwater penetrations:

  These penetrations are a special adaptation of the high-energy penetrations. The design is the same as the high-energy penetration except it has a guard pipe that fits tightly over the process pipe in the inner containment sleeve that is designed to dissipate heat and prevent the concrete from overheating.

- Standard piping penetration:

  This penetration type is used for moderate or low energy piping lines. The basic configuration consists of an inline flued head component attached to the inner containment embedded pipe sleeve. There is no guard pipe, but isolation of the annulus is provided by an expansion joint attached to the pipe and the outer shield wall sleeve. These penetrations consist of:

  – Process pipe and flued head – Process pipes are welded or seamless and are made of carbon or stainless steel. The pipes are welded to the flued head. Flued heads are made from forged carbon or stainless steel. Process pipes and flued heads conform to Subsection NC of the ASME BPV Code, Section III, Division 1, and meet the requirements of the piping system they serve as described in Sections 3.6.

  – Pipe Sleeve – Pipe sleeves are made from carbon or stainless steel and consist of the portion of the penetration that projects into the RCB and supports the flued head. Pipe sleeves conform to ASME BPV Code Section III, Division 1, Subsection NE (GDC 16).

- Spare penetrations:

  Spare penetrations are reserved for future use. Spare penetrations consist of the following major items:

  – Solid closure plate or pipe cap – Closure plates and pipe caps are made from carbon or stainless-steel and conform to the requirements of Subsection NC of the ASME BPV Code, Section III, Division 1, Subsection NC.

  – Pipe sleeve – Pipe sleeves are made from carbon or stainless-steel and consist of the portion of the penetration that projects into the RCB. Pipe sleeves conform to ASME BPV Code Section III, Division 1, Subsection NE (GDC 16).

Typical details of piping penetrations are illustrated in Figure 3.8-27—Containment Penetrations for Main Steam and Feedwater Pipes, Figure 3.8-28—Containment

Penetrations for High-energy Pipes, Figure 3.8-29—Containment Standard Piping Penetrations – Single Pipe, and Figure 3.8-30—Containment Standard Piping Penetrations – Multiple Pipes.

3.8.2.1.3 Electrical Penetration Sleeves

Sleeves for electrical penetrations consist of the portion of penetrations that projects into the RCB and supports the electrical assembly. Sleeves conform to ASME BPV Code Section III, Division 1, Subsection NE (GDC 16).

3.8.2.1.4 Fuel Transfer Tube Penetration Sleeve

The fuel transfer tube penetration is provided to transfer fuel between the refueling canal and the spent fuel pool during the refueling operations of the reactor. The penetration consists of an approximately 20 inch diameter stainless steel pipe installed inside a larger sleeve that is anchored to the concrete RCB. The steel sleeve conforms to Subsection NE of the ASME BPV Code, Section III, Division 1 (GDC 16). The inner pipe acts as the transfer tube. The sleeve is designed to provide integrity of the RCB, allow for differential movement between the RB internal structures and the FB and the RCB, and prevent leakage through the fuel transfer tube in the event of an accident. Bellows and water-tight seals are provided around the fuel transfer tube where it passes through the RB internal structures refueling canal concrete and the RSB and FB concrete. Figure 3.8-31—Fuel Transfer Tube Penetration illustrates the fuel transfer tube penetration.

3.8.2.2 Applicable Codes, Standards, and Specifications

The following codes, standards, specifications, design criteria, regulations, and regulatory guides are used in the design, fabrication, construction, testing, and inservice inspection of steel portions of the RCB that are intended to resist pressure, but are not backed by structural concrete (GDC 1, GDC 2, GDC 4, GDC 16 and GDC 50).

Section 3.8.1.2 describes codes, standards, and specifications applicable to the containment steel liner.

3.8.2.2.1 Codes

- ANSI/AISC N690-1994 (R2004), Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2.
- ANSI/AWS D1.1/D1.1M-2006, Structural Welding Code – Steel.
- ANSI/AWS D1.6-1999, Structural Welding Code – Stainless Steel.

- ASCE Standard 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary.
- ASME BPV Code – 2004 Edition:
  - Section II – Material Specifications.
  - Section III, Division 1 – Nuclear Power Plant Components.
  - Section V – Nondestructive Examination.
  - Section VIII – Pressure Vessels.
  - Section IX – Welding and Brazing Qualifications.
- Acceptable ASME BPV Code cases per RG 1.84.
- ASCE/SEI Standard 7-05, Minimum Design Loads for Buildings and Other Structures.
- ASCE/SEI Standard 37-02, Design Loads on Structures During Construction.
- SEI/ASCE Standard 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities.

3.8.2.2.2 Standards and Specifications

Industry standards such as those published by ASTM are used to define material properties, testing procedures, fabrication, and construction methods. The applicable ASTM standard specifications for materials are those permitted by Article NE-2000 of Section III, Division 1 of the ASME BPV Code. Applicable ASTM standard specifications for nondestructive methods of examination are those referenced in Appendix X and Article X-3000 of Section III, Division 1 of the ASME BPV Code.

Structural specifications cover the design of steel portions of the containment pressure boundary. These specifications cover the following areas:

- Equipment hatch and airlocks.
- Piping penetration sleeves.
- Electrical penetration sleeves.
- Fuel transfer tube penetration sleeve.

3.8.2.2.3 Design Criteria

The design of steel pressure retaining components of the RCB that are not backed by concrete complies with the following:

- Article NE-3000 of the ASME BPV Code 2004 Edition, Section III, Division 1 (GDC 1 and GDC 16).

3.8.2.2.4 Regulations

- 10 CFR 50, Licensing of Production and Utilization Facilities.
- 10 CFR 50, Appendix A – General Design Criteria for Nuclear Power Plants GDC 1, 2, 4, 16, and 50.
- 10 CFR 50, Appendix J – Primary Reactor Containment Leakage Testing for Water Cooled Power Reactors.

3.8.2.2.5 NRC Regulatory Guides

RGs applicable to the design and construction of steel portions of the RCB that resist pressure, but are not backed by structural concrete:

- RG 1.7, Revision 3.
- RG 1.57, Revision 1.
- RG 1.84, Revision 33.
- RG 1.136, Revision 3 (exception described in 3.8.1.3).
- RG 1.193, Revision 1.

3.8.2.3 Loads and Load Combinations

The U.S. EPR standard plant design loads envelope includes the expected loads over a broad range of site conditions. Design loads and loading combinations for steel portions of the RCB that are not backed by concrete are described in the following sections (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50). Section 3.8.1.3 addresses loads and loading combinations for design of the steel liner plate.

3.8.2.3.1 Design Loads

Steel portions of the RCB that are not backed by concrete are designed for the following loads:

The effects of missiles and external events such as hurricanes, tornados, aircraft hazards, and explosion pressure waves are not considered because the containment is protected from these effects by the RSB. RCB and RSB penetrations are protected by other Seismic Category I structures (i.e., Safeguards or FB).

Service Loads

- Normal loads – Normal loads are those loads encountered during normal plant operation and shutdown (GDC 4). This load category includes:
  - Dead loads (D) – Dead loads include the weight of the structure and any permanent equipment or material weights. Dead load effects also refer to internal moments and forces due to dead loads.
  - Live loads (L) – Live loads include any normal loads that vary with intensity or point of application, including moveable equipment. Live load effects also refer to internal moments and forces due to live loads. Live loads are applied, removed, or shifted in location to obtain the worst-case loading conditions. Impact forces due to moving loads are applied as appropriate for the loading condition.
  - Thermal loads (T_o) – Thermal loads consist of thermally induced forces and moments resulting from normal plant operation and environmental conditions. These are described in Section 3.8.1.3.1.
  - Pipe reactions (R_o) – Pipe reactions are those loads applied by piping system supports during normal operating or shutdown conditions based on the critical transient or steady state conditions. The dead weight of the piping and its contents are included. Appropriate dynamic load factors are used when applying transient loads, such as water hammers.
  - Pressure variant loads (P_v) – Pressure variant loads are those external pressure loads resulting from pressure variation either from inside or outside of containment.
  - Construction loads – Construction loads are those loads to which the structure may be subjected during construction of the plant. Construction loads will be applied to evaluate partially completed structures, temporary structures, and their respective individual members. Design load requirements during construction for buildings and other structures will be developed in accordance with Standard SEI/ASCE 37. The magnitude and location of construction loads will be applied to generate the maximum load effects of dead, live, construction, environmental, and lateral earth pressure loads. Consideration will be given to the loads and load effects of construction methods, equipment operation, and sequence of construction.
- Test loads – Test loads are those loads that are applied during structural integrity testing or leak-rate testing. This load category includes:
  - Test pressure loads (P_t) – Test pressure loads are those loads resulting from the pressure exerted on the RCB during the SIT at 1.15 times the design pressure and during the leak-rate test at 1.0 times the DBA pressure.
  - Test thermal loads (T_t) – Test thermal loads include thermal effects and loads experienced by the RCB during the structural integrity and leak-rate tests.

Factored Loads

- Severe environmental loads – Severe environmental loads are those loads that could be encountered infrequently during the life of the plant (GDC 2). This load category includes:
  - Wind loads (W) – Wind loads are not applicable on steel portions of the RCB because it is surrounded by other Seismic Category I structures that subsequently provide a shield.
  - OBE loads (E) – OBE loads are not applicable to the global design of the U.S. EPR because an OBE level of one-third the SSE has been selected (See Section 3.7.1 for a description of the OBE). However, penetrations will be evaluated for fatigue resulting from OBE-induced stress cycles as described in Section 3.7.3. For these evaluations, the OBE loads will be equal to one-third the SSE load. If a component screens out of an analysis for cyclic operation, Level B service limit load combinations may be eliminated.
- Extreme environmental loads – Extreme environmental loads are those loads that are credible but are highly improbable (GDC 2) This load category includes:
  - SSE loads (E') –SSE loads are those loads generated by an earthquake with a peak horizontal ground acceleration of 0.30 g. Seismic loads in the vertical direction and two orthogonal horizontal directions are considered to act simultaneous. Section 3.7 provides a description of how SSE loads are determined and combined. SSE loads are considered due to applied inertia loads. This includes dead loads, live loads, and hydrostatic loads (i.e., water in storage pools and tanks).
- Abnormal loads – Abnormal loads are those loads generated by a postulated high-energy pipe break accident (GDC 4 and GDC 50). This event is classified as a DBA.

  These loadings include an appropriate dynamic load factor to account for the dynamic nature of the load, unless a time-history analysis is performed to justify otherwise.

  Abnormal loads include the following:
  - Internal flooding loads (F_a) – Loads resulting from the internal flooding of containment during or following a postulated DBA.
  - Pressure load (P_a) – Pressure equivalent static load within or across a compartment or building, generated by a postulated pipe break.
  - Thermal loads (T_a) – Thermal loads generated by the postulated pipe break (including thermal load T_o).
  - Accident pipe reaction loads (R_a) – Pipe reactions generated by the postulated pipe break (including pipe reaction load R_o).

- Pipe break loads (R_r) – Local loads following a postulated pipe break. Unless a time-history analysis is performed to justify otherwise, these loadings include an appropriate dynamic load factor to account for the dynamic nature of the load. This load category includes:

  - Pipe break reaction loads (R_{rr}) – R_{rr} is defined as the equivalent static load on the structure generated by the reaction of the high energy pipe during the postulated break.

  - Pipe break jet impingement loads (R_{rj}) – R_{rj} is defined as the jet impingement equivalent static load on the structure generated by the postulated break.

  - Pipe break missile impact loads (R_{rm}) – R_{rm} is defined as the missile impact equivalent static load on the structure generated by or during the postulated break, such as pipe whipping.

Other Loads

Other loads refer to postulated events or conditions that are not included in design basis (GDC 4). The loading conditions and effects are evaluated without regard to the bounding conditions under which SSC are required to perform design basis functions. This load category includes:

- Aircraft hazard (A) – Aircraft hazard refers to the loads on a structure resulting from the impact of an aircraft. The evaluation of this loading condition is considered as part of the plant safeguards and security measures. Aircraft hazard loads are not applicable to steel portions of the RCB because it is surrounded by other Seismic Category I structures that provide a shield.

- Explosion pressure wave (B) – Explosion pressure wave refers to the loads on a structure resulting from an explosion in the vicinity of the structure. The evaluation of this loading condition is considered as part of the plant safeguards and security measures. Explosion pressure wave loads are not applicable to steel portions of the RCB because it is surrounded by other Seismic Category I structures that provide a shield.

- Combustible gas loads (P_{g1} and P_{g2}) – Combustible gas loads are those pressure loads that result from a fuel-clad metal-water reaction, an uncontrolled hydrogen burn, and from a postaccident condition for the containment inerted by carbon dioxide. Regulatory Position C.5 of RG 1.136 provides the loads and load combinations acceptable for analysis and design of containment when exposed to the loading conditions associated with combustible gas. There is no inerting gas system in the U.S. EPR. The principal combustible gas for the U.S. EPR is hydrogen. The containment design pressure is 62 psig based on DBA conditions. RG 1.136, Regulatory Position C.5 and RG 1.7 specify a pressure of 45 psig combined with dead load (D) as a minimum design condition. Therefore, the strains and stresses for the RCB calculated using the U.S. EPR design pressure in the load combinations in Table CC-3230-1 of the ASME BPV Code bounds the results of the pressure specified in RG 1.136 and RG 1.7 (Refer to Section 6.2.5 for a description of combustible gas loads). Therefore, for the Level C service limits load combination, the sum $P_{g1} + P_{g2}$ may be applied as a minimum of 45 psig.

- Missile loads other than wind or tornado-generated missiles – Missile loads are not applicable to steel portions of the RCB resulting from activities of nearby military installations, turbine failures, or other causes. RCB and RSB penetrations are protected by other Seismic Category I structures (i.e., Safeguards or FBs).

3.8.2.3.2 Design Load Combinations

Loading combinations for steel items of the RCB that are not backed by concrete and are in accordance with Subsection NE of the ASME BPV Code, Section III, Division 1, as augmented by the applicable provisions of RG 1.57 (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50).

The effects of missiles and external events such as hurricanes, tornados, aircraft hazards, and explosion pressure waves are not considered because the containment is protected from these effects by the RSB. RCB and RSB penetrations are protected by other Seismic Category I structures (i.e., Safeguards or FBs).

Loads and loading combinations encompass the soil cases described in Section 3.7.1, using the design criteria described in Section 3.7.1 and Section 3.7.2.

The following loading combinations are considered for ASME Code Class MC RCB components that are completely enclosed within Seismic Category I structures. Stress intensities will be computed in accordance with Article NE-3215 of the ASME BPV Code III, Division 1.

Testing Load Combination

Where:

P^* = the set of calculated stress components associated with the analysis results for each load combination

$P^* = D + L + P_t + T_t$.

Construction Load Combinations

Temporary construction loads and the effects of environmental loads during construction of ASME Code Class MC components will be considered. SEI/ASCE 37-02 will be used to provide minimum design load requirements for these components during construction.

Design Load Combinations

These include design load combinations for which steel portions of the RCB ASME Code Class MC components will be designed, including LOCA conditions for which containment function is required (GDC 4 and GDC 50).

$P^* = D + L + P_a + T_a + R_a.$

Service Load Combinations

The service load combinations correspond to, and include Levels A, B, C, and D service limits as defined in Article NE-3113 of the ASME BPV Code, Section III, Division 1. The post-LOCA flooding condition is also included. Loads are combined according to their sequence of occurrence with consideration of their dynamic effect on containment.

Level A Service Limits

These service limit load combinations are applicable to service loads to which the containment is subjected. This includes LOCA conditions, for which the containment function is required (GDC 4 and GDC 50).

$P^* = D + L + T_o + R_o + P_v$

$P^* = D + L + T_a + R_a + P_a.$

RG 1.57 contains load combinations which include P_{g3}, defined as pressure resulting from postaccident inerting. The U.S. EPR does not utilize a postaccident inerting hydrogen control system. Therefore, load combinations containing P_{g3} are not applicable.

Level B Service Limits

These service limit load combinations include the loads subject to Level A service limits, plus the additional loads resulting from natural phenomena during which the plant must remain operational (GDC 2, GDC 4, and GDC 50). For the load effects of the OBE, only the contribution to cyclic loading needs to be considered because the OBE is defined as one-third of the SSE. If a component screens out of an analysis for cyclic operation, Level B service limit load combinations may be eliminated.

$P^* = D + L + T_o + R_o + P_v + E$

$P^* = D + L + T_a + R_a + P_a + E$

Level C Service Limits

These service limit load combinations include the loads subject to Level A service limits, plus the additional loads resulting from natural phenomena for which safe shutdown of the plant is required (GDC 2, GDC 4, GDC 50).

$P^* = D + L + T_o + R_o + P_v + E'$

$P^* = D + L + T_a + R_a + P_a + E'$

$P^* = D + P_{g1} + P_{g2.}$

In the last load combination, $P_{g1} + P_{g2}$ should not be less than 45 psig and evaluation of instability is not required as specified by the code.

Level D Service Limits

These service limit load combinations include other applicable service limits and dynamic loads for which containment function is required (GDC 2, GDC 4, and GDC 50).

$P^* = D + L + T_a + R_a + P_a + R_{rr} + R_{rj} + R_{rm} + E'$

$P^* = D + L + F_a + E.$

3.8.2.4 Design and Analysis Procedures

The steel items described in Section 3.8.2.1 will be designed and analyzed in accordance with Article NE-3000 of Subsection NE of the ASME BPV Code, Section III, Division 1, and as augmented by the applicable provisions of RG 1.57 (GDC 1 and GDC 16).

Containment penetrations, or portions thereof, within the jurisdictional boundaries defined by ASME BPV Code, Section III, Division 1, Subsection NE do not exceed the stress intensity limits defined by Articles NE-3221.1, NE-3221.2, NE-3221.3, and NE-3221.4 of the ASME BPV Code. Code class shell components are evaluated for buckling under earthquake, thermal, and pressure loads. Buckling of shells with more complex geometries and loading conditions than those covered by Article NE-3133 of the Code is considered in accordance with ASME BPV Code Case N-284-1 and additional guidance in RG 1.193. An acceptable approach to evaluating buckling of shells is to perform a non-linear analysis. Code class MC components are screened for cyclic service analysis according to the criteria given in Article NE-3221.5 of the ASME BPV Code.

Refer to Section 3.5.3 for a description of requirements for missile barrier design and ductility requirements applicable to the design of steel portions of the RCB.

The following sections provide individual descriptions of the design and analysis procedures performed to verify the structural integrity of the steel items. Section 3.8.1 addresses the design and analysis procedures used to qualify the RCB concrete structure for openings provided through the containment pressure boundary for these items. Containment ultimate capacity analysis results are described in Section 3.8.1.4.11, which includes evaluation of major containment steel penetrations.

3.8.2.4.1 Equipment Hatch, Airlocks, and Construction Opening

The equipment hatch described in Section 3.8.2.1.1 is supported entirely by the concrete shell of the RCB. The barrel of the equipment hatch is embedded in the concrete containment shell and welded at the periphery to the liner plate. The liner plate is thickened in the vicinity of the equipment hatch penetration. The equipment hatch cover is dished and stiffened by a reinforcing ring where it interfaces with the barrel of the equipment hatch.

The two airlocks described in Section 3.8.2.1.1 are supported by attachment to sleeves embedded in the concrete shell of the RCB and by supports attached to the RSB wall. These supports provide for differential movements of the containment and shield walls. The doors for both ends of the airlocks are flat, and the bulkhead ends of the components are dished.

The construction opening closure cap described in Section 3.8.2.1.1 is attached to and supported by a sleeve embedded in the concrete shell of the RCB. The closure cap is a dish shaped metal structure welded to the embedded sleeve flange.

The equipment hatch, airlocks, and construction opening closure cap will be evaluated for the combinations of loads described in Section 3.8.2.3.2. Analyses and limits for the resulting stress intensities in the equipment hatch, airlocks, and the construction opening closure cap will be designed in accordance with Articles NE-3130, NE-3200, NE-3325, and NE-3326 of Section III, Division 1 of the ASME BPV Code.

3.8.2.4.2 Piping, Electrical, and Fuel Transfer Tube Penetration Sleeves

The penetration sleeves are welded to the containment liner plate and are anchored to the RCB concrete shell. Penetration sleeves are subjected to various combinations of mechanical, thermal, and seismic loadings and will be evaluated for the combination of loads described in Section 3.8.2.3.2.

If the penetration sleeves are subjected to cyclic service, the associated peak stress intensities will be evaluated. The required analysis and associated stress intensity limits will be in accordance with Articles NE-3130 and NE-3200 of Section III, Division 1 of the ASME BPV Code.

3.8.2.4.3 Design Report

Design information and criteria for Seismic Category I structures are provided in Sections 2.0, 2.4, 2.5, 3.3, 3.5, 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5. Design results are presented in Appendix 3E for Seismic Category I structure critical sections.

3.8.2.5 Structural Acceptance Criteria

Structural acceptance criteria for steel containment items described in Section 3.8.2.1 are in accordance with Subsection NC and NE of the ASME BPV Code, Section III, Division 1, including allowable stress limits, strain limits, deformation limits, and factors of safety. These are augmented by the requirements of RG 1.57 (GDC 1, GDC 2, GDC 4, GDC 16, and GDC 50). Containment steel items not backed by concrete that are intended to resist pressure will be designed to meet the acceptance criteria for the load combinations listed in Section 3.8.2.3.2.

Steel items that are an integral part of the RCB pressure boundary will be designed to meet minimum leakage rate requirements. The leakage rate must not exceed the acceptable value indicated in the applicable technical specification.

The design and analysis methods, as well as the type of construction materials, are chosen to allow assessment of the capability of steel items to function properly throughout the plant life.

A SIT is performed as described in Section 3.8.2.7. Surveillance testing provides assurance of the continuing ability of each item to meet its design functions. Surveillance requirements are addressed in Section 3.8.2.7.

Items that form part of the containment pressure boundary are stamped in accordance with the applicable section of the ASME BPV Code used for their design or fabrication.

3.8.2.6 Materials, Quality Control, and Special Construction Techniques

Steel items that are not backed by concrete that are part of the containment pressure boundary are fabricated from materials that meet the requirements specified in Article NE-2000 of Section III, Division 1 of the ASME BPV Code, except as modified by applicable and acceptable ASME BPV Code cases (GDC 1).

Quality control for containment steel items conforms to Articles NE-2000, NE-4000, and NE-5000 of Section III, Division 1 of the ASME BPV Code (GDC 1).

Section 3.8.1.6 provides a description of welding requirements for steel items for the RCB, quality control for steel items for the RCB, and materials used for penetration sleeves, steel embedments, and corrosion retarding compounds.

Use of neoprene-based gaskets and seals are kept to a minimum because of the presence of fluoride or chloride ions and the increased potential for stress corrosion cracking.

Steel items such as the equipment hatch, airlocks, fuel transfer tube, and penetrations are prefabricated and installed as subassemblies during construction. No special techniques are used for construction of containment steel items not backed by concrete. Section 3.8.1.6 provides additional information of modular construction techniques used for the RCB.

3.8.2.7 Testing and Inservice Inspection Requirements

A SIT is performed for steel containment components not backed by concrete in accordance with Article NE-6000 of Subsection NE of the ASME BPV Code, Section III, Division 1 (GDC 1).

Testing and inservice surveillance for the steel items consists of leakage testing of the containment and pressure retaining subassemblies (GDC 1 and GDC 16). Section 6.2.6 describes the leakage tests and associated acceptance criteria.

3.8.3 Concrete and Steel Internal Structures of Concrete Containment

3.8.3.1 Description of the Internal Structures

RB internal structures consist of reinforced concrete walls and floors, steel framing members, and other concrete and steel structural elements that are located inside of the RCB. The RB internal structures provide support for components and radiation shielding for the RCS and refueling operations. The foundation basemat inside of the RCB supports the RB internal structures at the bottom interface. To prevent an interaction between the structures for design basis loading conditions, clearance is maintained between the containment wall and internal structures. RB internal structures important to safety are not shared with another unit (GDC 5).

The RB internal structures are Seismic Category I, except for miscellaneous structures such as platforms, stairs, guard rails, and other ancillary items. These miscellaneous structures are designed as Seismic Category II to prevent adverse impact on the Seismic Category I structures in the event of a SSE. Seismic classification of structures, systems and components (SSC) is addressed in Section 3.2.

The following figures show the main levels of the RB internal structures and sectional views of the building:

- Figure 3.8-2—Reactor Building Plan at Elevation -20 Feet (top of the foundation basemat inside containment).

- Figure 3.8-3—Reactor Building Plan at Elevation -8 Feet (top of concrete at start of containment wall).
- Figure 3.8-4—Reactor Building Plan at Elevation +5 Feet (top of heavy floor for nuclear steam supply system (NSSS) component support).
- Figure 3.8-5—Reactor Building Plan at Elevation +17 Feet (plan at centerline of reactor vessel piping nozzles).
- Figure 3.8-6—Reactor Building Plan at Elevation +29 Feet (top of grating floor for component access).
- Figure 3.8-7—Reactor Building Plan at Elevation +45 Feet (top of grating floor for component access).
- Figure 3.8-8—Reactor Building Plan at Elevation +64 Feet (top of concrete operating floor).
- Figure 3.8-9—Reactor Building Plan at Elevation +79 Feet (top of partial concrete floor).
- Figure 3.8-10—Reactor Building Plan at Elevation +94 Feet (top of pressurizer cubicle).
- Figure 3.8-11—Reactor Building Section A-A.
- Figure 3.8-12—Reactor Building Section B-B.
- Figure 3.8-13—Reactor Building Section C-C.

The RB internal structures consist of the following major structures that support nuclear steam supply system (NSSS) components, provide access for plant operation and maintenance, and support safety-related functions of the plant:

- Reactor vessel (RV) support structure and reactor cavity.
- Steam generator (SG) support structures.
- Reactor coolant pump (RCP) support structures.
- Pressurizer (PZR) support structure.
- Operating floor and intermediate floors.
- Secondary shield walls.
- Refueling canal walls.
- Polar crane support structure.
- The RB internal structures basemat.

- IRWST.
- Core melt retention area.

These major RB internal structures are further described in Section 5.4, which contains descriptions of steel supports for the RV, four SGs, four RCPs, and the PZR.

Supports are also provided for distribution systems as part of the RB internal structures, which include pipe supports; equipment supports; cable tray and conduit supports; and heating, ventilation and air conditioning (HVAC) duct supports. Platforms, ladders, stairs, guard rails, and other miscellaneous structures are provided for equipment access and maintenance.

3.8.3.1.1 Reactor Vessel Support Structure and Reactor Cavity

The RV support structure is comprised of a reinforced circular concrete wall that extends from the top of the RB internal structures basemat at elevation -20 feet, 2 inches to the steel supports for the RV piping at approximately elevation +20 feet. This circular wall also serves as the interior wall for the IRWST, and provides radiation shielding for the RV and RCP. A narrow chamber extends through the circular wall just above the internal structures basemat to provide an outlet from the bottom of the RV cavity to the core melt retention area. The top, inside edge of the circular concrete wall supports eight steel RV support assemblies that are located under the RCP nozzles. Section 5.4.14 describes the design of the RV steel supports. The circular concrete wall also functions as the primary radiation shield wall around the RV. The wall is approximately 8 feet, 11 inches thick. The reactor refueling cavity begins at the top of the circular wall at elevation +24 feet, 5 inches.

Large penetrations in the circular RV support concrete wall are provided for the primary loop piping and the cavity ventilation system. A permanently installed cavity seal ring and neutron shield assembly rests on an embedded ring at the top of the wall. This seal and shield assembly is fabricated of stainless steel and radiation shielding material that bridges the annular gap between the RV and vessel cavity concrete wall. This ring seals the lower RV cavity to prevent water leakage from the refueling canal located above.

The RV supports and cavity concrete wall resists normal operating loads, seismic loads, and loads induced by postulated pipe rupture events, including a LOCA (GDC 4 and GDC 5). The supports limit the movement of the RV within allowable limits under the applicable combinations of loadings, and minimize resistance to thermal movements during plant operations.

Refer to Figure 3.8-2, Figure 3.8-3, Figure 3.8-4, Figure 3.8-11, Figure 3.8-12, and Figure 3.8-13 for general arrangement layouts of the RV support structure.

3.8.3.1.2 Steam Generator Support Structures

The SGs are supported and restrained to resist normal operating loads, seismic loads, and loads induced by pipe rupture. The supports prevent the rupture of the primary reactor coolant pipes due to a postulated rupture in the main steam (MS) or feedwater lines. The supports minimize resistance to thermal movements during operation.

The 6 feet, 7 inches thick heavily reinforced concrete floor at elevation +4 feet, 11 inches supports the four SGs. Four steel columns with pinned joints are provided under each SG to support the vessels vertically from the concrete floor. Keyed joints at the top of the steel support columns interface with lower lateral steel supports that connect to steel embedments in the concrete cubicle walls for each SG. Section 5.4.14 describes the design of these steel component supports.

The RB internal structure concrete walls form individual cubicles for each of the SGs. These walls isolate the SGs to protect other plant SSC in the event of a pipe rupture in one of the piping reactor coolant loops (RCL). The SG cubicle outer walls also serve as secondary shield walls for protection against radiation from the reactor piping and coolant, as described in Section 3.8.3.1.6.

Steel supports within each of the cubicles, which are mounted to the concrete slab at approximately elevation +64 feet, provide upper lateral support for the SGs. Connection of the upper lateral supports to the concrete includes steel subassemblies that are embedded in the concrete slab and cubicle walls. Section 5.4.14 provides a description of the design of the SG upper lateral supports.

Steel framing and grating platforms provided throughout each SG cubicle provide maintenance access to the SGs. Pipe supports and restraints are mounted to the SG cubicle walls to support piping during normal and abnormal plant conditions, and to protect other plant equipment from the effects of a broken pipe in the event of a postulated accident.

Removable steel grating is provided over the top of each SG cubicle at elevation +113 feet. This allows for potential replacement of the SGs over the life of the plant. Removable panels in the interior wall of each SG cubicle above approximately elevation +70 feet enable future component replacement or major maintenance activities. These reinforced concrete wall panels are keyed into the side walls of the SG cubicles and to the slab at the bottom of the panels to prevent dislodgment during a seismic event.

See Figures 3.8-4, 3.8-5, 3.8-6, 3.8-7, 3.8-8, 3.8-9, 3.8-10, 3.8-11, 3.8-12, and 3.8-13 for the general arrangement layout of the SG support structures.

3.8.3.1.3 Reactor Coolant Pump Support Structures

The RCPs are supported to prevent excessive deflection during normal operating, seismic, and pipe rupture conditions. Under LOCA and other loading conditions, the pumps are prevented from generating missiles that might damage other safety-related components. The RCP supports minimize resistance to thermal movements during operation.

The 6 feet, 7 inches thick concrete floor supports the four RCPs at elevation +4 feet, 11 inches adjacent to the SGs. Three steel columns with pinned joints are provided under each RCP for support. Steel subassemblies are embedded in the concrete floor to connect the RCP support columns to the structure. Section 5.4.14 describes the design of these steel component supports.

The RB internal structure walls form cubicles for each of the RCPs that are adjacent to but separate from each of the SG cubicles. These walls isolate each of the RCPs to protect plant SSCs in the event of a pipe rupture in one of the RCLs. As with the SG cubicles, the RCP cubicle outer walls also serve as secondary radiation shield walls. Steel supports mounted to the walls of the RCP cubicles provide lateral support for the top of the RCPs. There are two lateral supports for each RCP, which are located at approximately elevation +28 feet, with portions of the supports embedded into the concrete walls. Section 5.4.14 provides a description of the design of the RCP lateral supports.

Steel framing and grating platforms provide maintenance access to the pumps throughout each RCP cubicle. Pipe supports and restraints are mounted to the cubicle walls to support piping during normal and abnormal plant conditions and to protect other plant equipment from the effects of a broken pipe in the event of a postulated accident. Removable steel grating or concrete hatches over the top of each RCP cubicle allow for pump maintenance and replacement.

See Figures 3.8-4, 3.8-5, 3.8-6, 3.8-7, and 3.8-11 for the general arrangement layout of the RCP support structures.

3.8.3.1.4 Pressurizer Support Structure

The PZR is supported and restrained to resist normal operating loads, seismic loads, and loads induced by postulated pipe rupture. Upper lateral supports minimize resistance to thermal movements during operation.

The PZR is located in a compartment formed by the secondary shield walls, SG cubicle walls, reactor cavity, and other intermediate walls. The PZR is supported vertically by three steel assemblies located at an intermediate concrete floor at approximately elevation +49 feet. Steel subassemblies are embedded in the concrete floor to connect the PZR support assemblies to the structure. Eight lugs connected to the embedments in an intermediate concrete floor at approximately elevation +68 feet support the top of the PZR laterally. Section 5.4.14 describes the design of the steel supports.

Several intermediate concrete and steel grating floors are provided inside the PZR cubicle for maintenance access. A removable concrete hatch is provided in the top of the cubicle at elevation +93 feet, 6 inches to allow the replacement of the PZR.

See Figures 3.8-6, 3.8-7, 3.8-8, 3.8-9, 3.8-10, 3.8-12, and 3.8-13 for the general arrangement layout of the PZR support structure.

3.8.3.1.5 Operating Floor and Intermediate Floors

The operating floor of the RB internal structures is located at approximately elevation +64 feet. Refueling operations take place at the operating floor, which provides support for the refueling machine and other equipment. The equipment hatch provides access at the operating floor level for bringing large components and equipment into the RCB. The emergency airlock provides access to the operating floor at [ ]

Intermediate floors are provided throughout the RB internal structures. These floors support and provide access to equipment and components throughout the building. The floor at elevation +4 feet, 11 inches supports the SGs and RCPs and also serves as the roof for the IRWST.

As described in Section 3.8.1.1, separation is provided between RB internal structures floor slabs and walls and the RCB to allow for differential movement. Internal floors are constructed of reinforced concrete or steel grating supported by structural steel framing. The RB internal structures floors are shown in Figures 3.8-2, 3.8-3, 3.8-4, 3.8-5, 3.8-6, 3.8-7, 3.8-8, 3.8-9, 3.8-10, 3.8-11, 3.8-12 and 3.8-13.

3.8.3.1.6 Secondary Shield Walls

The secondary shield wall provides radiation shielding and support for components. This shield wall is a circular reinforced concrete wall with an external radius of approximately 63 feet. The reinforced concrete secondary shield wall is 3 feet, 11 inches thick where it shields the RCS pipes and SG tube bundles. The secondary shield wall is anchored to the RB internal structures basemat at approximately elevation -7 feet, 6 inches. The secondary shield wall extends from the RB internal structures basemat at approximately elevation -7 feet, 6 inches up to the operating floor at approximately elevation +64 feet. This wall continues up to approximately elevation +113 feet around the SG cubicles.

Figures 3.8-2, 3.8-3, 3.8-4, 3.8-5, 3.8-6, 3.8-7, 3.8-8, 3.8-9, 3.8-10, 3.8-11, 3.8-12 and 3.8-13 show the layout of the secondary shield walls.

3.8.3.1.7 Refueling Canal Walls

The refueling canal is located above and to the south of the reactor cavity on the FB side of the RB internal structures. The refueling canal is filled with borated water during reactor refueling operations for radiation shielding of the reactor fuel. The refueling canal enables the transfer of the reactor fuel to and from the FB through the fuel transfer tube, as described in Section 3.8.2, and it provides storage areas for reactor components and lifting equipment.

The refueling canal is constructed of approximately 4 feet thick reinforced concrete walls. The interior surface of the refueling canal concrete walls and floor are lined with 0.25 inch thick stainless steel liner plates. The liner plates are not load bearing structural members. Leak detection channels are provided at joints in the refueling canal liner plates to contain and monitor potential leakage of water when the canal is flooded during reactor refueling operations. The refueling canal walls in conjunction with the secondary shield walls form the SG and RCP cubicles. The refueling canal walls connect the cubicles and help provide lateral support for the RB internal structures.

A concrete missile shield is provided on top of the refueling canal walls to absorb the impact of a control rod ejection due to the postulated failure of a control rod drive mechanism (CRDM) housing. See Section 3.5.1.2 for a description of the CRDM missile shield.

See Figures 3.8-5, 3.8-6, 3.8-7, 3.8-8, 3.8-11, 3.8-12, and 3.8-13 for the general arrangement layout of the refueling canal walls.

3.8.3.1.8 Polar Crane Support Structure

Structural steel built-up crane girders mounted on crane brackets evenly spaced around the inside face of the RCB wall support the polar crane. The crane brackets are welded from steel plates and embedded in the RCB wall concrete. Section 9.1.5 provides the details of the overhead heavy handling system, which includes the polar crane.

3.8.3.1.9 Reactor Building Internal Structures Basemat, In-Containment Refueling Water Storage Tank, and Core Melt Retention Area

The RB internal structures basemat is comprised of the reinforced concrete in the lower part of containment above the liner plate. The top of the RB internal structures basemat is nominally at elevation -20 feet, 2 inches, with the top elevation of the basemat lowered in the core melt retention area. The bottom of the RB internal structures basemat is at elevation -25 feet, 7 inches.

The internal structures basemat concrete fills the lower area of the containment liner and supports the RB internal structures. Anchors are not provided on the inside surface of the liner or on the underside of the flat portion of the liner. Anchors are provided around the outer surface of the embedded sides of the liner. Overturning moments and sliding forces of the RB internal structures relative to the liner plate are resisted by structural dead weight and lateral bearing. Section 3.8.1.4.10 describes the interface of the RB internal structures with the RCB liner plate.

The IRWST is located above the internal structures basemat. The IRWST provides storage of refueling water and serves as the source of water for the safety injection and containment spray systems. The concrete floor at top elevation +4 feet, 11 inches forms the roof of the IRWST. The reactor cavity circular concrete wall and the concrete side walls of the core melt retention area form the inside walls of the IRWST. The concrete around the embedded lower portion of the containment liner forms the outside walls of the IRWST. The entire surface of the IRWST is lined with stainless steel. The liner plates are not load bearing structural members.

The core melt retention area is located above the internal structures basemat between azimuths 129° and 231°. The core melt retention system provides for mitigation of potential severe accident (SA) scenarios. This area provides a volume to capture molten core debris up to and including the total inventory of the reactor core, RV internals, and lower RV head. The core melt retention area spreads the molten core debris over a large area and stabilizes the core debris with water. Spreading increases the surface-to-volume ratio of the melt to promote fast cooling and to limit the release of radionuclides into the containment atmosphere. These features provide a passive transformation of the molten core into a cooled, solid configuration without operator action. The core melt retention features are described in Section 19.2.

See Figures 3.8-2, 3.8-11, 3.8-12, and 3.8-13 for the general arrangement layout of the RB internal structures basemat, IRWST, and core melt retention area.

3.8.3.1.10 Distribution System Supports

Structural steel supports are provided for distribution systems as part of the RB internal structures. These include pipe supports, equipment supports, cable tray and conduit supports, HVAC duct supports, and other component supports. Distribution system supports are primarily constructed of steel shapes and tubing, which are anchored to the concrete RB internal structures using embedded steel plates, cast-in-place anchor bolts, and drilled-in concrete anchors.

3.8.3.1.11 Platforms and Miscellaneous Structures

Platforms and miscellaneous structures (e.g., ladders, guard rails, stairs) are provided for access and maintenance to plant equipment and components. These items are primarily constructed of steel beams, angles, channels, tubing, and grating.

3.8.3.2 Applicable Codes, Standards, and Specifications

The following codes, standards, specifications, design criteria, regulations, and regulatory guides are used in the design, fabrication, construction, testing, and inservice inspection of concrete and steel RB internal structures (GDC 1, GDC 2, GDC 4 and GDC 5). Section 5.4.14 describes the applicable codes, standards, and specifications for the design of NSSS component supports.

3.8.3.2.1 Codes and Standards

- ACI 301-05, Specifications for Structural Concrete for Buildings.
- ACI 304R-00, Guide for Measuring, Mixing, Transporting, and Placing Concrete.
- ACI 305.1-06, Specification for Hot-Weather Concreting.
- ACI 306R-88 (Re-approved 2002), Cold-Weather Concreting (Reference 49).
- ACI 306.1-90 (Re-approved 2002), Standard Specification for Cold Weather Concreting.
- ACI 308R-01, Guide to Curing Concrete (Reference 50).
- ACI 308.1-98, Standard Specification for Curing Concrete (Reference 39).
- ACI 311.4R-05, Guide for Concrete Inspection (Reference 40).
- ACI 347-04, Guide to Formwork for Concrete.
- ACI 349-01/349-R01, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary on Code Requirements for Nuclear Safety Related Concrete Structures (exception described in 3.8.4.4 and 3.8.4.5) (GDC 1).
- ACI 349.1R-07, Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures (Reference 41).
- AISC 303-05, Code of Standard Practice for Steel Buildings and Bridges (Reference 42).
- ANSI/AISC N690-1994, Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2, 2004 (GDC 1).
- ANSI/AISC 341-05, Seismic Provisions for Structural Steel Buildings, American Institute of Steel Construction, including Supplement 1 (Reference 43).
- AISC 348-04/2004 RCSC, Specification for Structural Joints Using ASTM A325 and A490 Bolts (Reference 44).

- ASCE Standard 4-98, Seismic Analysis of Safety-Related Nuclear Structures and Commentary.
- ASCE/SEI Standard 7-05, Minimum Design Loads for Buildings and other Structures.
- ASCE/SEI Standard 43-05, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities.
- ANSI/AWS D1.1/D1.1M 2006, Structural Welding Code - Steel.
- ANSI/AWS D1.4-2005, Structural Welding Code - Reinforcing Steel.
- ANSI/AWS D1.6-1999, including January 6, 2005 update, Structural Welding Code – Stainless Steel.
- ANSI/AWS D1.8-2005, Structural Welding Code – Seismic Supplement (Reference 45).
- ASME Boiler and Pressure Vessel Code - 2004 Edition, Section III, Division 2 - Code for Concrete Reactor Vessels and Containments (GDC 1).
- ASME Boiler and Pressure Vessel Code - 2004 Edition, Section III, Division 1 – Nuclear Power Plant Components (GDC 1).
- ASME NOG-1-04, Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder).
- SEI/ASCE Standard 37-02, Design Loads on Structures During Construction.

3.8.3.2.2 Specifications

Industry standards (e.g., those published by the ASTM) are used to specify material properties, testing procedures, fabrication methods, and construction methods. Section 3.8.3.6 addresses the applicable standards used.

Structural specifications cover areas related to the design and construction of the RB internal structures. These specifications emphasize important points of the industry standards for these structures and reduce options that otherwise would be permitted by the industry standards. These specifications cover the following areas:

- Concrete material properties.
- Mixing, placing, and curing of concrete.
- Reinforcing steel and splices.
- Structural steel.
- Stainless steel liner plate and embedments.

- Miscellaneous and embedded steel.
- Anchor bolts.
- Expansion anchors.
- Polar crane.
- Miscellaneous cranes and hoists.

3.8.3.2.3 Design Criteria

- ACI 349-01/349-R01, Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary on Code Requirements for Nuclear Safety-Related Concrete Structures (GDC 1).
- ANSI/AISC N690-1994, Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2 (2004) (GDC 1).

3.8.3.2.4 Regulations

- 10 CFR Part 50, Appendix A, General Design Criteria for Nuclear Power Plants, GDC 1, GDC 2, GDC 4, GDC 5, and GDC 50.
- 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Processing Plants.
- 10 CFR Part 50, Appendix S, Earthquake Engineering Criteria for Nuclear Power Plants.

3.8.3.2.5 NRC Regulatory Guides

RGs applicable to the design and construction of RB internal structures:

- RG 1.61, Revision 1, March 2007 (exception described in 3.7.1).
- RG 1.69, December 1973.
- RG 1.136, Revision 3, March 2007 (exception described in 3.8.1.3).
- RG 1.142, Revision 2, November 2001 (exception described in 3.8.3.3).
- RG 1.160, Revision 2, March 1997.
- RG 1.199, November 2003.

3.8.3.3 Loads and Load Combinations

The U.S. EPR standard plant design loads envelope includes the loads over a broad range of site conditions (GDC 1, GDC 2, GDC 4, GDC 5 and GDC 50). The loads on RB internal structures are separated into the following categories:

- Normal loads.
- Severe environmental loads.
- Extreme environmental loads.
- Abnormal loads.

A COL applicant that references the U.S. EPR design certification will confirm that site-specific loads lie within the standard design envelope for RB internal structures, or perform additional analyses to verify structural adequacy.

Section 5.4.14 addresses the loads and loading combinations and design stress limits for the RCS component and pipe supports.

3.8.3.3.1 Design Loads

Loads on RB internal structures are in accordance with ACI 349-2001 and the guidelines of RG 1.142, Revision 2, November 2001 for concrete structures, and in accordance with ANSI/AISC N690-1994 including Supplement 2 (2004) for steel structures. RG 1.142 delineates the acceptability of ACI 349-1997 with exceptions. The U.S. EPR standard plant design is based on the 2001 edition of the code, with the exceptions noted above. Use of the 2001 edition of the code is acceptable as it incorporates needed updates to the 1997 version. This includes anchorage of wall reinforcing without the use of confined cores in certain situations, and is in keeping with RG 1.199, which adopted the 2001 version Appendix B with exceptions in the area of load combinations. In addition, the guide has supplementary recommendations in the areas of materials, installation, and inservice inspection.

Seismic Category I safety-related RB internal structures are designed for the following loads.

Normal Loads

Normal loads are those loads encountered during normal plant operation, startup, shutdown, and construction (GDC 4). This load category includes:

- Dead Loads (D)—Dead loads include the weight of the structure and any permanent equipment or material weights. Dead load effects also refer to internal moments and forces due to dead loads.

- Live Loads (L)—Live loads include any normal loads that vary with intensity or point of application (or both), including moveable equipment. Live load effects also refer to internal moments and forces due to live loads. Live loads are applied, removed, or shifted in location to obtain the worst-case loading conditions. Impact forces due to moving loads are applied according to the loading condition. In general, a live load of 400 pounds per square foot is applied to RB internal structures concrete floors, and 100 pounds per square foot live load is applied to steel grating floors and platforms. Live loads are applied to cranes and their supports for the lifting capacity and test load applied for the lifting device. Additional point loads are applied to concrete floors and concrete and steel floor beams in local design.

- Hydrostatic Loads (F)—Hydrostatic loads are due to fluids stored in pools and tanks in the RB internal structures (e.g., the IRWST and refueling canal). Pools and tanks may have either constant or fluctuating liquid levels. Hydrodynamic loads resulting from seismic excitation of fluids are included as a component of the safe shutdown earthquake load.

- Thermal Loads (T_o)—Thermal loads consist of thermally induced forces and moments resulting from normal plant operation and environmental conditions. Thermal loads and their effects are based on the critical transient or steady-state condition. Thermal expansion loads due to axial restraint, as well as loads resulting from thermal gradients, are considered. The following ambient air temperatures are for normal operation.

  RB internal ambient temperatures:

  - During normal operation:

    - Equipment Area: 131°F (maximum), 59°F (minimum).

    - Service Area: 86°F (maximum), 59°F (minimum).

  - During normal shutdown: 86°F (maximum), 59°F (minimum).

- Pipe Reactions (R_o)—Pipe reactions are those loads applied by piping system supports during normal operating or shutdown conditions based on the critical transient or steady-state conditions. The dead weight of the piping and its contents are included. Dynamic load factors are used when applying transient loads, such as water hammer.

- Construction Loads—Construction loads are those loads to which the structure may be subjected during construction of the plant. Construction loads will be applied to evaluate partially completed structures, temporary structures, and their respective individual members. Design load requirements during construction for buildings and other structures will be developed in accordance with Standard SEI/ASCE 37-02. The magnitude and location of construction loads will be applied to generate the maximum load effects of dead, live, construction, and environmental loads. Consideration will be given to the loads and load effects of construction methods, equipment operation, and sequence of construction.

Severe Environmental Loads

Severe environmental loads are those loads that could be encountered infrequently during the life of the plant (GDC 2). The RB internal structures are protected by the RSB and the RCB; therefore, wind, earth pressure, or external flood loads do not apply. There are no OBE loads applicable to the overall design of the RB internal structures because an OBE level of one-third the SSE has been selected. See Section 3.7.1 for a description of the OBE. Severe environmental loads are not applicable to the design of RB internal structures.

Extreme Environmental Loads

Extreme environmental loads are those loads that are credible but are highly improbable (GDC 2). The RB internal structures are protected by the RSB and the RCB; therefore, tornado and external missile loads do not apply. This load category includes:

- Safe Shutdown Earthquake (E')—SSE loads are those loads generated by an earthquake with a peak horizontal ground acceleration of 0.30g. Seismic loads in the vertical direction and two orthogonal horizontal directions are considered to act simultaneously. Section 3.7 provides a description of how SSE loads are determined and combined. SSE loads are considered due to applied inertia loads, including dead loads, live loads, and hydrodynamic loads (i.e., water in storage pools and tanks), including combination of these loads using the square root of the sum of the squares (SRSS) method or the 100-40-40 percent rule described in Section 3.8.3.4.4.

Abnormal Loads

Abnormal loads are those loads generated by a postulated high-energy pipe break causing a LOCA within a building or compartment (GDC 4 and GDC 50). This event is classified as a DBA. Included in this category are: Internal flooding loads (F_a), Pressure loads (P_a), Thermal loads (T_a), Accident pipe reaction loads (R_a), and Pipe break loads (R_r).

The Pipe break load is subcategorized as Pipe break reaction loads (R_{rr}), Pipe break jet impingement loads (R_{rj}), and Pipe break missile impact loads (R_{rm}). These loadings include a dynamic load factor to account for the dynamic nature of the load, unless a time-history analysis is performed to justify otherwise.

Abnormal loads include the following loads:

- Internal flood loads (F_a)—Loads resulting from internal flooding of containment during or following a postulated DBA.

- Pressure load (P_a)—Pressure equivalent static load within or across a compartment generated by the postulated pipe break and including a dynamic load factor to account for the dynamic nature of the load.

- Thermal load (T_a)—Thermal loads generated by the postulated pipe break and including T_o.

- Accident pipe reactions (R_a)—Pipe reactions generated by the postulated pipe break and including R_o.

- Pipe break loads (R_r)—Local equipment and piping loads generated following a postulated pipe break. Unless a time-history analysis is performed to justify otherwise, these loadings include a dynamic load factor to account for the dynamic nature of the load. The pipe break load (R_r) is considered to act as three separate components (R_{rr}, R_{rj}, R_{rm}), which are defined in the following paragraphs. In determining an appropriate equivalent static load for R_{rr}, R_{rj}, and R_{rm}, elasto-plastic behavior may be assumed with appropriate ductility ratios, provided excessive deflections do not result in the loss of function of any safety-related SSC.

  – Pipe break reaction loads (R_{rr})—R_{rr} is defined as the equivalent static load on the structure generated by the reaction of the high-energy pipe during the postulated break.

  – Pipe break jet impingement loads (R_{rj})—R_{rj} is defined as the jet impingement equivalent static load on the structure generated by the postulated break.

  – Pipe break missile impact loads (R_{rm})—R_{rm} is defined as the missile impact equivalent static load on the structure generated by or during the postulated break, such as pipe whipping.

Other Loads

Other loads refer to postulated events or conditions that are not included in the design basis (GDC 4). These loading conditions and effects are evaluated without regard to the bounding conditions under which SSC perform design basis functions. This load category includes:

- Aircraft hazard (A)—Aircraft hazard refers to loads on a structure resulting from the impact of an aircraft. The evaluation of this loading condition is considered as part of the plant safeguards and security measures. There are no aircraft hazard loads on the RB internal structures since they are surrounded by other Seismic Category I structures that shield them from these loads.

- Explosion pressure wave (B)—Explosion pressure wave refers to loads on a structure resulting from an explosion in the vicinity of the structure. The evaluation of this loading condition is considered as part of the plant safeguards and security measures. There are no explosion pressure wave loads on the RB internal structures because they are surrounded by other Seismic Category I structures that shield them from these loads.

- Missile loads other than wind - or tornado-generated missiles—The RSB and the RCB protect the RB internal structures from impact of externally generated missiles. The RB internal concrete and steel structures are designed for internally generated missile loads as described in Section 3.5.

3.8.3.3.2 Load Combinations

Load combinations for design of RB internal structures are in accordance with ACI 349-2001 and guidelines of RG 1.142, Revision 2, November 2001 for concrete structures, and in accordance with ANSI/AISC N690-1994 including Supplement 2 (2004) for steel structures (GDC 1, GDC 2, GDC 4, GDC 5 and GDC 50).

The following definitions apply to load combinations for concrete and steel RB internal structures:

- For concrete members, U is defined as the section strength required to resist design loads based on the strength design methods described in ACI 349.
- For steel members, S is defined as the required section strength based on the elastic design methods and the allowable stresses defined in Part Q1 of ANSI/AISC N690.
- For steel members, Y is defined as the section strength required to resist design loads based on plastic design methods described in Part Q2 of ANSI/AISC N690.

Loads and loading combinations encompass the soil cases described in Section 2.5, using the design criteria described in Section 3.7.1 and Section 3.7.2.

Concrete Reactor Containment Building Internal Structures

The following load combinations define the design limits for Seismic Category I concrete RB internal structures.

- Normal load combinations (for strength design method):

  $U = 1.4D + 1.4F + 1.7L$

  $U = (0.75)(1.4D + 1.4 F + 1.7L + 1.7T_o + 1.7R_o)$

- Factored load combinations (for strength design method):

  $U = D + F + L + T_o + R_o + E'$

  $U = D + F + L + T_a + R_a + F_a + 1.5P_a$

  $U = D + F + L + T_a + R_a + F_a + P_a + R_{rr} + R_{rj} + R_{rm} + E'$

Steel Reactor Containment Building Internal Structures

The following load combinations define the design limits for Seismic Category I steel RB internal structures. For normal service load conditions, either the elastic working stress design methods of Section Q1 or the plastic design methods of Section Q2 of ANSI/AISC N690, including Supplement 2, are used. For factored load conditions, the elastic working stress design method is used.

- Service load combinations for elastic working stress design method:

  $S = D + F + L$

  $S = D + F + L + T_o + R_o$

  If thermal stresses due to T_o and R_o are present, the following load combination is also considered:

  $1.5S = D + F + L + T_o + R_o$

- Service load combinations for plastic design method:

  $Y = 1.7D + 1.7F + 1.7L$

  $Y = (1.3)(D + F + L + T_o + R_o)$

- Factored load combinations for elastic working stress design method:

  1.6S[1] $= D + F + L + T_o + R_o + E'$

  1.6S[1] $= D + F + L + T_a + R_a + F_a + P_a$

  1.7S[1] $= D + F + L + T_a + R_a + F_a + P_a + R_{rr} + R_{rj} + R_{rm} + E'$

  For factored load combinations, in computing the required section strength (S), the plastic section modulus of steel shapes may be used, except for those which do not meet the ANSI/AISC N690 criteria for compact sections.

- Factored load combinations for plastic design method:

  $0.9Y = D + F + L + T_o + R_o + E'$

  $0.9Y = D + F + L + T_a + R_a + F_a + 1.5P_a$

  $0.9Y = D + F + L + T_a + R_a + F_a + P_a + R_{rr} + R_{rj} + R_{rm} + E'$

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1. The stress limit coefficient in shear must not exceed 1.4 in members and bolts. The stress limit coefficient where axial compression exceeds 20 percent of normal allowable must be 1.5 for load combinations defined for 1.6S, and 1.6 for the load combination defined for 1.7S.

3.8.3.4 Design and Analysis Procedures

Seismic Category I concrete structural elements and members are designed in accordance with ACI 349-2001 and its appendices (GDC 1). Exceptions to the code found in RG 1.142 are incorporated into the design and are accommodated in the loading combinations described in Section 3.8.3.3.2 for concrete structures.

Seismic Category I steel members and assemblies are designed in accordance with the requirements of ANSI/AISC N690-1994 (R2004) (GDC 1).

Design of concrete embedments and anchors conforms to Appendix B of ACI 349-2001 and guidelines of RG 1.199. Ductility is provided by designing anchorage systems so that a steel failure mode controls the design.

Section 5.4.14 describes the applicable design and analysis procedures used for the design of steel portions of the NSSS component supports which interface with the RB internal structures concrete and steel embedments.

Computer modeling and classical manual techniques are used to analyze the RB internal structures by applying loads and loading combinations as described in Section 3.8.3.3. An overall computer model of the NI Common Basemat Structure is used which includes the RB internal structures. Local analyses are then performed for specific structural walls, slabs, and members to account for local effects of specific equipment loads, localized pipe break loads, hydrostatic and hydrodynamic loads, and other conditions (e.g., openings and local changes in member cross-sections). The results from the local analyses are combined with overall analysis results to produce the final analysis for the design of Seismic Category I concrete and steel elements and members.

The following sections describe specific techniques and criteria used for analysis and design of the RB internal structures.

Appendix 3E provides a description of specific analysis and design procedures for RB internal structures critical sections.

3.8.3.4.1 Overall Analysis and Design Procedures

The RB internal structures are included in the ANSYS V10.0 SP1 finite element overall computer model of the NI Common Basemat Structure that is described in Section 3.8.1.4. Boundary conditions for the ANSYS computer model and methods used for application of axisymmetric and non-axisymmetric loads, transient and localized loads, and other parameters used in the model are described in Section 3.8.1.4. The RB internal structures are modeled in combination with the overall NI Common Basemat Structure and basemat using a mesh of ANSYS finite elements. The finite element model for the RB internal structures consists of the primary load-carrying walls, floors, columns, beams, and NSSS concrete equipment supports. Gaps are maintained between the internal structures and the containment wall to allow for structural movements during seismic events, containment pressurization, and other loading conditions. The RB internal structures are supported by the internal structures basemat. Section 3.8.1.4 provides a description of how the internal structures basemat interfaces with the containment liner above the NI Common Basemat Structure foundation basemat in the computer model. Section 3.8.5 describes modeling of the NI Common Basemat Structure foundation basemat.

ANSYS SHELL43 elements are used to model walls and floors and other concrete elements in the RB internal structures. SHELL43 is a three-dimensional, four-node shell element that is suitable for moderately thick shell structures. It can also provide out-of-plane shear forces and has an elastic-plastic capability. The steel liner causes discontinuity between the NI Common Basemat Structure foundation basemat and the base of the RB interior structure. This transition is modeled using multi-point constraints to allow sub-modeling of the interior structure and interface, as needed. For static modeling considerations, the individual companion nodes are coupled together. The strength of the liner is not relied upon to carry structural loadings.

Overall analysis of the RB internal structures considers the loads and loading combinations defined in Section 3.8.3.3. The following localized abnormal loads are not included in the overall analysis:

- Subcompartment pressure loads (P_a).
- Pipe break thermal loads (T_a).
- Accident pipe reactions (R_a).
- Pipe break reaction, jet impingement, and missile loads (R_{rr}, R_{rj}, R_{rm}).
- Local flood loads (F_a).

Local analyses address these localized loads. The overall analysis includes reaction loads from the RCS components (i.e., RV, SGs, RCPs, and PZR) due to LOCA pipe breaks (GDC 4 and GDC 50).

Figure 3.8-32—Reactor Building Internal Structures ANSYS Model, Figure 3.8-33—Reactor Building Internal Structures ANSYS Model – Section through Center of Building Looking West, Figure 3.8-34—Reactor Building Internal Structures ANSYS Model – Section through Reactor Cavity and Refueling Canal, Figure 3.8-35—Reactor Building Internal Structures ANSYS Model – Section through Center of Building Looking North, Figure 3.8-36—Reactor Building Internal Structures ANSYS Model – Section through Center of Building Looking Northwest, Figure 3.8-37—Reactor Building Internal Structures ANSYS Model – View of IRWST and Internal Structures

Basemat show the finite element model used for analysis of the RB internal structures. Additional descriptions of the RB internal structures computer model are provided in Appendix 3E.

Loads and load combinations defined in Section 3.8.3.3 are used to determine the strength requirements of members and elements. The following criteria apply for load combinations for concrete and steel RB internal structures:

- A one-third increase in allowable stresses for concrete and steel members due to seismic (E') loadings is not permitted.
- Where any load reduces the effects of other loads, the corresponding coefficient for that load is 0.9 if it can be demonstrated that the load is always present or occurs simultaneously with other loads.
- Where the structural effects of differential settlement, creep, or shrinkage may be significant, they are included with the dead load (D) as applicable.
- For load combinations in which a reduction of the maximum design live load (L) has the potential to produce higher member loads or stresses, multiple cases are considered where the live load (L) is varied between its maximum design value and zero.
- For steel members, thermal loads may be neglected when it can be shown that they are secondary and self limiting in nature.
- For load combinations including the loads P_a, T_a, R_a, R_{rr}, R_{rj}, or R_{rm}, the maximum values of these loads, including an appropriate dynamic load factor, are used unless a time-history analysis is performed to justify otherwise.
- For load combinations including loads R_{rr}, R_{rj}, and R_{rm}, the load combinations are first satisfied with these loads set to zero. However, when considering these concentrated loads, local section strength capacities may be exceeded under the effect of these concentrated loads, provided there is not a loss of function of any safety-related SSC.

Concrete and steel structural elements and members are designed for axial tension and compression forces, bending moments, torsion, and in-plane and out-of-plane shear forces for the controlling loading combinations that are determined from the ANSYS computer analysis and local analyses. Internal structures behave within the elastic range under design basis loads. However, the ability of the structures to perform beyond yield is considered for abnormal loads associated with a pipe break, which results in rupture reactions, jet impingement and pipe whip, and for missile impact loads.

The strength-design methods described in ACI 349-2001 and its appendices, including the exceptions detailed in RG 1.142, are used for the design of concrete walls, floors and other structural elements for RB internal structures (GDC 1). The ductility requirements of this code are satisfied so that a steel reinforcing failure mode controls over concrete failure modes. The recommendations of Appendix C of ACI 349-2001 are met for impulsive and impactive loading conditions (e.g., loading combinations that include pipe break missile impact loads).

Steel member and assembly design utilizes the allowable stress design methods of ANSI/AISC N690-1994 (R2004), including Supplement 2 (GDC 1). Steel items are maintained elastic for normal and extreme loadings in their respective combinations. Local yielding is permitted for abnormal loadings (e.g., pipe break accident loadings).

3.8.3.4.2 Local Analysis and Design

Local analyses are performed for concrete and steel structural elements and members by using sub-models expanded from the overall analysis model and by using manual techniques, in combination with overall model analysis results. Sub-models are performed by refining the element mesh in the overall ANSYS model. Local discontinuities (e.g., openings, thickened areas, local loads, and changes in member cross-section) are included in the sub-models.

Local analysis and design consider the same member and element forces and moments as described for overall design. In addition, local effects (e.g., punching shear and transfer of anchorage loads to the structure) are considered. Local analyses also are used for design of secondary structures (e.g., platforms, equipment supports, crane supports).

The recommendations of ACI 349-2001 and its appendices, including the exceptions in RG 1.142, are followed for concrete element and member local design (GDC 1).

Design of concrete embedments and anchors conforms to Appendix B of ACI 349-2001 and guidelines of RG 1.199. Ductility is provided by designing anchorage systems so that a steel failure mode controls the design.

ANSI/AISC N690-1994 (R2004), including Supplement 2, and ANSI/AISC 341-05, are followed for local steel member design (GDC 1).

The design of bolted connections is in accordance with ANSI/AISC N690, Section Q1.16 and AISC 348-04/2004 RCSC. Bolted in connections are fully tensioned, regardless of design methodology, unless justified otherwise.

The design of welded connections is in accordance with ANSI/AWS D1.1/D1.1M 2006 and ANSI/AWS D1.6-99, including January 6, 2005 update.

The design of bolted connections in combination with welded connections is in accordance with Section Q.15.10 of ANSI/AISC N690.

Openings in walls and slabs of RB internal structures are shown on construction drawings. Openings are acceptable without analysis if they meet the criteria identified in ACI 349, Section 13.4.2. Round pipe sleeves are used in lieu of rectangular penetrations, where possible. Corners of rectangular openings in walls or slabs are provided with diagonal reinforcing to reduce cracking due to stress concentrations at these locations in accordance with ACI 349, Section 14.3.7.

Appendix 3E provides a description of analysis and design results for critical areas of the RB internal structures.

Section 5.4.14 describes the design of interfacing steel assemblies which support the NSSS components and attach to, or interact with, embedments in the concrete. Steel supports for the RCS components and piping, including the base plates at the face of concrete structures, are designed in accordance with ASME Section III Division 1, Subsection NF. Embedded portions of RCS component and pipe supports, which are beyond the jurisdictional boundary of the ASME Code, are designed in accordance with ACI 349-2001, including Appendix B, and also in accordance with ANSI/AISC N690-1994 (R2004), including Supplement 2.

3.8.3.4.3 Static Analysis and Design

Dead loads (D), live loads (L), hydrostatic loads (F), pipe reactions (R_o), and normal thermal loads (T_o) are considered in the analysis and design of RB internal structures for the static normal load concrete and service load steel loading combinations. Normal thermal loads are considered as self-relieving for the overall RB internal structures. Concrete and steel members are designed to accommodate these static loads within the elastic range of their section strength.

Static fluid pressure loads are considered for design of the walls and floors of the IRWST and refueling canal. Moving loads are considered for mobile plant equipment (e.g., the polar crane, refueling machine, and other cranes and hoists).

3.8.3.4.4 Seismic and Other Dynamic Analyses and Design

Seismic analyses and designs of the RB internal structures conform to the procedures described in Section 3.7.2. The procedures in ASCE Standard 4-98 are used in the analysis and design of structural elements and members subjected to load combinations that include seismic loadings. Seismic accelerations are determined from the structural stick model described in Section 3.7.2. These accelerations are applied to the ANSYS model of the RB internal structures as static-equivalent loads at the elevations used in the stick model.

Seismic SSE (E’) loads are obtained by multiplying the dead load and 25 percent of the design live load by the structural acceleration obtained from the seismic analysis of the structure. Seismic loads are also considered due to the mass of fluids in tanks and canals as described herein (Section 3.8.3.4.4). The design live load is used for the local analysis of structural elements and members. Consideration is given to the amplification of these accelerations due to local flexibility of structural elements and members. Construction loads are not included when determining seismic loads. Other temporary loads are evaluated for contributing to the seismic loads on a case-by-case basis.

Seismic loads from the three components of the earthquake are combined using the SRSS method or the 100-40-40 percent rule described in ASCE 4-98. The 100-40-40 combination is expressed mathematically as follows:

Where:

R = the reaction force or moment that is applied in the three orthogonal directions x, y, and z.

$R = (\pm 1.0R_X \pm 0.4R_Y \pm 0.4R_Z)$

$R = (\pm 0.4R_X \pm 1.0R_Y \pm 0.4R_Z)$

$R = (\pm 0.4R_X \pm 0.4R_Y \pm 1.0R_Z)$.

The effects of local flexibilities in floor slabs and wall panels are considered to determine if additional seismic accelerations should be applied to their design beyond those determined from the seismic stick model. Local flexibility evaluations are performed by determining the natural frequency of the floor or wall panel and comparing this to the frequency of the zero period acceleration on the applicable response spectra. Additional acceleration is applied when the natural frequency of the panel results in higher accelerations than the zero period acceleration. In cases where local flexibilities are determined to be a factor, additional out-of-plane accelerations are applied to the inertia loads on these panels for determining out-of-plane bending and shear loads.

Additional seismic loads due to accidental torsion are considered as described in Section 3.7.2. This is to account for variations in material densities, member sizes, architectural variations, equipment loads, and other variations from the values used in the analysis and design of the RB internal structures. Due to these potential variations, an additional eccentricity of the mass is included at the floor elevations and is equivalent to five percent of the maximum building dimension.

Seismic Category I concrete structural elements and their connections are detailed for ductility in accordance with ACI 349-2001, Chapter 21.

Structural Stiffness Considerations

Conservative values of concrete creep and shrinkage based on past experience are used in the design of the RB internal structures. Moments, forces, and shears are obtained on the basis of uncracked section properties in the analysis. However, in sizing the reinforcing steel, the concrete is not relied upon for resisting tension. Thermal moments are modified by cracked-section analysis using analytical techniques, when appropriate.

The effect of local wall and floor slab flexibility is included where necessary. The concrete section properties used in calculating the amplified seismic forces include an appropriate level cracking for the particular element under consideration. The amplified forces are also used in the design of the structural members that support the flexible element.

Section 3.8.3.6 describes methods used to confirm that concrete properties satisfy design requirements.

Seismic Structural Damping

Seismic analysis of RB internal structures uses the following SSE structural damping values recommended by RG 1.61.

Structure Type	Percent of Critical Damping
• Welded Steel	4
• Bolted Steel, Slip-Critical Connections	4
• Bolted Steel, Bearing Connections	7
• Reinforced Concrete	7

Hydrodynamic Load Analyses

Hydrodynamic loads are applied to the IRWST and refueling canal walls and floors to account for the impulsive and impactive effects of water moving and sloshing in the tank as a result of seismic excitation. These loads are considered as part of the seismic SSE loads, and components of these loads in the three orthogonal directions are combined in the same manner as other seismic loads. ASCE Standard 4-98 is used to determine hydrodynamic loadings. The effect of tank structure flexibility on spectral acceleration is included when determining the hydrodynamic pressure on the tank walls for the impulsive mode.

Design for hydrodynamic loads is within the elastic range of concrete and steel members and elements.

Polar Crane Seismic Analyses

Design of the RCB for seismic loads from the polar crane is performed with the crane in positions that result in maximum stresses on the supporting containment wall. See Section 3.8.1 for additional information on the design of the RCB.

For seismic load combinations, the polar crane design is based on the trolley being located in different positions along the bridge girders. Seismic evaluations are performed with and without the critical load raised to different positions for the trolley locations to determine which hook position produces the primary response of the crane. For analysis purposes, the critical load is defined as that of the reactor head. The design of the crane includes seismic restraints (up-kick lugs), which prevent the bridge and trolley from dislodging from their respective rails.

Refer to Section 9.1.5 for additional information on the polar crane.

Pipe Rupture Loads

Local analyses of the RB internal structures consider the following abnormal loads:

- Sub-compartment pressure loads (P_a).
- Pipe break thermal loads (T_a).
- Accident pipe reactions (R_a).
- Pipe break reaction, jet impingement, and missile loads (R_{rr}, R_{rj}, R_{rm}).
- Local flood loads (F_a).

These loads are applied to concrete and steel structures that enclose and support the RV, SGs, RCPs, PZR, RCS piping, MS and feedwater system piping, and other areas subject to abnormal loads.

Subcompartment pressure loads (P_a) are not applied to the overall ANSYS computer model because they do not result in global loadings on the RB internal structures. Subcompartment pressure loads are evaluated in local design of the concrete walls and floors for the applicable compartments. Subcompartment pressure loads resulting from a LOCA event are evaluated as time-dependent loads across concrete walls and floors that enclose the SGs, RCPs, PZR, and the RCS piping. Pipe breaks are not postulated in the reactor cavity. Concrete and steel members are designed to accommodate subcompartment pressure loads within the elastic range of the section strength.

Pipe break thermal loads (T_a) are considered in local analyses of concrete walls and floors. Accident thermal loads are evaluated as time-dependent loads across concrete walls and floors that enclose the SGs, RCPs, and the PZR. Concrete temperature is limited to 150°F for normal loading conditions. For short-term and accident thermal conditions, the concrete temperature is allowed to increase to 350°F for interior surfaces. Localized areas are allowed to reach 650°F from fluid jets in the event of a pipe failure. ACI 349-01/349-R01, Appendix A and ACI 349.1R-07 is the basis used for thermal design of concrete.

Accident pipe reaction loads (R_a) are considered on the NSSS equipment and piping supports, including supports for the RV, SGs, RCPs, PZR, and RCS piping. These loads are applied to the overall ANSYS computer model by applying worst-case LOCA loads to these component supports in separate load cases to determine overall effects on the RB internal structures (GDC 4 and GDC 50). Worst-case accident pipe reaction loads are further evaluated in local designs of the component supports in the critical sections described in Appendix 3E. Concrete and steel members are designed to accommodate accident pipe reaction loads within the elastic range of their section strength.

Pipe break reaction, jet impingement, and missile loads (R_{rr}, R_{rj}, R_{rm}) are not applied to the overall ANSYS computer model because they do not result in global loadings on the RB internal structures. These loads are considered in local design of concrete walls and floors and steel members. As defined in Section 3.8.3.3.1 under the definitions of abnormal loads, dynamic load factors are applied when analyzing structures for the static equivalent of these loads. Elasto-plastic behavior may be assumed with appropriate ductility ratios, provided that excessive deflections do not result in the loss of function of any safety-related SSC. Appendix C of ACI 349-2001 is used to determine pipe break reactions, jet impingement, and missile impact impulsive and impactive loads. The design of the RB internal structures for these loads conforms to the procedures described in Section 3.5 for internally generated missiles. Section 3.5 also describes ductility limits that are met for impactive and impulsive loadings.

Local flood loads (F_a) are applied to walls and floors of the RB internal structures in the overall ANSYS computer model. Concrete and steel members are designed to accommodate these flood loads within the elastic range of their section strength.

3.8.3.4.5 Design Report

Design information and criteria for Seismic Category I structures are provided in Sections 2.0, 2.4, 2.5, 3.3, 3.5, 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5. Design results are presented in Appendix 3E for Seismic Category I structure critical sections.

3.8.3.5 Structural Acceptance Criteria

Limits for allowable stresses, strains, deformations, and other design criteria for reinforced concrete RB internal structures are in accordance with ACI 349-2001, and its appendices, including the exceptions specified in RG 1.142, with the exception that the shear strength reduction factor of 0.85 is used as allowed in ACI 349-2006. The exceptions specified in RG 1.142 (GDC 1, GDC 2, GDC 4 and GDC 50) are considered.

Limits for allowable loads on concrete embedments and anchors are in accordance with Appendix B of ACI 349-2001 and guidance given in RG 1.199.

Limits for the allowable stresses, strains, deformations and other design criteria for structural steel RB internal structures are in accordance with ANSI/AISC N690-1994, including Supplement 2 (GDC 1, GDC 2, GDC 4 and GDC 50).

Limits for allowable stresses, strains, and deformations on steel RCS component and pipe supports, including the base plates for these supports at the face of concrete structures, are in accordance with ASME Section III Division 1, Subsection NF.

The design of RB internal structures is generally controlled by load combinations containing SSE seismic loads. Stresses and strains are within the ACI 349-2001 and ANSI/AISC N690-1994 limits.

Appendix 3E provides design results for critical areas of the RB internal structures.

3.8.3.6 Materials, Quality Control, and Special Construction Techniques

This section contains information relating to the materials, quality control programs, and special construction techniques used in the fabrication and construction of concrete and steel internal structures of the RB internal structures (GDC 1).

3.8.3.6.1 Concrete Materials

Concrete materials for the RB internal structures conform to ACI 349-2001, Chapter 5, as supplemented by RG 1.142, and ACI 301-05 (GDC 1). Where required for radiation shielding, concrete conforms to RG 1.69.

Concrete Mix Design

Structural concrete used in the construction of the RB internal structures has a minimum compressive strength (i.e., f'_c) of 6000 psi at 90 days. The concrete density is between 140 pounds per cubic foot and 160 pounds per cubic foot. Poisson’s ratio for the concrete is 0.17, unless otherwise justified.

Concrete mix design is determined based on field testing of trial mixtures with actual materials used.

Testing:

- Ultimate concrete strength, as well as early strength in support of an aggressive construction schedule.

- Concrete workability and consistency.
- Concrete admixtures.
- Heat of hydration and temperature control for large or thick concrete pours.
- Special exposure requirements when identified on design drawings.

Cement:

- Cement used for the concrete RB internal structures conforms to ASTM C150, ASTM C595 (excluding Types S and SA), or ASTM C845-04.
- Cement is a low-alkali cement, not containing more than 0.60 percent by weight of total alkalis (Na_2O + $0.658K_2O$).

Aggregates:

- Aggregates used for the RB internal structures conform to ACI 349-2001, Section 3.3.
- Aggregates conform to ASTM C33.

Admixtures:

- Air-entraining admixtures conform to ASTM C260.
- Chemical admixtures conform to ASTM C494 or ASTM C1017.
- Fly ash and other pozzolanic admixtures conform to ASTM C618.
- Grout fluidizers conform to ASTM C937.
- Ground-granulated blast furnace slag used as an admixture conform to ASTM C989.
- Silica fume used as an admixture conforms to ASTM C1240.
- Admixtures used in concrete mixtures containing ASTM C845 expansive cement are compatible with the cement and produce no deleterious effects.

Mix Water:

- Mix water used for the RB internal structures conforms to ACI 349-2001, Section 3.4.

Concrete Placement

Site-specific construction specifications address requirements and procedures for concrete placement. Construction specifications address the following:

- Desired volume of concrete pours and rate of deposition.
- Special forming requirements.
- Maximum height of pours.
- Temperature limitations; weather conditions and concrete mix, including methods for temperature control.
- Curing requirements and procedures.

Placement of concrete is performed with consideration given to the following codes:

- ACI 304R-00, Guide for Measuring, Mixing, Transporting, and Placing Concrete.
- ACI 305.1-06, Specification for Hot-Weather Concreting (Reference 9).
- ACI 306R-88 (Re-approved 2002), Cold-Weather Concreting.
- ACI 306.1-90 (Re-approved 2002), Standard Specification for Cold Weather Concreting.
- ACI 308R-01, Guide to Curing Concrete (Reference 52).
- ACI 308.1-98, Standard Specification for Curing Concrete.
- ACI 311.4R-05, Guide for Concrete Inspection.
- ACI 347-04, Guide to Formwork for Concrete.

3.8.3.6.2 Reinforcing Steel and Splice Materials

Reinforcing steel materials for the RB internal structures conform to ACI 349-2001 (GDC 1).

Materials

- Reinforcing steel used in the concrete RB internal structures conforms to ASTM A615 or ASTM A706 and the additional items specified in ACI 349-2001, Sections 3.5.1 through 3.5.4.
- Smooth wire for spiral reinforcement conforms to ASTM A82 (Reference 51).
- Welded plain wire fabric reinforcement conforms to ASTM A185 (Reference 52).
- Welded deformed wire fabric reinforcement conforms to ASTM A497 (Reference 53).
- Welded splices and mechanical splices of reinforcing bars are used.

- Materials used for bar-to-bar sleeves for mechanical cadweld-type rebar splices in the RB internal structures conform to ASTM A513, ASTM A519, or ASTM A576.
- Material for threaded and swaged reinforcement splices are determined by the manufacturer and are qualified in accordance with provisions of ACI 349-01, Section 12.14.3. These devices meet the provisions of Subarticle CC-4333 of the ASME BPV Code, Section III, Division 2.

Fabrication and Placement

Fabrication and placement of reinforcing bars for RB internal structures is in accordance with ACI 349-2001, Chapter 7.

Welding conforms to the ASME BPV Code, Section III, Division 2, Subsection CC, as supplemented by RG 1.136 and AWS D1.4-2005 (GDC 1).

Mechanical splices are subject to the testing and acceptance criteria of ACI 349-2001, Section 12.14.3.

3.8.3.6.3 Structural Steel

Structural steel materials for the RB internal structures conform to ANSI/AISC N690-1994 including Supplement 2 (2004) and AISC 303-05 (GDC 1).

Materials

Seismic Category I structural steel conforms to ASTM material specifications identified in ANSI/AISC N690, Section Q1.4.1. Materials for structural steel members include those listed in Table 3.8-8.

High strength bolting materials conform to ASTM A325 (Reference 54), or ASTM A490 (Reference 55). Other bolting materials conform to ASTM A307 (Reference 56).

Structural bolts conform to the ASTM material specifications identified in ANSI/AISC N690, Section Q1.4.3, or other materials identified in the AISC/RCSC. Bolting materials for structural steel include those listed in Table 3.8-9. Anchor rods conform to the material specifications in ASTM F1554 (Reference 46).

Structural bolts utilize nuts and washers as recommended by ASTM for the particular bolting material and as identified in AISC/RCSC. Structural bolting nut and washer materials for structural steel include those listed in Table 3.8-10—Structural Bolting Nut and Washer Materials.

Structural steel, steel pipe, or tubing used in composite compression members in Seismic Category I concrete structures conforms to the specifications in Section 3.5.6 of ACI 349-2001.

Welding materials conform to ANSI/AWS D1.1/D1.1M 2006, or ANSI/AWS D1.6-99, including the January 6, 2005 update, except as modified by ANSI/AISC N690, Sections Q1.17.1 and Q1.17.2.1. The compatibility of filler metal with base metal is specified in Table 3.1 of AWS D1.1.

Fabrication and Erection

Fabrication and erection of structural steel, welding, and bolting conforms to the following codes:

- ANSI/AISC N690-1994, Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2 (2004).
- AISC 348-04/2004 RCSC, Specification for Structural Joints Using ASTM A325 and A490 Bolts.
- ANSI/AWS D1.1/D1.1M 2006, Structural Welding Code – Steel.
- ANSI/AWS D1.6-1999, including January 6, 2005 update, Structural Welding Code – Stainless Steel.
- ANSI/AWS D1.8 2005, Structural Welding Code – Seismic Supplement.

3.8.3.6.4 Quality Control

In addition to the quality control procedures addressed in Section 3.8.3.6.1, Section 3.8.3.6.2, and Section 3.8.3.6.3, refer to Chapter 17 for a description of the quality assurance program for the U.S. EPR (GDC 1).

3.8.3.6.5 Special Construction Techniques

The RB internal structures are constructed using proven methods common to heavy industrial construction. Special, new, or unique construction techniques are not used.

Modular construction methods are used to the extent practical for prefabricating portions of the IRWST liner, refueling canal liner, reinforcing, concrete formwork, and other portions of the RB internal structures. Such methods have been used extensively in the construction industry. Rigging is pre-engineered for heavy lifts of modular sections. Permanent and temporary stiffeners are used on liner plate sections and other modularized items to satisfy code requirements for structural integrity of the modular sections during rigging operations.

Steel decking and plates and supporting steel beams may be used to form concrete floors. In these instances, the decking thickness is in addition to the floor thickness shown on the dimensional arrangement drawings, provided in Appendix 3B. The decking, plates, and beams may be left in place, in which case they are designed for applicable seismic loads and other loading conditions. Other types of formwork that may also be used is left in place and become a permanent part of the structure. Such items conform to code requirements and are designed to prevent their failure from affecting Seismic Category I SSC.

3.8.3.7 Testing and Inservice Inspection Requirements

Section 5.4.14 describes the tests and inspections for the RCS component supports.

Monitoring and maintenance of RB internal structures is performed in accordance with RG 1.160 (GDC 1).

Section 9.1.5 describes the tests and inspections for the polar crane. Physical access is provided to perform inservice inspections of the RB internal structures. Gaps are provided between the containment liner and concrete RB internal structures, which provide space necessary to inspect the liner at wall and floor locations inside containment

3.8.4 Other Seismic Category I Structures

3.8.4.1 Description of the Structures

Other Seismic Category I structures in the U.S. EPR include the following buildings and structures:

- Reactor Shield Building (RSB) and annulus – located on the Nuclear Island (NI) Common Basemat Structure foundation basemat.
- Fuel Building (FB) – located on the NI Common Basemat Structure foundation basemat.
- Safeguard Buildings (SB) 1, 2, 3, and 4 – located on the NI Common Basemat Structure foundation basemat.
- Emergency Power Generating Buildings (EPGB) 1 and 2, and 3 and 4 – two separate buildings.
- Essential Service Water Buildings (ESWB) 1, 2, 3, and 4 - the ESWB houses the Essential Service Water Cooling Towers (ESWCT) and the Essential Service Water Pump Buildings (ESWPB).
- Distribution system supports – included in the above structures.
- Platforms and miscellaneous structures – included in the above structures.

Figure 3B-1 provides a site plan of the U.S. EPR showing the location of these Seismic Category I buildings and structures.

Structures described within this section are not shared with any other power plant units (GDC 5).

Section 3.7.2 addresses design requirements for non-safety-related structures to preclude adverse interaction effects on Seismic Category I structures.

A combined license (COL) applicant that references the U.S. EPR design certification will describe any differences between the standard plant layout and design of Seismic Category I structures required for site-specific conditions.

A COL applicant that references the U.S. EPR design certification will address site-specific Seismic Category I structures that are not described in this section.

3.8.4.1.1 Reactor Shield Building and Annulus

The RSB is a heavily reinforced concrete structure comprised of a cylindrical wall and dome roof. The RSB is approximately 186 feet in diameter by 230 feet high, which completely encloses the Reactor Containment Building (RCB). The RSB protects the RCB from missiles and loadings resulting from external events (e.g., hurricanes, tornados, aircraft hazards, and explosion pressure waves). The RSB serves as an additional preventative barrier to the release of radiation or contamination in the event of accident conditions. The NI Common Basemat Structure foundation basemat supports the RSB.

The RSB is surrounded by SBs 1, 2, 3, 4, and by the FB, which are Seismic Category I safety-related structures. The walls and slabs of SBs 1 and 4 frame into the RSB cylindrical wall for support. The roofs and external walls of SBs 2 and 3 and the FB frame into the RSB wall for support; however, the interior walls and floors of these buildings are separated from the RSB to isolate the interior portions of the structures in the event of an aircraft hazard or blast loading event. Where they are enclosed within the SBs and the FB, the lower portions of the RSB cylindrical wall are approximately 4 feet, 3 inches thick. The RSB cylindrical wall and dome that are exposed to the environment above the roofs of the adjacent SBs and FBs are approximately 5 feet, 11 inches thick.

The Reactor Building (RB) annulus is the space between the RSB and the RCB. The annular space is approximately 5 feet, 11 inches wide between the faces of the concrete walls of the two buildings. The RB annulus is an area that provides access for personnel to inspect the outside of the RCB, and to route piping, ventilation ducts, electrical cables, and other items. A slight negative pressure is maintained in the annulus to facilitate the secondary function of the RSB as a barrier to the release of contamination.

Figures 3.8-3—Reactor Building Plan at Elevation -8 Feet (top of concrete at start of containment wall), 3.8-4—Reactor Building Plan at Elevation +5 Feet (top of heavy floor for nuclear steam supply system (NSSS) component support), 3.8-5—Reactor Building Plan at Elevation +17 Feet (plan at centerline of reactor vessel piping nozzles), 3.8-6— Reactor Building Plan at Elevation +29 Feet (top of grating floor for component access), 3.8-7—Reactor Building Plan at Elevation +45 Feet (top of grating floor for component access), 3.8-8—Reactor Building Plan at Elevation +64 Feet (top of concrete operating floor), 3.8-9—Reactor Building Plan at Elevation +79 Feet (top of partial concrete floor), 3.8-10—Reactor Building Plan at Elevation +94 Feet (top of pressurizer cubicle), 3.8-11— Reactor Building Section A-A, 3.8-12— Reactor Building Section B-B, and 3.8-13—Section C-C show the arrangements of the RSB and annulus.

3.8.4.1.2 Fuel Building

The FB is a reinforced concrete structure that extends approximately 58 feet out from the RSB wall by 160 feet long by 140 feet high. The FB is located on the side of the RSB that is opposite of SBs 2 and 3. Hardening of the exterior walls and roof of the FB protects it against external events (e.g., tornado missiles, aircraft hazard and blast loadings). Dual exterior walls are provided from the foundation up to the ceiling to isolate interior structures from the exterior walls in order to mitigate the effects of external events.

The FB houses various structures, systems, and components (SSC) related to fuel storage and handling operations, including storage areas for new and spent fuel, the fuel pool cooling system, and handling systems that allow the placement of spent fuel into casks for storage. The operating floor level of the FB provides access to the RCB equipment hatch. Stair towers on either end of the FB connect the FB to SBs 1 and 4 and provide protection to the lower portion of the RSB wall. The NI Common Basemat Structure foundation basemat supports the FB.

A large pool in the FB stores and handles new and spent reactor fuel. The fuel transfer tube through the RCB shell wall connects the spent fuel pool to the RB internal structures refueling cavity. The spent fuel pool is lined with stainless steel plate. Leak detection channels are provided behind seams in the liner plate for monitoring of potential pool leaks. Section 9.1.2 addresses fuel storage racks. Section 9.1.5 addresses cranes in the FB.

The vent stack is a steel structure approximately 12 feet, 6 inches in diameter by 100 feet high located on top of the stair tower structure between the FB and SB 4. The vent stack serves as the exhaust for the Nuclear Auxiliary Building (NAB). The vent stack is classified as Seismic Category II due to its location adjacent to the safety-related NI Common Basemat Structure; however, the vent stack serves no safety-related functions. The effects of loadings from the vent stack are considered in the design of the FB. See Section 3.7.2 for design requirements for the Seismic Category II vent stack.

Figures 3.8-38—Fuel Building Plan Elevation -31 Feet, 3.8-39—Fuel Building Plan Elevation -20 Feet, 3.8-40—Fuel Building Plan Elevation -11 Feet, 3.8-41—Fuel Building Plan Elevation 0 Feet, 3.8-42—Fuel Building Plan Elevation +12 Feet, 3.8-43—Fuel Building Plan Elevation +24 Feet, 3.8-44—Fuel Building Plan Elevation +36 Feet, 3.8-45—Fuel Building Plan Elevation +49 Feet, 3.8-46—Fuel Building Elevation +64 Feet, 3.8-47—Fuel Building Plan Elevation +79 Feet, 3.8-48—Fuel Building Plan Elevation +90 Feet, 3.8-49—Fuel Building Plan Elevation +112 Feet, 3.8-50—Fuel Building Section A-A, 3.8-51—Fuel Building Section B-B, and 3.8-52Fuel Building Section C-C show the arrangements of the FB.

3.8.4.1.3 Safeguard Buildings

The SBs 1, 2, 3, and 4 are reinforced concrete structures located around approximately three-fourths of the periphery of the RSB. Stair towers are provided between the different SBs and the FB. These stair towers provide personnel access among the various elevations of the NI Common Basemat Structure and tie the buildings around the periphery of the RSB together. The RCB airlocks are accessible from the SBs and the stair towers.

The SBs house four divisions (Divisions 1 through 4) that are contained within three separate structures. Divisions 1 and 4 are housed in SBs 1 and 4 located on opposite sides of the RSB. A common wall in a third structure separates SBs 2 and 3 Divisions 2 and 3. Each division of the SBs contains a redundant safety system train. The lower levels of the SBs house mechanical systems, while the upper levels contain electrical, instrumentation, controls, and heating, ventilation, and air conditioning (HVAC) systems. Emergency feedwater storage tanks are provided in the SBs, which are lined with stainless steel to prevent leakage. Cable, pipe, and duct shafts are located within the SBs for routing distribution systems between the various elevations of the buildings. These shafts are constructed of reinforced concrete and steel. The main control room (MCR) is located [

]

Physical separation of the three SB structures and additional hardening of the buildings 2 and 3 structure protects against damage to multiple divisions in the case of external events (e.g., tornado missiles, aircraft hazard or blast loadings). SBs 2 and 3 are hardened by providing a dual roof and exterior walls, thickening the roof slab, and decoupling interior walls and slabs from the exterior walls and roof. The combined structure for buildings 2 and 3 extends approximately 92 feet out from the RSB wall by 180 feet long by 140 feet high. SB 1 has overall dimensions of approximately 87 feet out from the RSB wall by 100 feet long by 115 feet high. SB 4 has dimensions of approximately 87 feet out from the RSB wall by 100 feet long by 150 feet high. The NI Common Basemat Structure foundation basemat supports the SBs.

The main steam (MS) and feedwater valve stations are comprised of reinforced concrete compartments located within the SBs. Divisions 1 and 2 of the valve stations are located in SB 1, while Divisions 3 and 4 of the valve stations are located in SB 4. This arrangement results in a two-by-two redundancy. The physical separation of the valve stations results in at least two valve stations remaining unaffected in the case of external events (e.g., aircraft hazard). The reinforced concrete walls protect the individual valve stations against internal hazards.

Figures 3.8-53—Safeguard Building 1 Plan Elevation -31 Feet, 3.8-54—Safeguard Building 1 Plan Elevation -16 Feet, 3.8-55—Safeguard Building 1 Plan Elevation 0 Feet, 3.8-56—Safeguard Building 1 Plan Elevation +15 Feet, 3.8-57—Safeguard Building 1 Plan Elevation +27 Feet, 3.8-58—Safeguard Building 1 Plan Elevation +39 Feet, 3.8-59—Safeguard Building 1 Plan Elevation +55 Feet, 3.8-60—Safeguard Building 1 Plan Elevation 69 Feet, 3.8-61—Safeguard Building 1 Plan Elevation +81 Feet, 3.8-62—Safeguard Building 1 Plan Elevation +96 Feet, and 3.8-63—Safeguard Building 1 Section A-A show the arrangements of SB 1.

Figures 3.8-64—Safeguard Building 2 & 3 Plan Elevation -31 Feet, 3.8-65—Safeguard Building 2 & 3 Plan Elevation -16 Feet, 3.8-66—Safeguard Building 2 & 3 Plan Elevation 0 Feet, 3.8-67—Safeguard Building 2 & 3 Plan Elevation +15 Feet, 3.8-68—Safeguard Building 2 & 3 Plan Elevation +27 Feet, 3.8-69—Safeguard Building 2 & 3 Plan Elevation +39 Feet, 3.8-70—Safeguard Building 2 & 3 Plan Elevation +53 Feet, 3.8-71—Safeguard Building 2 & 3 Plan Elevation +69 Feet, 3.8-72—Safeguard Building 2 & 3 Plan Elevation +79 Feet, 3.8-73—Safeguard Building 2 & 3 Plan Elevation +94 Feet, and 3.8-74—Safeguard Building 2 & 3 Section B-B show the arrangements of SBs 2 and 3.

Figures 3.8-75—Safeguard Building 4 Plan Elevation -31 Feet, 3.8-76—Safeguard Building 4 Plan Elevation -16 Feet, 3.8-77—Safeguard Building 4 Elevation 0 Feet, 3.8-78—Safeguard Building 4 Elevation +15 Feet, 3.8-79—Safeguard Building 4 Plan Elevation +26 Feet, 3.8-80—Safeguard Building 4 Elevation +39 Feet, 3.8-81—Safeguard Building 4 Plan Elevation +55 Feet, 3.8-82—Safeguard Building 4 Elevation +69 Feet, 3.8-83—Safeguard Building 4 Plan Elevation +81 Feet, 3.8-84—Safeguard Building 4 Plan Elevation +96 Feet, and 3.8-85—Safeguard Building 4 Section A-A show the arrangements of SB 4.

3.8.4.1.4 Emergency Power Generating Buildings

The EPGB 1 and 2 are housed in one building while EPGB 3 and 4 are housed in a separate building. These two buildings are identified hereafter as EPGBs.

The two EPGBs are located adjacent to the NI Common Basemat Structure and in the general vicinity of the ESWBs. As depicted in Figure 3B-1, each building is physically separated from the NI Common Basemat Structure and is located on the opposite sides to provide sufficient separation to protect against common external events (e.g., aircraft hazard).

The EPGBs are essentially identical but are mirror images of one another. Each EPGB is approximately 178 feet long by 95 feet wide. The height of the EPGBs varies from approximately 51 feet, 6 inches above the top of the basemat foundation in the areas of the diesel fuel storage tanks, to 68 feet for the remainder of the structure.

Each EPGB is primarily constructed of reinforced concrete and supported by its own independent reinforced concrete basemat foundation. Structural steel framing is limited to steel platforms and composite beams.

Each EPGB contains two main diesel generators, the supporting equipment and also contains two fuel storage tanks, HVAC equipment, electrical equipment, and batteries. Within each structure, reinforced concrete walls separate the two main diesels and the diesel fuel storage tanks to protect against internal hazards. External walls and slabs are sized to protect against external hazards (e.g., wind, missile and explosion pressure wave).

Figure 3.8-89—Emergency Power Generating Buildings - Plan Elevation 0’-0”, Figure 3.8-90—Emergency Power Generating Buildings - Plan Elevation 33’-4”, Figure 3.8-91—Emergency Power Generating Buildings - Plan Elevation 51’-6”, Figure 3.8-92—Emergency Power Generating Buildings Plan Elevation 68’-0”, Figure 3.8-93—Emergency Power Generating Buildings – Section A-A, and Figure 3.8-94—Emergency Power Generating Buildings - Section B-B provides the elevation and section views of the EPGBs.

3.8.4.1.5 Essential Service Water Buildings

The ESWBs house the ESWCTs and the ESWPBs. The function of the ESWBs is to house equipment and cooling water associated with the essential service water system (ESWS). This system provides a source of cooling water to the component cooling water system (CCWS) heat exchangers, the Emergency Power Generator heat exchangers, and Essential Service Water HVAC system to support the safe operation and orderly shutdown of the plant, during normal operation or under accident conditions. As depicted in Figure 3B-1 each of the four structures is located in the vicinity of the NI Common Basemat Structure, but ESWBs 1 and 2 are physically separated from ESWBs 3 and 4 by the NI Common Basemat Structure to provide sufficient protection against external events (e.g., aircraft hazard).

Each ESWB is a reinforced concrete, shear wall structure approximately 164 feet by 108 feet wide by 118 feet high (i.e., from the bottom of the basemat to elevation 96 feet). Each structure is embedded 22 feet below grade. The primary portion of the structure is approximately 128 feet long by 108 feet wide, and houses two cooling towers, each with a water storage basin. On the side of the cooling towers facing the containment building, a structurally integrated pump house structure is located, enclosing primarily pumps and electrical equipment. The ESWPB is approximately 35 feet by 64 feet, with a roof at elevation 63 feet.

Exterior walls and slabs are sized for protection against external hazards, including tornado generated missiles and postulated blast loads. Two compartments are provided for air draft between elevation 14 feet and 43 feet, 6 inches.

Figure 3.8-95—Essential Service Water Building- Plan Elevation 0'0", Figure 3.8-96—Essential Service Water Building - Plan Elevation 14'-0", Figure 3.8-97—Essential Service Water Building - Plan Elevation 47'-0", Figure 3.8-98—Essential Service Water Building - Plan Elevation 63'-0", Figure 3.8-99—Essential Service Water Building - Plan Elevation 80'-0", Figure 3.8-100—Essential Service Water Building - Plan Elevation 96'-0", Figure 3.8-101—Essential Service Water Building - Section A-A, and Figure 3.8-102—Essential Service Water Building - Section B-B provides the elevation and section views of the ESWBs.

3.8.4.1.6 Distribution System Supports

Structural steel supports are provided for Seismic Category I distribution systems as part of other Seismic Category I structures. These include pipe supports, equipment supports, cable tray and conduit supports, HVAC duct supports, and other component supports. Distribution system supports are primarily constructed of steel shapes and tubing, which are anchored to other Seismic Category I concrete structures using embedded steel plates, cast-in-place anchor bolts, or drilled-in concrete anchors.

3.8.4.1.7 Platforms and Miscellaneous Structures

Platforms and miscellaneous structures (e.g., ladders, guard rails, stairs) are provided for access and maintenance to plant equipment and components housed in other Seismic Category I structures. These items are primarily constructed of steel beams, angles, channels, tubing, and grating. Platforms and miscellaneous structures are Seismic Category I, Seismic Category II, or Conventional Seismic depending on their safety function and potential interaction of the items with Seismic Category I SSC.

3.8.4.1.8 Buried Conduit and Duct Banks

The design of buried conduit and duct banks is site-specific. The design criteria for safety-related buried conduit and duct banks are provided below and in Section 3.8.4.4:

Safety-related conduit located outside of the building envelope is installed Seismic Category I and buried individually, as multiple conduits or in assemblies known as duct banks. [[Buried conduits are steel while conduits in encased duct banks may be poly-vinyl-chloride (PVC) or steel. Duct banks may be directly buried in the soil;

encased in lean concrete, concrete, or reinforced concrete. Concrete or reinforced concrete encased duct banks will be used in heavy haul zones, under roadway crossings, or where seismic effects dictate the requirement. Encasement in lean concrete may be used in areas not subject to trenching or passage of heavy haul equipment, or where seismic effects on the conduit are not significant.]] Duct bank depth and encasement methods will also consider effects from external hazards (e.g. tornado missile).

The analysis of duct banks considers the type of loading imposed on the duct bank (seismic wave passage load, static surcharge, buoyancy, settlement, tornado missile), soil properties, the geometry of the duct bank (curved versus straight), and boundary conditions imposed on the ends of the duct bank. Reinforced concrete encasement for duct banks used in heavy haul routes or road crossings are evaluated for postulated loadings and provisions defined in Section 3.8.4.4.

A COL applicant that references the U.S. EPR design certification will provide a description of Seismic Category I buried conduit and duct banks.

3.8.4.1.9 Buried Pipe and Pipe Ducts

The design of buried pipe and pipe ducts is site-specific. Buried pipe and pipe ducts are either directly buried in the soil or placed in reinforced concrete structures, or other materials, that are constructed below grade for routing Seismic Category I pipes between structures. Section 3.8.4.4 provides the design criteria for Buried Pipes and Pipe Ducts.

A COL applicant that references the U.S. EPR design certification will provide a description of Seismic Category I buried pipe and pipe ducts.

3.8.4.1.10 Masonry Walls

No masonry walls are used in Seismic Category I structures in the U.S. EPR.

3.8.4.2 Applicable Codes, Standards, and Specifications

The following codes, standards, specifications, design criteria, regulations, and regulatory guides are used for the design, fabrication, construction, testing, and inservice inspection of Seismic Category I structures other than the RCB and RB internal structures (GDC 1, GDC 2, GDC 4, and GDC 5).

3.8.4.2.1 Codes and Standards

- ACI 301-05 - Specifications for Structural Concrete for Buildings.
- ACI 304R-00 - Guide for Measuring, Mixing, Transporting, and Placing Concrete.

- ACI 305.1-06 - Hot-Weather Concreting.
- ACI 306R-88 (Re-approved 2002) - Cold-Weather Concreting.
- ACI 306.1-90 (Re-approved 2002) - Standard Specification for Cold Weather Concreting.
- ACI 308R-01 - Guide to Curing Concrete.
- ACI 308.1-98 - Standard Specification for Curing Concrete.
- ACI 311.4R-05 - Guide for Concrete Inspection (Reference 40).
- ACI 347-04 - Guide to Formwork for Concrete.
- ACI 349-01/349-R01 - Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary on Code Requirements for Nuclear Safety Related Concrete Structures (exception described in 3.8.4.4 and 3.8.4.5) (GDC 1).
- ACI 349.1R-07 - Reinforced Concrete Design for Thermal Effects on Nuclear Power Plant Structures.
- ACI 350-06 - Code Requirements for Environmental Engineering Concrete Structure (Reference 58).
- ACI 350.3-06 - Seismic Design of Liquid-Containing Concrete Structures (Reference 59).
- AISC 303-05 - Code of Standard Practice for Steel Buildings and Bridges.
- ANSI/AISC N690-1994 - Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2 (2004) (GDC 1).
- ANSI/AISC 341-05 - Seismic Provisions for Structural Steel Buildings, American Institute of Steel Construction, including Supplement 1.
- ANSI/ANS-6.4-2006 - Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants (Reference 4).
- AISC 348-04/2004 RCSC - Specification for Structural Joints Using ASTM A325 and A490 Bolts.
- ANSI/AWS D1.1/D1.1M 2006 - Structural Welding Code – Steel.
- ANSI/AWS D1.4-2005 - Structural Welding Code - Reinforcing Steel.
- ANSI/AWS D1.6-99, including January 6, 2005 update - Structural Welding Code – Stainless Steel.
- ANSI/AWS D1.8 2005 - Structural Welding Code – Seismic Supplement.

- ASCE Standard 4-98 - Seismic Analysis of Safety-Related Nuclear Structures and Commentary.
- ASME BPV Code - 2004 Edition, Section III, Division 2 – Code for Concrete Reactor Vessels and Containments.
- ASME NOG-1-2004 - Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girders).
- ASME B31.3 - 1996 - Process Piping, American Society of Mechanical Engineers (Reference 60).
- ASME B31.4 - 1992 - Liquid Transportation System for Hydrocarbon, Liquid Petroleum Gas, Anhydrous Ammonia, and Alcohols (Reference 61).
- ASME B31.8 - 1995 - Gas Transportation and Distribution Piping Systems.
- ASCE/SEI Standard 7-05 - Minimum Design Loads for Buildings and Other Structures (Reference 62).
- ASCE/SEI Standard 43-05 - Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities.
- SEI/ASCE Standard 37-02 - Design Loads on Structures During Construction.

3.8.4.2.2 Specifications

Industry standards (e.g., those published by the ASTM) are used to specify material properties, testing procedures, fabrication methods, and construction methods.

Structural specifications cover areas related to the design and construction of other Seismic Category I structures. These specifications emphasize important points of the industry standards for these structures and reduce options that would otherwise be permitted by the industry standards. These specifications cover the following areas:

- Concrete material properties.
- Mixing, placing, and curing of concrete.
- Reinforcing steel and splices.
- Structural steel.
- Steel liner plate and embedments.
- Miscellaneous and embedded steel.
- Anchor bolts.
- Expansion anchors.

- Cranes and hoists.

3.8.4.2.3 Design Criteria

- ACI 349-01/349-R01 - Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary on Code Requirements for Nuclear Safety Related Concrete Structures (GDC 1).
- ANSI/AISC N690-1994 - Specification for the Design, Fabrication, and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2 (2004) (GDC 1).

3.8.4.2.4 Regulations

- 10 CFR Part 50, Appendix A - General Design Criteria for Nuclear Power Plants, GDC 1, GDC 2, GDC 4, and GDC 5.
- 10 CFR Part 50, Appendix B - Quality Assurance Criteria for Nuclear Power Plants and Fuel Processing Plants."
- 10 CFR Part 50, Appendix S - Earthquake Engineering Criteria for Nuclear Power Plants.

3.8.4.2.5 NRC Regulatory Guides

Regulatory Guides applicable to the design and construction of other Seismic Category I structures:

- RG 1.61, Revision 1, March 2007 (exception described in 3.7.1).
- RG 1.69, December 1973.
- RG 1.115, Revision 1, July 1977.
- RG 1.142, Revision 2, November 2001 (exception described in 3.8.3.3).
- RG 1.160, Revision 2, March 1997.
- RG 1.199, November 2003.

3.8.4.3 Loads and Load Combinations

The U.S. EPR design loads envelope includes the loads over a broad range of site conditions. The loads on other Seismic Category I structures are separated into the following categories:

- Normal loads.
- Severe environmental loads.

- Extreme environmental loads.
- Abnormal loads.

A COL applicant that references the U.S. EPR design certification will confirm that site-specific loads lie within the standard design envelope for other Seismic Category I structures, or perform additional analyses to verify structural adequacy.

3.8.4.3.1 Design Loads

Loads on other Seismic Category I structures are in accordance with ACI 349-2001 and RG 1.142, Revision 2, November 2001 for concrete structures, and in accordance with ANSI/AISC N690-1994 including Supplement 2 (2004) for steel structures (GDC 1, GDC 2, GDC 4, and GDC 5).

Other Seismic Category I structures are designed for the following loads, as described in Section 3.8.4.4.:

Normal Loads

Normal loads are those loads encountered during normal plant operation, startup, shutdown, and construction (GDC 4). This load category includes:

- Dead loads (D)—Dead loads include the weight of the structure and any permanent equipment or material weights. Dead load effects also refer to internal moments and forces due to dead loads.

  For buried items, the dead load includes the weight of the soil overburden. The soil overburden load includes the weight of the overlying soil prism.

- Live loads (L)—Live loads include any normal loads that vary with intensity and point of application, including moveable equipment and precipitation loads. Live load effects also refer to internal moments and forces due to live loads. Live loads are applied, removed, or shifted in location to obtain the worst-case loading conditions. Impact forces due to moving loads are applied for the loading condition.

  In general, a live load of 400 pounds/ft^2 is applied to FB concrete floors, and 100 pounds/ft^2 live load is applied to concrete floors and to steel grating floors and platforms in other Seismic Category I structures. Floor live loads may vary according to the function of individual floors. Truck loads, fuel cask shipment loads, and loads due to replacement of RCS components are considered as live loads in the loading and material handling bays of the FB. Live loads are applied to cranes and their supports for the lifting capacity and test loads applied for lifting devices. Additional point loads are applied to concrete floors and to concrete and steel beams in local design.

  The design live load for rainfall is based on a rate of 19.4 inches per hour, as described in Section 2.4.

The design live load due to rain, snow, and ice is based on 100 pounds/ft^2 on the ground, as described in Section 2.4. This value is postulated as a meteorological site parameter for the extreme winter precipitation load and includes the weight of the 100 year return period snowpack and the weight of the 48 hour probable maximum winter precipitation. Roof snow and ice loads are determined using Chapter 7 of ASCE/SEI 7-05, "Minimum Design Loads for Buildings and Other Structures." The following factors are used to compute snow loads on the roofs of Seismic Category I structures:

– C_e, exposure factor = 1.0.

– C_t, thermal factor = 1.0.

– I, importance factor = 1.00 for Seismic Category I structures.

For buried items, the live load includes the effects of surface traffic such as truck loads, rail loads, construction equipment, and construction or maintenance activities.

- Hydrostatic loads (F)—Hydrostatic loads are due to fluids stored in pools and tanks in other Seismic Category I structures (e.g., the spent fuel pool and emergency feedwater storage tanks). Pools and tanks may have either constant or fluctuating liquid levels. Hydrodynamic loads resulting from seismic excitation of fluids are included as a component of the safe shutdown earthquake (SSE) load.

- Thermal loads (T_o)—Thermal loads consist of thermally induced forces and moments resulting from normal plant operation and environmental conditions. Thermal loads and their effects are based on the critical transient or steady-state condition. Thermal expansion loads due to axial restraint, as well as loads resulting from thermal gradients, are considered.

The external ambient air temperatures for other Seismic Category I structures are as follows:

– Maximum outside air temperature: 115°F.

– Minimum outside air temperature: -40°F.

– Ground temperature: 50°F.

Internal ambient temperatures for other Seismic Category I structures, except the FB, are as follows:

– During normal operation: 100°F (maximum).

– During normal operation: 50°F (minimum).

FB internal ambient temperatures are as follows:

– During normal operation: 110°F (maximum).

– During normal operation: 50°F (minimum).

– During abnormal conditions: 200°F (maximum).

Spent fuel pool fluid temperatures are as follows:

– During normal operation: 150°F (maximum).

– During normal operation: 70°F (minimum).

– During abnormal conditions: 180°F (maximum).

- Pipe reactions (R_o)—Pipe reactions are those loads applied by piping system supports during normal operating or shutdown conditions based on the critical transient or steady state conditions. The dead weight of the piping and its contents are included. Dynamic load factors are used when applying transient loads, such as water hammers.

- Soil loads and lateral earth pressure (H)—Soil loads and lateral earth pressure are loads that result from soil bearing pressures applied to buried exterior walls and structures up to the finished grade elevation of the surrounding soil. Refer to Section 2.5.4.2 for the soil parameters used to determine soil loads and lateral earth pressure. Normal soil loads consider saturated soil up to a groundwater elevation of -3.3 feet relative to the site finished grade.

- Construction loads—Construction loads are those loads to which the structure may be subjected during construction of the plant. Construction loads will be applied to evaluate partially-completed structures, temporary structures, and their respective individual members. Design load requirements during construction for buildings and other structures will be developed in accordance with Standard SEI/ASCE 37-02, "Design Loads on Structures During Construction." The magnitude and location of construction loads will be applied to generate the maximum load effects of dead, live, construction, environmental, and lateral earth pressure loads. Consideration will be given to the loads and load effects of construction methods, equipment operation, and sequence of construction.

Severe Environmental Loads

Severe environmental loads are those loads that could be encountered infrequently during the plant life (GDC 2). This load category includes:

- Wind loads (W)—Wind loads are those loads resulting from wind pressure acting on external surfaces of structures due to normal design wind speeds. See Section 3.3.1 for wind parameters and methods used to determine wind loads. Wind loads in this category do not include tornado wind forces.

- Operating basis earthquake (OBE)—There are no OBE loads applicable to the design of other Seismic Category I structures, since an OBE level of one-third the SSE has been selected. See Section 3.7 for a description of the OBE.

Extreme Environmental Loads

Extreme environmental loads are those loads that are credible but are highly improbable (GDC 2). This load category includes:

- Safe shutdown earthquake (E')—SSE loads are those loads generated by an earthquake with a peak horizontal ground acceleration of 0.30 g. Seismic loads in the vertical direction and two orthogonal horizontal directions are considered to act simultaneously. Section 3.7 provides a description of how SSE loads are determined and combined. SSE loads are considered due to applied inertia loads, including dead loads, live loads, hydrodynamic loads (i.e., water in storage pools and tanks), and soil loads, including combination of these loads using the square root of the sum of the squares (SRSS) method or the 100-40-40 percent rule described in Section 3.8.4.4.1.

  The SSE component of soil loads is determined using densities for saturated soil to account for the weight of the soil plus the weight of either normal or flood water levels. This includes using load cases for normal groundwater level at 3.3 feet below plant grade, and for flood water level at 1.0 foot below plant grade. Earthquake-induced soil pressures are developed in accordance with Section 3.5.3 of ASCE 4-98.

- Tornado loads (W_t)—Tornado loads are those loads on external surfaces of structures resulting from a design basis tornado. See Section 3.3.2 for tornado design parameters and methods used to determine tornado loads. See Section 3.5 for design methods and parameters used to determine tornado-generated missile loads. Tornado loads include:

  - Tornado wind pressure (W_w).
  - Tornado differential pressure (W_p).
  - Tornado-generated missiles (W_m).

- External flood loads—External flood loads are included with soil loads and lateral earth pressure loads (H) and with SSE loads (E') as previously described by considering saturated soil conditions.

Abnormal Loads

Abnormal loads are those loads generated by a postulated high-energy pipe break accident (i.e., loss of coolant accident (LOCA)) within a building or compartment (GDC 4). This event is classified as a design basis accident. Included in this category are: Internal Flooding loads (F_a), Pressure loads (P_a), Thermal loads (T_a), Accident pipe reaction loads (R_a), and Pipe break loads (R_r). The Pipe break load is subcategorized as: Pipe break reaction loads (R_{rr}), Pipe break jet impingement loads (R_{rj}), and Pipe Break Missile Impact loads (R_{rm}). These loadings include a dynamic load factor to account for the dynamic nature of the load, unless a time-history analysis is performed to justify otherwise. Abnormal loads include the following loads:

- Internal flood loads (F_a)—Loads resulting from internal flooding of other Seismic Category I structures during or following a postulated pipe system failure that presents the risk of common mode failures of safety-related equipment (e.g., failures of cooling water systems in SBs 1 through 4). Hydrostatic loads from the maximum possible water level are applied to affected walls, slabs, and the basemat foundation.

- Pressure load (P_a)—Pressure equivalent static load within or across a compartment or building generated by the postulated break and including a dynamic load factor to account for the dynamic nature of the load.

- Thermal load (T_a)—Thermal loads generated by the postulated break and including T_o.

- Accident pipe reactions (R_a)—Pipe reactions generated by the postulated break and including R_o.

- Pipe break loads (R_r)—Local equipment and piping loads generated following a postulated pipe break. Unless a time-history analysis is performed to justify otherwise, these loadings include a dynamic load factor to account for the dynamic nature of the load. The pipe break load (R_r) is considered to act as three separate components (R_{rr}, R_{rj}, R_{rm}), which are defined below. In determining the equivalent static load for R_{rr}, R_{rj}, and R_{rm}, elasto-plastic behavior may be assumed with ductility ratios, provided excessive deflections do not result in loss of function of any safety-related SSC.

  - Pipe break reaction loads (R_{rr})—R_{rr} is defined as the equivalent static load on the structure generated by the reaction of the high-energy pipe during the postulated break.

  - Pipe break jet impingement loads (R_{rj})—R_{rj} is defined as the jet impingement equivalent static load on the structure generated by the postulated break.

  - Pipe break missile impact loads (R_{rm})—R_{rm} is defined as the missile impact equivalent static load on the structure generated by or during the postulated break, such as pipe whipping.

Other Loads

Other loads refer to postulated events or conditions that are not included in the design basis (GDC 4). These loading conditions and effects are evaluated without regard to the bounding conditions under which SSC are required to perform design basis functions. This load category includes:

- Aircraft hazard (A)—Aircraft hazard refers to loads on a structure resulting from the impact of an aircraft. The evaluation of this loading condition is considered as part of the plant safeguards and security measures.

- Explosion pressure wave (B)—Explosion pressure wave refers to loads on a structure resulting from an explosion in the vicinity of the structure. The evaluation of this loading condition is considered as part of the plant safeguards and security measures.

- Missile loads other than wind or tornado-generated missiles—The tornado-generated missile spectra presented in Table 3.5-1 is considered to bound other external missile loads for the U.S. EPR other Seismic Category I structures. Turbine missiles and conformance to RG 1.115 are addressed in Section 3.5. As described in Section 3.5.1.3, the impact of turbine missiles on other Seismic Category I structures is not considered safety significant based on the redundancy and the low probability of a turbine missile being generated. Other Seismic Category I concrete and steel structures are designed for internally generated missile loads as described in Section 3.5.

3.8.4.3.2 Loading Combinations

Load combinations for design of other Seismic Category I structures are in accordance with ACI 349-2001 and RG 1.142, Revision 2, November 2001 for concrete structures, and in accordance with ANSI/AISC N690-1994 including Supplement 2 (2004) for steel structures (GDC 1, GDC 2, GDC 4, and GDC 5).

The following criteria apply for load combinations for concrete and steel Seismic Category I structures other than the RCB and RB internal structures:

- For concrete members, U is defined as the section strength required to resist design loads based on the strength design methods described in ACI 349.

- For steel members, S is defined as the required section strength based on the elastic design methods and the allowable stresses defined in Part Q1 of ANSI/AISC N690.

- For steel members, Y is defined as the section strength required to resist design loads based on plastic design methods described in Part Q2 of ANSI/AISC N690.

Loads and loading combinations encompass the soil cases described in Section 3.7.1, using the design criteria described in Section 3.7.1 and Section 3.7.2.

Other Seismic Category I Structures – Concrete

The following load combinations define the design limits for concrete Seismic Category I structures, other than the RCB and RB internal structures:

- Service load combinations for the strength design method.

  $U = 1.4(D + F) + 1.7(L + H + R_o)$

$U = 1.4(D + F) + 1.7(L + H + W + R_o)$

$U = (0.75)(1.4D + 1.4F + 1.7L + 1.7H + 1.7T_o + 1.7R_o)$

$U = (0.75)(1.4D + 1.4F + 1.7L + 1.7H + 1.7W + 1.7T_o + 1.7R_o)$.

- Factored load combinations for the strength design method.

$U = D + F + L + H + T_o + R_o + E'$

$U = D + F + L + H + T_o + R_o + W_t$

$U = D + F + L + H + T_a + R_a + F_a + 1.4P_a$

$U = D + F + L + H + T_a + R_a + F_a + P_a + R_{rr} + R_{rj} + R_{rm} + E'$.

Other Seismic Category I Structures - Steel

The following load combinations define the design limits for steel Seismic Category I structures, other than the RCB and RB internal structures. For normal service load conditions, either the elastic working stress design methods of Section Q1 or the plastic design methods of Section Q2 of ANSI/AISC N690, including Supplement 2, are used.

- Service load combinations for the elastic working stress design method.

S[2] = D + F + L + H

S[2] = D + F + L + H + W

S[2] = $D + F + L + H + T_o + R_o$

S[2] = $D + F + L + H + T_o + R_o + W$.

- Service load combinations for the plastic design method.

$Y = (1.7)(D + F + L + H)$

$Y = (1.7)(D + F + L + H + W)$

$Y = (1.3)(D + F + L + H + T_o + R_o)$

$Y = (1.3)(D + F + L + H + W + T_o + R_o)$

- Factored load combinations for the elastic working stress design method.

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

$1.6S^3 = D + F + L + H + T_o + R_o + E'$

$1.6S^3 = D + F + L + H + T_o + R_o + W_t$

$1.6S^3 = D + F + L + H + T_a + R_a + F_a + P_a$

$1.6S^3 = D + F + L + H + T_a + F_a + P_a$ (This load combination is used when the global non-transient sustained effects of T_a are considered).

$1.7S^3 = D + F + L + H + T_a + R_a + F_a + P_a + R_{rr} + R_{rj} + R_{rm} + E'$.

- Factored load combinations for the plastic design method.

$Y = 1.1\ (D + F + L + H + T_o + R_o + E')$

$Y = 1.1\ (D + F + L + H + T_o + R_o + W_t)$

$Y = 1.1\ (D + F + L + H + T_a + R_a + F_a + 1.25P_a)$

$Y = 1.1\ (D + F + L + H + T_a + R_a + F_a + P_a + R_{rr} + R_{rj} + R_{rm} + E')$.

3.8.4.4 Design and Analysis Procedures

Analysis and design procedures are similar for the various concrete and steel other Seismic Category I structures but vary somewhat from structure to structure. The general analysis and design procedures applicable to other Seismic Category I structures are explained below. The procedures specific to the following other Seismic Category I structures are also described.

- The RSB and annulus, FB, and SBs.
- The EPGBs.
- The ESWBs.
- Buried conduit and duct banks, and buried pipe and pipe ducts.

Design and analysis procedures described in the following sections also apply to the design of supports for Seismic Category I distribution systems (i.e., pipe supports, equipment supports, cable tray supports, conduit supports, HVAC duct supports, and other component supports) and to Seismic Category I platforms and miscellaneous steel structures located within other Seismic Category I buildings and structures.

3. The stress limit coefficient in shear must not exceed 1.4 in members and bolts. The stress limit coefficient where axial compression exceeds 20 percent of normal allowable must be 1.5 for load combinations defined above for 1.6S, and 1.6 for the load combination defined above for 1.7S.

3.8.4.4.1 General Procedures Applicable to Other Seismic Category I Structures

Other Seismic Category I concrete structural elements and members are designed in accordance with the requirements of ACI 349-2001 and its appendices (GDC 1). Exceptions to code requirements specified in RG 1.142 are incorporated into the design and are accommodated in the loading combinations described in Section 3.8.4.3.2 for concrete structures.

The design of concrete walls, floors, and other structural elements for other Seismic Category I structures is performed using the strength-design methods described in ACI 349-2001, with the exception that the shear strength reduction factor of 0.85 is used as allowed in ACI 349-2006. Use of this shear strength reduction factor is acceptable because the loss of strength and stiffness due to cyclic inelastic loading in structural members of nuclear structures is smaller when compared to that of a conventional building structure, where a lower reduction factor is used. The ductility requirements of ACI 349-2001 are satisfied to provide a steel reinforcing failure mode and prevent concrete failure for design basis loadings.

The design of anchors and embedments conforms to the requirements of Appendix B of ACI 349-2001 and RG 1.199. Ductility is provided by designing anchorage systems such that a steel failure mode controls the design. The requirements of Appendix C of ACI 349-2001 are followed for impulsive and impactive loading conditions (e.g., loading combinations that include pipe break missile impact loads or tornado-generated missile impact loads).

Other Seismic Category I steel members and assemblies are designed in accordance with ANSI/AISC N690-1994 (R2004, including Supplement 2) (GDC 1). Steel member design uses the allowable stress design methods of ANSI/AISC N690.

The design of bolted connections is in accordance with ANSI/AISC N690, Section Q1.16 and AISC 348-04/2004 RCSC, "Specification for Structural Joints Using ASTM A325 and A490 Bolts." Bolted connections are designed to be fully tensioned (e.g., slip critical) unless justified otherwise.

The design of welded connections is in accordance with AWS D1.1 or AWS D1.6.

The design of bolted connections in combination with welded connections is in accordance with Section Q.15.10 of ANSI/AISC N690.

Loads and load combinations defined in Section 3.8.4.3 are used to determine strength requirements of members and elements of other Seismic Category I structures. Abnormal pipe break accident loads only apply to limited areas of structures located on the NI Common Basemat Structure. The following criteria apply for load combinations for concrete and steel other Seismic Category I structures:

- The one-third increase in allowable stresses for concrete and steel members due to seismic (E') or wind (W and Wt) loadings is not permitted.

- Where any load reduces the effects of other loads, the corresponding coefficient for that load is 0.9 if it can be demonstrated that the load occurs simultaneously with other loads.

- Where the structural effects of differential settlement, creep, or shrinkage may be significant, they are included with the dead load (D) as applicable.

- For load combinations in which a reduction of the maximum design live load (L) has the potential to produce higher member loads and stresses, multiple cases are considered where the live load (L) is varied between its maximum design value and zero.

- Roofs with a slope of less than 0.25 inches per foot are analyzed for adequate stiffness to preclude progressive deflection as water ponding is created from the snow load or from rainfall on the surface. The analysis considers the potential blockage of the primary drainage system of the area that is subject to ponding loads. The analysis uses the larger of the snowmelt depth or rain load.

- For steel members, thermal loads may be neglected when it can be shown that they are secondary and self limiting in nature.

- For load combinations including the loads P_a, T_a, R_a, R_{rr}, R_{rj}, or R_{rm}, the maximum values of these loads, including a dynamic load factor, are used unless a time-history analysis is performed to justify otherwise.

- For load combinations including loads R_{rr}, R_{rj}, R_{rm}, or W_m, these load combinations are first satisfied with these loads set to zero. However, when considering these concentrated loads, local section strength capacities may be exceeded under the effect of these concentrated loads, provided there is not a loss of function of any safety-related SSC.

- Twenty five percent of the design live load is considered with tornado load combinations. The full potential live load is used for the local analysis of structural members.

- Tornado loads are applied to roofs and exterior walls of other Seismic Category I structures. If tornado pressure boundaries are not established at the exterior walls, interior walls are designed as tornado pressure boundaries.

- For load combinations that include a tornado load (W_t), the tornado load parameter combinations described in Section 3.3 are used.

Concrete and steel structural elements and members are designed for axial tension and compression forces, bending moments, torsion, and in-plane and out-of-plane shear forces for the controlling loading combinations that are determined from analysis. Concrete and steel members and elements remain elastic for loadings other than impact. Local yielding is permitted for localized areas subjected to tornado-generated missile loads, pipe break accident loadings, and beyond design basis loadings. The structural integrity of members and elements is maintained for the loading combinations described in Section 3.8.4.3.

Analysis and design of other Seismic Category I structures are performed using a combination of computer models and local analyses. Computer models are used to perform overall analysis of major structures. The loads and loading combinations described in Section 3.8.4.3 are applied to the overall computer model to design for global effects of the loadings. Local analyses and designs are performed using refined computer submodels and manual calculations. Local analyses and designs are used to account for local discontinuities (e.g., openings, thickened areas, local loads, punching shear checks, and changes in member cross-section). Local analyses are also used to determine designs for items such as component supports, embedments, anchors, platforms, and other miscellaneous structural items. Techniques used for major structures are described in Sections 3.8.4.4.2 through 3.8.4.4.5.

Refer to Section 9.1.5 for design requirements applicable to cranes located in other Seismic Category I structures.

Openings in walls and slabs of other Seismic Category I structures are shown in construction drawings. Openings are acceptable without analysis if they meet the criteria identified in ACI 349, Section 13.4.2. Round pipe sleeves are used in lieu of rectangular penetrations where possible. Corners of rectangular openings in walls and slabs are provided with diagonal reinforcing to reduce cracking due to stress concentration at these locations in accordance with ACI 349, Section 14.3.7.

Appendix 3E describes analysis and design results for critical sections of other Seismic Category I structures.

Section 3.7.2 addresses design procedures applicable to non-safety-related structures to preclude adverse interaction effects on Seismic Category I structures.

Static Analysis and Design

Dead loads (D), live loads (L), hydrostatic loads (F), soil loads and lateral earth pressure loads (H), wind loads (W), pipe reactions (R_o), and normal thermal loads (T_o) are considered in the analysis and design of other Seismic Category I structures for the static normal load concrete and service load steel loading combinations. Concrete and steel members are designed to accommodate these static loads within the elastic range of their section strength. For concrete structures, uncracked section properties are used to proportion loadings to members. However ultimate strength design is used to reinforce concrete elements and members subjected to the normal factored loading combinations defined in Section 3.8.4.3.2.

Static fluid pressure loads are considered for design of the walls and floors of tanks and storage pools. Moving loads are considered for mobile plant equipment (e.g., cranes, hoists, truck bays in buildings, maintenance aisles).

Seismic and Other Dynamic Analyses and Design

Seismic analyses and designs of other Seismic Category I structures conform to the procedures described in Section 3.7.2. The requirements of ASCE 4-98 are used in the analysis and design of structural elements and members subjected to load combinations that include seismic loadings. Seismic accelerations are determined from structural stick models as described in Section 3.7.2. These accelerations are applied to the finite element computer models of other Seismic Category I structures as static-equivalent loads at the elevations used in the stick model.

Seismic SSE (E') loads are obtained by multiplying the dead load and 25 percent of the design live load by the structural accelerations obtained from the seismic analyses of each structure. A minimum of 75 percent of the roof snow load is included in the structural mass for seismic analysis of Seismic Category I structures. Seismic loads are also considered due to the mass of fluids in tanks and canals as described below for hydrodynamic loads. The full potential live load, including precipitation, is used for the local analysis of structural elements and members. Consideration is given to the amplification of seismic accelerations obtained from the structural stick model of each structure, due to local flexibility of structural elements and members. Construction loads are not included when determining seismic loads. Other temporary loads are evaluated for contributing to the seismic loads on a case-by-case basis.

Seismic loads from the three components of the earthquake motion are combined using the SRSS method or the 100-40-40 percent rule described in ASCE 4-98. The 100-40-40 combination is expressed mathematically as follows:

Where:

R = the reaction force or moment that is applied in the three orthogonal directions x, y, and z:

$$R = (\pm 1.0R_X \pm 0.4R_Y \pm 0.4R_Z)$$

$$R = (\pm 0.4R_X \pm 1.0R_Y \pm 0.4R_Z)$$

$$R = (\pm 0.4R_X \pm 0.4R_Y \pm 1.0R_Z).$$

The effects of local flexibilities in floor slabs and wall panels are considered to determine if additional seismic accelerations should be applied to their design beyond those determined from the seismic stick model. Local flexibility evaluations are performed by determining the natural frequency of the floor or wall panel and comparing this to the frequency of the zero period acceleration on the applicable response spectra. Additional acceleration is applied when the natural frequency of the panel results in higher accelerations than the zero period acceleration. In cases where local flexibilities are determined to be a factor, additional out-of-plane accelerations are applied to the inertia loads on these panels for determining out-of-plane bending and shear loads.

Additional seismic loads due to accidental torsion are considered as described in Section 3.7.2. This is to account for variations in material densities, member sizes, architectural variations, equipment loads, and other variations from the values used in the analysis and design of other Seismic Category I structures. Due to these potential variations, an additional eccentricity of the mass is included at the floor elevations that are equivalent to 5 percent of the maximum building dimension.

Seismic Category I concrete structural elements and their connections are detailed for ductility in accordance with ACI 349-2001, Chapter 21.

Structural Stiffness Considerations

Conservative values of concrete creep and shrinkage are used in the design of other Seismic Category I structures. Moments, forces, and shears are obtained on the basis of uncracked section properties in the analysis. However, in sizing the reinforcing steel required, the concrete is not relied upon for resisting tension. Thermal moments are modified by cracked-section analysis using analytical techniques, when the state of loading indicates the development of cracks.

The effect of local wall and floor slab flexibility is included where the analysis indicates the existence of this condition. The concrete section properties used in calculating the amplified seismic forces include an appropriate level cracking for the particular element under consideration. The amplified forces are also used in the design of the structural members that support the flexible element.

Section 3.8.4.6 describes methods used to confirm that concrete properties satisfy design requirements.

Seismic Structural Damping

Seismic analysis of other Seismic Category I structures uses the following SSE structural damping values as recommended by RG 1.61.

Structure Type	Percent of Critical Damping
• Welded Steel	4
• Bolted Steel, Slip Critical Connections	4
• Bolted Steel, Bearing Connections	7

- Reinforced Concrete 7

Hydrodynamic Loads

Hydrodynamic loads are applied to the walls and floors of the spent fuel pool and liquid storage tanks in the SBs and in the ESWBs to account for the impulsive and impactive effects of the water moving and sloshing in the tanks as a result of seismic excitation. These loads are considered as part of the seismic SSE loads, and components of these loads in the three orthogonal directions are combined in the same manner as other seismic loads. The requirements of ASCE 4-98, "Seismic Analysis of Safety-Related Nuclear Structures," ASCE Manual No. 58, USAEC TID-7024, and other proven methods are used to determine hydrodynamic loadings. The effect of tank structure flexibility on spectral acceleration is included when determining the hydrodynamic pressure on the tank wall for the impulsive mode.

Design for hydrodynamic loads is within the elastic range of concrete and steel members and elements.

Thermal Analysis and Design

Normal thermal loads (T_o) are considered in the analysis and design of other Seismic Category I structures. Abnormal pipe break accident thermal loads (T_a) are considered to have no effect on the overall structure of other Seismic Category I structures and are only considered in local analyses.

For steel members, thermal loads are neglected when it can be shown that they are secondary and self limiting in nature.

For concrete structures, the requirements of ACI 349, Appendix A, ACI 349.1R, or thermal analysis computer programs or similar procedures are used to evaluate thermally induced forces and moments. When considering the combined effects of thermal stress and stress due to other loads, the analysis satisfies the requirements of Appendix A of ACI 349.

Pipe Rupture Loads

Other Seismic Category I structures will be evaluated for pipe rupture loads. Local analyses of other Seismic Category I structures consider the following abnormal loads for areas that house high-energy piping systems:

- Subcompartment pressure loads (P_a).
- Pipe break thermal loads (T_a).
- Accident pipe reactions (R_a).

- Pipe break reaction, jet impingement, and missile loads (R_{rr}, R_{rj}, R_{rm}).
- Local flood loads (F_a).

Subcompartment pressure loads (P_a) resulting from a LOCA event are evaluated as time-dependent loads across concrete walls and floors that enclose high-energy piping systems. Concrete and steel members are designed to accommodate subcompartment pressure loads within the elastic range of the section strength.

Pipe break thermal loads (T_a) are considered in local analyses of concrete walls and floors. Accident thermal loads are evaluated as time-dependent loads across concrete walls and floors that enclose high-energy piping systems subject to LOCA events. The thermal design of concrete is in accordance with ACI 349-01/349-R01, Appendix A and ACI 349.1R-07.

Accident pipe reaction loads (R_a) are considered on piping supports, including supports for the MS and feed water piping. Concrete and steel members are designed to accommodate accident pipe reaction loads within the elastic range of their section strength.

Pipe break reaction, jet impingement, and missile loads (R_{rr}, R_{rj}, R_{rm}) are considered in local design of concrete walls and floors and steel members. Dynamic load factors are applied when analyzing structures for the static equivalent of these loads. Elasto-plastic behavior may be assumed with ductility ratios, provided that excessive deflections do not result in the loss of function of any safety-related SSC. Pipe break reactions, jet impingement, and missile impact impulsive and impactive loads are in accordance with Appendix C of ACI 349-2001. The design of other Seismic Category I structures for these loads conforms to the procedures described in Section 3.5 for internally generated missiles. Section 3.5 also describes ductility limits that are followed for impactive and impulsive loadings.

Flood loads (F_a) are applied to walls and floors in the local design of other Seismic Category I structures. Concrete and steel members are designed to accommodate these flood loads within the elastic range of their section strength.

Missile Impact Design

The design of Seismic Category I structures for internally generated and externally generated missiles conforms to the procedures described in Section 3.5.

Concrete missile barriers subject to missile impact loads are designed in accordance with Appendix C of ACI 349. Steel missile barriers subject to missile impact loads are designed in accordance with the requirements of ASCE No. 58. Missile protection barriers that use composite sections will be evaluated for local damage using the residual velocity of the missile perforating the first element as the striking velocity of the missile for the next element in the section.

Seismic Category I structures, shields, and barriers designed to withstand the effects of missile impacts are evaluated for local damage in the impacted area, including an estimation of the depth of penetration and, in the case of concrete barriers, the potential for generation of secondary missiles by spalling or scabbing. Global and regional effects of missile impact are also evaluated for concrete and steel missile barriers.

Dynamic load factors are applied when analyzing structures for the static equivalent of missile impact loads. Elasto-plastic behavior may be assumed with ductility ratios, provided excessive deflections do not result in loss of function of any safety-related SSC.

Structures that are not classified as Seismic Category I structures are not relied upon to shield Seismic Category I structures from the effects of missile impact.

Flood Design

In addition to designing for the external flood loads described in Section 3.8.4.3.1, Seismic Category I structures are protected against external flooding by the following methods:

- Exterior wall penetrations below plant flood level are sealed to prevent flood waters from entering Seismic Category I buildings.
- Finished yard grade around Seismic Category I structures is sloped to direct flood water and runoff away from the structures.
- Finished floor elevations are at one foot above plant finished grade where openings are provided for personnel and maintenance access.
- Water stops are provided in below grade exterior construction joints.
- Floor drainage is provided for building interior floors to collect water that could potentially enter the buildings.

See Section 3.4 for additional information on flood protection.

3.8.4.4.2 Reactor Shield Building and Annulus, Fuel Building, and Safeguard Buildings – NI Common Basemat Structure Other Seismic Category I Structures

Loads from the loading combinations described in Section 3.8.4.3 are applied to the NI Common Basemat Structure other Seismic Category I structures, which include the RSB, the FB, and SBs. Vertical loads transfer to the NI Common Basemat Structure foundation basemat through concrete exterior walls, concrete interior walls, and concrete and steel columns. Lateral loads transfer to the NI Common Basemat Structure foundation basemat by diaphragm action of the concrete roof slabs and intermediate concrete floor slabs, which transfer loads to the interior and exterior concrete shear walls. Lateral loads transfer to the soil subgrade by friction and passive earth pressure.

The reinforced concrete roof slabs and intermediate floor slabs are analyzed and designed as two-way slabs. Reinforced concrete walls are analyzed and designed as shear walls and compression members, which are also subjected to out-of-plane bending moments, torsion, and out-of-plane shear. Analysis and design of the NI Common Basemat Structure foundation basemat is addressed in Section 3.8.5.

The dynamic increment for the seismic soil surcharge loads on the exterior below-grade walls of NI Common Basemat Structure other Seismic Category I structures is determined by multiplying the surcharge static load by the maximum vertical zero period acceleration (ZPA) at the ground surface determined in the seismic analyses described in Section 3.7.2. Seismic-induced lateral soil pressures on below-grade walls are evaluated for the following cases:

- The seismic soil pressure is equal to the sum of the static earth pressure plus the dynamic earth pressure calculated in accordance with ASCE 4-98, Section 3.5.3.2.
- The seismic soil pressure is equal to the passive earth pressure.

NI Common Basemat Structure other Seismic Category I structures are included in the ANSYS V10.0 SP1 finite element overall computer model of the NI Common Basemat Structure that is described in Section 3.8.1.4.1. The NI Common Basemat Structure model includes the RSB, FB, and SBs as well as the RCB, RB internal structures, and the NI Common Basemat Structure foundation basemat that are described in other sections. Boundary conditions for the ANSYS computer model and methods used for application of axisymmetric and non-axisymmetric loads, transient and localized loads, and other parameters used in the model are described in Section 3.8.1.4.

The NI Common Basemat Structure other Seismic Category I structures are modeled using a mesh of ANSYS finite elements representing primary load-carrying walls, floors, columns, and beams. Gaps are maintained between structures adjacent to Seismic Category I structures to allow for structural movements during seismic events, containment pressurization, missile strikes, aircraft impact, explosions, and other loading conditions. Exterior walls and roofs of the hardened SBs 2 and 3, RSB, and the FB are modeled to be independent of the internal structures, because there is no physical connection of internal walls and slabs in these structures with the outside walls and roof.

ANSYS SHELL43 solid shell elements are used to model walls and floors and other concrete elements in the NI Common Basemat Structure other Seismic Category I structures. SHELL43 is a three-dimensional, four-node shell element that is suitable for moderately thick shell structures. SHELL43 can also provide out-of-plane shear forces and has an elastic-plastic capability. BEAM44 members are used to model beams and columns. The ANSYS finite element computer program is used to analyze the NI Common Basemat Structure other Seismic Category I structures for the loads and load combinations described in Section 3.8.4.3.

The finite element model used for the analysis of the NI Common Basemat Structure is shown in Figures 3.8-86—ANSYS Finite Element Model of Nuclear Island Common Basemat Structure – Outside View, 3.8-87—ANSYS Finite Element Model of Nuclear Island Common Basemat Structure – Section Through Fuel Building and Safeguard Building 2/3 Island, and 3.8-88—ANSYS Finite Element Model of Nuclear Island Common Basemat Structure – Section Through Safeguard Buildings 4 and 1.

Local analyses are used to analyze other Seismic Category I structures for locally applied loadings that have no significant effect on the overall behavior of the structures. Local analyses are performed for the pipe rupture loads described in Section 3.8.4.4.1 and for the missile impact loads also described in Section 3.8.4.4.1, as well as for other loadings and local structural areas.

Subsystem supports (i.e., pipe supports, HVAC duct supports, electrical conduit supports, cable tray supports) are analyzed and designed using local analyses. Analysis and design of subsystem supports are performed in accordance with the same criteria and codes specified for design of other Seismic Category I structures. See Section 3.7.3 for additional descriptions of methods used for seismic analyses of distribution systems.

Section 9.1.2 addresses fuel storage racks.

3.8.4.4.3 Emergency Power Generating Buildings

The EPGBs are reinforced concrete shear wall structures. Vertical loads transfer to the reinforced concrete foundation basemat through the reinforced concrete walls. Lateral loads transfer to the foundation basemat by diaphragm action of the reinforced concrete roof slabs to the reinforced concrete walls. Lateral loads from the foundation basemat are transferred to the supporting soil through bearing, friction, and passive earth pressure.

The reinforced concrete walls are designed as shear walls which are subjected to compression loads, in-plane and out-of-plane bending moments, and in-plane and out-of-plane shear. The floor slab at elevation 51 feet, 6 inches consists of a composite slab with composite structural steel beams. The roof slab at elevation +68 feet, zero inches is primarily designed as a one-way slab due to the relative aspect ratio between the lines of support.

The EPGBs are analyzed and designed using a 3D finite element model representing the structure. The finite element model is generated using the GT STRUDL computer code to accomplish the following:

- Provide an accurate representation of the structure for translation to a soil structure interaction (SSI) model (by SASSI 2000) for seismic analysis (See Section 3.7.2 for information on the extrapolation of the GT STRUDL finite element model for the seismic analysis).
- Conduct a static analysis of the EPGBs using equivalent static seismic loads; and other applicable design loads.
- Provide input for the design of reinforced concrete structural elements.

The finite element model of the EPGBs consists of SBHQ6 and SBHT6 elements representing the load carrying reinforced concrete walls and slabs, as these element types are suitable for capturing both the in-plane and out-of-plane effects from the corresponding applied loads.

Compression only spring boundary conditions are utilized to represent the soil and accurately capture uplift effects in the foundation basemat design.

The equivalent SSI model includes modifications to the stiffness of the various composite beams at elevation 51 feet, 6 inches, as well as modifications to account for cracking. The stiffness of these composite beams is included in the SASSI 2000 model to capture out-of-plane response. Stiffness of the composite beams is not required in the static analysis model as only in-plane stresses in the concrete slab are determined.

For the composite beams and floor slab at elevation 51 feet, 6 inches, the corresponding floor accelerations from the SASSI analysis output are applied to tributary floor areas and walls to obtain the seismic loads associated with the out-of-plane loads. Dead load, live load, equipment loads, and piping loads are combined with the seismic loads. The composite beams are analyzed outside of the finite element model. Structural design of the composite beams is in accordance with the provisions of ANSI/AISC N690-1994 (R2004).

The in-plane and out-of-plane results from the GT STRUDL equivalent static analysis are extracted and used to design reinforced concrete shear walls and slabs according to provisions of ACI 349-01. The evaluation of walls and slabs for external hazards (e.g., tornado generated missiles and blast loads) is also performed by local wall and slab analyses. Structural element reinforcement is designed to provide sufficient ductility.

Additional information on the seismic analysis approach for the EPGBs is contained in Section 3.7.2.

For the design of the EPGBs, some details for the composite beams and slabs at elevation 51 feet, 6 inches, particularly changes in beam sizes and floor openings, as well as certain aspects of mechanical design layout, are not reflected in the SASSI Finite Element Model used for SSI analyses. Inclusion of these details in the SASSI Finite Element Model are not expected to have any significant impact on the seismic forces used in the design of the EPGBs, but may impact the in-structure response spectra. Therefore, a subsequent analysis will be performed with these details in the Finite Element Model to confirm the seismic responses and in-structure response spectra presented in Section 3.7.2. The design of the EPGBs will conform to the structural acceptance criteria described in Section 3.8.4.5.

3.8.4.4.4 Essential Service Water Buildings

Reinforced concrete elements for the four ESWBs consist of slabs, beams, shear walls, and foundation basemat to transfer imposed loads to the supporting soil. Structural steel framing is used to support the missile barriers protecting the safety-related fans.

Similar to the EPGBs, the ESWBs are analyzed and designed using a 3D finite element model representing the structure. The finite element model is generated using the GT STRUDL computer code. The use of the model for both static and dynamic analyses, including extraction of results for design, is almost identical to the methods presented in Section 3.8.4.4.3. Similarly, the GT STRUDL model is used to provide an accurate representation of the structure for translation to an SSI model (SASSI 2000) for seismic analysis. As such, only model variations are addressed below.

In addition to structural dead loads, slab live loads, piping loads and equipment loads, the GT STRUDL finite element model for the ESWBs includes the weight of non-structural fill, hydrostatic loads, hydrodynamic loads, and soil pressures (including surcharge pressures). The appropriate accelerations from the SSI analysis are applied to the tributary floor areas and walls to obtain the equivalent static seismic loads.

Dead load, live load, equipment loads, and piping loads are combined with the equivalent static seismic loads for structural design in accordance with the provisions of ACI 349-01, with supplemental guidance of RG 1.142, ACI 350-06, and ACI 350.3-06. The evaluation of walls and slabs for external hazards (e.g., tornado generated missiles) is performed by local analyses, including ductility evaluations. The elastic solution methodology of ASCE 4-98 is used for the dynamic soil pressures associated with the 22 feet embedment of the ESWBs.

Seismic induced lateral soil pressure on below grade walls are evaluated considering the following cases:

- The seismic soil pressure as equal to the sum of the static earth pressure plus the dynamic earth pressure calculated in accordance with ASCE 4-98, Section 3.5.3.2.
- The seismic soil pressure as equal to the passive earth pressure.

Additional information on the seismic analysis approach for the ESWBs is contained in Section 3.7.2.

For the design of the ESWBs, the foundation basemat extension, as explained in the ESWB section of Appendix 3E, is not reflected in the SASSI Finite Element Model used for SSI analyses. Therefore, a subsequent analysis will be performed with these added details in the Finite Element Model to confirm the foundation basemat design. The design of the ESWBs will conform to the structural acceptance criteria described in Section 3.8.4.5.

3.8.4.4.5 Buried Conduit and Duct Banks, and Buried Pipe and Pipe Ducts

The design of buried conduit and duct banks, and buried pipe and pipe ducts is site-specific. Buried Seismic Category I conduit, electrical duct banks, pipe, and pipe ducts will be analyzed and designed in accordance with the specific requirements of the systems. In addition, these items will be designed for the effects of soil overburden, surcharge, groundwater, flood, seismic soil interaction, and other effects of burial. Concrete components of buried items will be designed in accordance with ACI 349-2001, including the exceptions specified in RG 1.142. Steel components of buried items will be designed in accordance with ANSI/AISC N690-1994 (R2004), including Supplement 2.

Static and long-term analyses of buried items will be based on soil properties under consolidated drained conditions of the soil. Buried items will be designed for soil loads corresponding to the weight of the overlying soil prism.

Live loads will be applied, such as those imposed by truck and rail traffic and by construction equipment and activities. Impact factors will be applied to live loads as appropriate. Where buried items are vulnerable to highway or railway traffic loads, the potential for fatigue-induced failure will be evaluated. The minimum burial depth of buried items will conform to guidance from ASME 31.4 and ASME 31.8.

Buried items will be designed for freeze-thaw induced stresses and for other thermally induced stresses due to soil and ambient air temperatures. Interfacial longitudinal friction effects will be evaluated for buried pipes that are encased in larger pipes or in concrete trenches or boxes.

In cases where buried items are located below the ground water table or where seasonal change in the ground water table is significant, the effect of buoyancy and the increased weight of water will be evaluated. These evaluations will include the effects of fluctuations in ground water level and the effects of flood.

Seismic load effects on buried items will be evaluated using dynamic analyses or equivalent static load methods. For seismic-related and dynamic analyses, the shear strength of soil will be based on the consolidated-undrained triaxial stress conditions of the soil. The procedure for evaluating the structural integrity of buried items under seismic conditions will involve determination of the axial and bending strains in the system due to seismic wave propagation in the surrounding soil mass. The axial force and bending stresses will be computed using the buried item material properties (e.g., Young's modulus and pipe section modulus). Pipe ovalization will be computed based on the applicable static and dynamic loads imposed on the pipe from the soil and surcharge loads. Soil-structure interaction analyses will be performed for buried piping systems based on the free-field earthquake motion, considering the three orthogonal components of the motion. The influence of geotechnical properties such as strain rate and magnitude, confining stress, and relative density on pore pressure, damping, and shear modulus will be incorporated into analyses. Response of buried items to burial depth, groundwater, presence of adjacent structures, and soil heterogeneity will be evaluated in seismic analyses.

Buried items will be evaluated for the effects of settlement and ground movement, including potential damage related to compaction of soil during construction, long-term elastic and consolidation settlement (total and differential), freeze-thaw induced settlement, seismic-induced settlement, seismic wave propagation, and seismic-induced permanent ground deformation. The effects of differential settlement between buried pipes and the buildings or structures to which pipes are anchored will be evaluated. At site locations where differential settlement is significant, flexible anchors may be used in lieu of rigid anchors. Support structures will be designed to resist the resulting axial loads, bending stresses, and shear stresses imposed by buried items on the structure.

Refer to the AREVA NP Inc., U.S. Piping Analysis and Pipe Support Design Topical Report (Reference 37) for additional analysis and design procedures applicable to buried piping.

A COL applicant that references the U.S. EPR design certification will describe the design and analysis procedures used for buried conduit and duct banks, and buried pipe and pipe ducts.

A COL applicant that references the U.S. EPR design certification will use results from site-specific investigations to determine the routing of buried pipe and pipe ducts.

A COL applicant that references the U.S. EPR design certification will perform geotechnical engineering analyses to determine if the surface load will cause lateral or vertical displacement of bearing soil for the buried pipe and pipe ducts and consider the effect of wide or extra heavy loads.

3.8.4.4.6 Design Report

Design information and criteria for Seismic Category I structures are provided in Sections 2.0, 2.4, 2.5, 3.3, 3.5, 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5. Design results are presented in Appendix 3E for Seismic Category I structure critical sections.

3.8.4.5 Structural Acceptance Criteria

Limits for allowable stresses, strains, deformations and other design criteria for other Seismic Category I reinforced concrete structures are in accordance with ACI 349-2001 and its appendices, with the exception that the shear strength reduction factor of 0.85 is used as allowed in ACI 349-2006 (GDC 1, GDC 2, and GDC 4). Limits for concrete design include the exceptions specified in RG 1.142.

Limits for allowable loads on concrete embedments and anchors are in accordance with the requirements of Appendix B of ACI 349-2001 and RG 1.199.

Limits for the allowable stresses, strains, deformations, and other design criteria for other structural steel Seismic Category I structures are in accordance with ANSI/AISC N690-1994 (R2004) including Supplement 2 (GDC 1, GDC 2, and GDC 4).

Allowable settlements for other Seismic Category I structures are described in Section 2.5.

The design of other Seismic Category I structures is generally controlled by load combinations containing SSE seismic loads. Stresses and strains are within the ACI 349-2001 limits, with the exceptions previously listed, and ANSI/AISC N690-1994 limits.

Appendix 3E provides design results for critical sections of other Seismic Category I structures.

Structural acceptance criteria for buried Seismic Category I pipe are addressed in the AREVA NP Inc., U.S. Piping Analysis and Pipe Support Design Topical Report.

A COL applicant that references the U.S. EPR design certification will confirm that site-specific Seismic Category I buried conduit, electrical duct banks, pipe, and pipe ducts satisfy the criteria specified in Section 3.8.4.4.5 and those specified in the AREVA NP Inc., U.S. Piping Analysis and Pipe Support Design Topical Report.

3.8.4.6 Materials, Quality Control, and Special Construction Techniques

This section contains information relating to the materials, quality control programs, and special construction techniques used in the fabrication and construction of concrete and steel Seismic Category I structures other than the RCB and the RB internal structures.

Construction of concrete radiation shielding structures and certain elements of design that relate to problems unique to this type of structure is in accordance to RG 1.69. The requirements and recommended practices contained in ANSI/ANS-6.4-2006, are generally acceptable for the construction of radiation shielding structures, as amended by the applicable exceptions noted in RG 1.69.

3.8.4.6.1 Materials

Concrete, reinforcing steel, and structural steel materials for other Seismic Category I structures are the same as described in Section 3.8.3.6 (GDC 1), except as follows:

Structural concrete used in the construction of other Seismic Category I structures has the following compressive strengths (f'_c) at 90 days.

- The NI Common Basemat Structures, including RSB, FB and SBs (except for foundation basemat): 6,000 psi minimum.
- The EPGBs: 5,000 psi minimum.
- The ESWBs: 5,000 psi minimum.
- Buried duct banks and pipe ducts: 4,000 psi minimum.

The use of epoxy coated reinforcing steel and waterproofing membranes for exterior walls and slabs will be evaluated on a site-specific basis as described in Section 3.8.5.6.

3.8.4.6.2 Quality Control

Quality control procedures for other Seismic Category I structures are the same as described in Section 3.8.3.6 (GDC 1).

3.8.4.6.3 Special Construction Techniques

Other Seismic Category I structures are constructed using proven methods common to heavy industrial construction. No special, new, or unique construction techniques are used.

Modular construction methods are used to the extent practical for pre-fabricating portions of the spent fuel pool liner, other tank liners, distribution system supports, reinforcing, concrete formwork, and other portions of other Seismic Category I structures. Such methods have been used extensively in the construction industry. Rigging is pre-engineered for heavy lifts of modular sections. Permanent and temporary stiffeners are used on liner plate sections and other modularized items to satisfy code requirements for structural integrity of the modular sections during rigging operations.

Steel decking and plates and supporting steel beams may be used to form concrete floors. In these instances, the decking thickness is in addition to the nominal floor thicknesses. The decking, plates, and beams may be left in place, in which case they are designed for applicable seismic loads and other loading conditions. Other types of formwork may also be used that are left in place and become a permanent part of the structure. Such items meet code requirements and are designed to prevent their failure from affecting Seismic Category I SSC.

3.8.4.7 Testing and Inservice Inspection Requirements

Monitoring and maintenance of other Seismic Category I structures is performed in accordance with the requirements of RG 1.160 (GDC 1).

Testing and inservice inspection of the spent fuel pool leak chase channels in the FB is addressed in Section 9.1.

Refer to Section 9.1.5 for testing and inservice inspection requirements applicable to cranes.

Physical access is provided to perform inservice inspections of exposed portions of other Seismic Category I structures.

Examination of inaccessible portions of below-grade concrete structures for degradation and monitoring of ground water chemistry are addressed in Section 3.8.5.7.

3.8.5 Foundations

3.8.5.1 Description of the Foundations

Foundations for Seismic Category I structures are provided for the following buildings and structures:

- NI Common Basemat Structure foundation basemat.
- EPGB foundation basemats.
- ESWB foundation basemats. The ESWBs house the ESWCTs and the ESWPBs.

Foundations for buried items are included in Section 3.8.4. Section 3.7.2 addresses design requirements for Non-Seismic Category I structures to preclude adverse interaction effects on Seismic Category I structures.

Figure 3B-1 provides a site plan of the U.S. EPR standard plant showing the outline of the foundation basemats for the NI Common Basemat Structure, EPGBs, and ESWBs, along with the location of each foundation basemat.

Structures described within this section are not shared with any other power plant units (GDC 5).

A COL applicant that references the U.S. EPR design certification will describe site-specific foundations for Seismic Category I structures that are not described in this section.

3.8.5.1.1 Nuclear Island Common Basemat Structure Foundation Basemat

The NI Common Basemat Structure foundation basemat is a heavily reinforced concrete slab that supports the NI Common Basemat Structure Seismic Category I structures. The RCB and the RSB are located near the center of the NI Common Basemat Structure foundation basemat, and they are surrounded by the FB and the four SBs. The NI Common Basemat Structure foundation basemat is a cruciform shape that has outline dimensions of approximately 360 feet by 360 feet by 10 feet thick, a foundation basemat of lesser thickness will be considered for rock sites. The bottom of the NI Common Basemat Structure foundation basemat is founded approximately at elevation -41 feet below plant grade. The NI Common Basemat Structure foundation basemat outline and section views are presented in Figures 3B-1, 3.8-11, 3.8-12, 3.8-13, 3.8-50, 3.8-51, 3.8-52, 3.8-63, 3.8-74, and 3.8-85.

The NI Common Basemat Structure foundation basemat provides anchorage of the vertical post-tensioning tendons in the RCB, which is described in Section 3.8.1. The portion of the NI Common Basemat Structure foundation basemat that is considered to provide support and anchorage for the RCB is the area under the circumference of the outer face of the RSB wall, as shown on Figure 3.8-11, Figure 3.8-12 and Figure 3.8-13. This portion of the NI Common Basemat Structure foundation basemat is designed in accordance with the ASME BPV Code 2004 Edition, Section III, Division 2. A circular gallery is provided beneath the NI Common Basemat Structure foundation basemat for maintenance access to the bottom of the vertical post-tensioning tendons provided in the RCB shell wall. The tendon access gallery is approximately 11 feet wide by 14 feet high, including an approximately 36 inch thick foundation slab under the gallery structure. No credit is taken in the design for the tendon gallery transmitting loads into the soil in vertical or horizontal bearing. Connection of the tendon gallery to the NI Common Basemat Structure foundation basement allows for differential movement between the concrete structures.

Sections 3.8.1 and 3.8.3 describe the interface of the RCB containment liner plate and upper internal basemat above the liner for supporting the RB internal structures. Section 3.8.4 describes the interface of the RSB, FB, and SBs with the NI Common Basemat Structure foundation basemat. Concrete walls and columns of these NI Common Basemat Structure Seismic Category I structures are anchored into the NI Common Basemat Structure foundation basemat with reinforcing bars to transmit vertical, horizontal, and bending moment loads into the basemat and to enhance the rigidity of the basemat.

Horizontal shear loads are transferred from the NI Common Basemat Structure foundation basemat to the underlying soil by friction between the bottom of the basemat, mud mat (or both), and the soil, and by passive earth pressure on the below-grade walls of the NI Common Basemat Structure Seismic Category I structures; shear keys are not used. Section 2.5.4.2 describes the friction coefficient properties of soil addressed for the U.S. EPR.

Buildings adjacent to the NI Common Basemat Structure are separated from the NI Common Basemat Structure foundation basemat to allow for differential seismic movements between buildings. Refer to Figure 3B-1, which illustrates the gaps between buildings.

Waterproofing membranes used under or within the NI Common Basemat Structure foundation basemat will be evaluated on a site-specific basis, as described in Section 3.8.5.6.

3.8.5.1.2 Emergency Power Generating Buildings Foundation Basemats

Each EPGB foundation basemat supports a building superstructure and associated equipment. At the super-structure and foundation basemat interface, heavily reinforced concrete shear walls function as bearing walls to transfer loads from floors and the roof. Each foundation basemat is embedded approximately five feet into the supporting soil and has overall dimensions of approximately 178 feet long by 94.5 feet wide by 6 feet thick. In the areas of the two diesel fuel oil storage tanks, the foundation basemat reduces in width from 94.5 feet to 42 feet.

Figure 3.8-89 illustrates the general arrangement plan, which also shows the primary shear walls at column lines A, C, E, G and J in the east-west direction, and column lines 11, 13, 17 and 19 in the north-south direction. Additional figures, provided in Appendix 3E, illustrate both the shear walls at the super-structure and foundation basemat interface and the foundation basemat reinforcement.

Figures 3.8-93 and 3.8-94 provide section views of the EPGB structure, which further clarify the relationship between the superstructure and the foundation basemat. Isometric views of the GT STRUDL model representing the overall structure are provided in Section 3.7.2.

3.8.5.1.3 Essential Service Water Buildings Foundation Basemats

The reinforced concrete foundation basemat for each ESWB supports the superstructure and water basin. At the super-structure and foundation basemat interface, heavily reinforced concrete shear walls function as bearing walls to transfer loads from the floors and the roof. Each foundation basemat is embedded approximately 22 feet into the supporting soil and has overall dimensions of approximately 164 feet by 128 feet wide by 6 feet thick.

Figures 3.8-101 and 3.8-102 provide cross-sections of the ESWB in each direction, illustrating the superstructure which bears on the foundation basemat. Figure 3.8-95 provides the general arrangement plan, which also illustrates the primary shear walls at column lines A, B, D and F in the east-west direction, and column lines 1, 2, 4 and 5 in the north-south direction. Additional figures provided in Appendix 3E illustrates both the shear walls at the super-structure and foundation basemat interface and the foundation basemat reinforcement. Isometric views of the GT STRUDL model representing the overall structure are provided in Section 3.7.2

3.8.5.2 Applicable Codes, Standards, and Specifications

Applicable codes, standards, specifications, design criteria, regulations, and regulatory guides that are used for the design, fabrication, construction, testing, and inservice inspection of Seismic Category I foundations are the same as those in Section 3.8.4.2 (GDC 1, GDC 2, GDC 4 and GDC 5).

In addition, the portion of the NI Common Basemat Structure foundation basemat under the RCB is designed in accordance with the ASME BPV Code–2004 Edition, Section III, Division 2 for support and anchorage of the concrete RCB.

3.8.5.3 Loads and Load Combinations

Loads and load combinations for Seismic Category I foundations are the same as those in Section 3.8.4.3.

In addition to the loads addressed in Section 3.8.4.3, the NI Common Basemat Structure foundation basemat is designed for the loads and load combinations from the RCB as described in Section 3.8.1.3. The NI Common Basemat Structure foundation basemat provides for anchorage of the RCB vertical post-tensioning tendons, and the portion of the basemat under the RCB is designed to accommodate loads from containment.

Loads and load combinations on Seismic Category I foundations are in accordance with ACI 349-01, RG 1.142, RG 1.199, and ANSI/AISC N690-1994, including Supplement 2 (2004) for steel structures (GDC 1, GDC 2, GDC 4 and GDC 5). Loads and load combinations on the portion of the NI Common Basemat Structure foundation basemat that supports the RCB are in accordance with the ASME BPV Code–2004 Edition, Section III, Division 2 and RG 1.136 (Exception: RG 1.136 endorses the 2001 Edition of the ASME BPV Code with the 2003 addenda (including exceptions taken in RG 1.136). The U.S. EPR standard plant design is based on the 2004 Edition of the BPV Code, inclusive of the exceptions taken in RG 1.136).

In addition to the load combinations specified above, the following load combinations are applied for Seismic Category I foundations to consider sliding and overturning due to earthquakes, winds, and tornados and against flotation due to floods:

$D + H + W$

$D + H + W_t$

$D + H + E'$

$D + F_b$

where:

F_b = the buoyant force of the design basis flood at maximum site water level. Refer to Section 3.8.4.3.1 for definitions of the other load parameters.

The U.S. EPR Seismic Category I foundations are also designed for the effects of short term and long term settlements. Section 2.5 provides the settlement limits considered for the U.S. EPR.

There are no OBE loads applicable to the design of Seismic Category I foundations, since an OBE level of one-third the SSE has been selected. See Section 3.7 for a description of the OBE.

3.8.5.4 Design and Analysis Procedures

Design and analysis procedures are similar for the various Seismic Category I foundations but vary somewhat from structure to structure. The general analysis and design procedures applicable to Seismic Category I foundations are provided in the following sections. Procedures specific to the following Seismic Category I foundations also are described.

- NI Common Basemat Structure foundation basemat.
- EPGBs foundation basemats.
- ESWBs foundation basemats.

3.8.5.4.1 General Procedures Applicable to Seismic Category I Foundations

Concrete foundation basemats for Seismic Category I structures are analyzed as flat slabs on elastic supports to represent the underlying soil. The underlying soil medium is represented by soil springs described in subsequent sections. Loads are applied to the foundation basemats by the interfacing reinforced concrete walls and structural steel columns that comprise the building structures being supported, as well as by equipment supported directly on the foundations. Intersecting concrete walls also serve to stiffen the foundation basemat slabs to increase resistance to bending moments resulting from soil pressures under the slabs. Foundations are analyzed for the various factored loads and load combinations identified in Section 3.8.5.3.

Seismic Category I foundation basemat structures transfer vertical loads from the buildings to the subgrade by direct bearing of the basemats on the subgrade. Horizontal shears, such as those produced by wind, tornados, and earthquakes are transferred to the subgrade by friction along the bottom of the foundation basemat or by passive earth pressure (or both). Waterproofing membranes used under or within the Seismic Category I foundations will be evaluated on a site-specific basis, as described in Section 3.8.5.6.

Design and analysis procedures for Seismic Category I foundations are the same as those described in Sections 3.8.1.4 and 3.8.4.4 for the respective structures that apply loads on the foundations.

Seismic Category I concrete foundations are designed in accordance with ACI 349-01 and its appendices (GDC 1). Exceptions to code requirements specified in RG 1.142 are incorporated into the design and are accommodated in the loading combinations described in Section 3.8.5.3. In addition, the portion of the NI Common Basemat Structure foundation basemat that supports the RCB is designed in accordance with the ASME BPV Code–2004 Edition, Section III, Division 2 for support and anchorage of the concrete RCB as described in Section 3.8.1.

The design of concrete foundations for Seismic Category I structures is performed using the strength-design methods described in ACI 349-01, with the exception that a shear reduction factor of 0.85 is used as allowed in ACI 349-06 (Reference 39). The ductility provisions of ACI 349-01 are satisfied to provide a steel reinforcing failure mode and to prevent concrete failure for design basis loadings.

Design of steel structures used for Seismic Category I foundations is performed in accordance with ANSI/AISC N690-1994 (R2004), including Supplement 2 (GDC 1). Steel member design uses the allowable stress design methods of ANSI/AISC N690.

Foundation design is performed for the spectrum of soil cases described in Section 3.7.1. Section 2.5 and Section 3.7 describe seismic parameters and design methods used for analyzing and designing Seismic Category I structures.

Soil-structure interaction and structure-soil-structure interaction effects are considered in the seismic analyses of Seismic Category I structures as described in Section 3.7.2. Figure 3B-1 illustrates separation distances between Seismic Category I structures upon which these interaction evaluations are based.

The NI Common Basemat Structure is designed for an average static soil bearing pressure of 14,500 pounds per square foot and a maximum static bearing pressure of 22,000 pounds per square foot. Accordingly, Seismic Category I foundations are sized and reinforced to accommodate these bearing pressure values.

The following criteria apply for load combinations for concrete and steel Seismic Category I foundations:

- The one-third increase in allowable stresses for concrete and steel members due to seismic (E') or wind (W and W_t) loadings is not permitted.
- Where any load reduces the effects of other loads, the corresponding coefficient for that load is 0.9 if it can be demonstrated that the load is always present or occurs simultaneously with other loads.
- For load combinations in which a reduction of the maximum design live load (L) has the potential to produce higher member loads and stresses, multiple cases are considered where the live load (L) is varied between its maximum design value and zero.
- Twenty five percent of the design live load is considered with tornado load combinations. The full potential live load is used for the local analysis of structural members.
- For load combinations that include a tornado load (W_t), the tornado load parameter combinations described in Section 3.3 are used.

Loads and load combinations defined in Section 3.8.5.3 are used to determine strength requirements of members and elements of Seismic Category I foundations. Concrete and steel structural elements and members are designed for axial tension and compression forces, bending moments, torsion, and in-plane and out-of-plane shear forces for the controlling loading combinations that are determined from analysis. Concrete and steel members and elements remain elastic for loadings other than impact. Local yielding is permitted for localized areas subjected to tornado-generated missile loads, pipe break accident loadings, and beyond design basis loadings. The structural integrity of members and elements is maintained for the loading combinations described in Section 3.8.5.3.

For the loading combinations identified in Section 3.8.5.3, the minimum factors of safety required to prevent sliding and overturning are specified in Table 3.8-11—Minimum Required Factors of Safety Against Overturning, Sliding, and Flotation for Foundations.

Normal lateral earth pressure loads consider saturated soil up to a groundwater elevation of -3.3 feet relative to site finished grade. Lateral soil loads due to external floods consider saturated soil up to elevation -1.0 feet relative to site finished grade. Seismic loads from all three components of the earthquake motion are combined using the SRSS method or the 100-40-40 percent rule described in ASCE 4-98, the same as described in Section 3.8.4.4. The SSE components of soil loads are determined using densities for saturated soil to account for the weight of the soil plus the weight of either normal or flood water levels. Earthquake-induced lateral soil pressures are developed in accordance with Section 3.5.3 of ASCE 4-98. The design of embedded elements, such as embedded walls on basemats, assumes that the lateral pressure due to the SSE is in phase with the inertial loads. In cases where passive pressure is assumed to act on embedded structures in the stability check against sliding, the walls of the structure are evaluated to withstand such earth pressure. Section 3.8.4.4.2 provides further information on how seismic-induced lateral earth pressures are determined for the NI Common Basemat Structure. These lateral load effects are considered in structure sliding and overturning analyses. Refer to Section 2.5.4.2 for the soil parameters used to determine soil loads and lateral earth pressure.

When the effects of vertical seismic acceleration are included in the stability check against sliding, the unfactored dead weight of the structure is used to calculate the resistance to sliding due to friction. Sliding distance estimates may be computed using the reserve energy approach described in ASCE /SEI 43-05 as a conservative alternate to time-history computed sliding displacements.

Buoyancy effects of saturated soil due to a groundwater level of elevation -3.3 feet below finished grade or to a flood water level of elevation -1.0 feet below finished grade are considered when performing sliding and overturning analyses. For uplift evaluations (i.e., flotation and seismic overturning), dead load includes the weight of water permanently stored in pools and tanks. Justification is provided for live loads that are included in loading combinations when evaluating structures for the effects of sliding and overturning.

The effects of differential foundation settlements are applied concurrently with the dead load using the same load factors. Also, the effects of varying settlements between adjacent foundations are considered for the design of mechanical and electrical systems (e.g., piping, cables) that are routed between structures founded on separate basemats. See Section 3.8.4.4.5 for analysis and design procedures for Seismic Category I buried items that interface with structures on separate foundations.

3.8.5.4.2 Nuclear Island Common Basemat Structure Foundation Basemat

The NI Common Basemat Structure foundation basemat is analyzed and designed using the ANSYS V10.0 SP1 finite element overall computer model (a static model) for NI Common Basemat Structure Seismic Category I structures, which is described in

Section 3.8.1.4.1. The NI Common Basemat Structure model includes the RCB, RB internal structures, RSB, FB, and SBs, as well as the NI Common Basemat Structure foundation basemat. This model is also used to determine the static bearing pressure on the supporting soils. A second model (a dynamic model) is used to determine dynamic soil bearing pressures as well as sliding and overturning factors of safety.

ANSYS SOLID45 solid elements are used to model the concrete basemat foundation in the NI Common Basemat Structure static analysis. SOLID45 is a three-dimensional, eight-node element that is suitable for moderately thick structures. Depending on the thickness of the basemat, between three to five layers of SOLID45 elements are used in the model, with an average of four elements in the typical 10 feet thick basemat areas. Figure 3.8-103, Nuclear Island Common Basemat Structure foundation basemat ANSYS Model illustrates the model used for design of the basemat.

Springs are used to represent soil that provides support for the concrete foundation basemat in the ANSYS model. These springs represent the compressibility of the soil and were developed to reflect the pressure distribution under the NI Common Basemat Structure. Springs values vary for each soil case based on the soil properties and the spring location under the modeled foundation. The distribution used is elliptical in nature and takes the form of:

$$K(x,y) = K_o[A - B^*(1 - x^2/2l^2 - y^2/2b^2)^{1/2}]$$

where:

$K(x, y)$ is the subgrade modulus at x, y corrected for mat stiffness (pounds/ft^2 per foot)

K_o is the weighted average subgrade modulus (pounds/ft^2 per foot)

A & B are constants for a soil type based on its properties, bearing pressure distribution and shape of the foundation.

x = is the coordinate in the length direction of the Foundation Mat (feet)

y = is the coordinate in the width direction of the Foundation Mat (feet)

b = half width of foundation

l = half length of foundation.

The Gazetas equation (Reference 57) was used to evaluate the total soil spring (K_o) for the foundation basemat of the NI Common Basemat Structure. Although Gazetas addresses the dynamic stiffness of the foundation basemat, the use of one-half the dynamic shear modulus in the equation approximates the total stiffness of the supporting soil medium under static conditions. Table 3.8-13—Static Spring Distribution provides the distribution equations and K_o values for each soil case.

Soil stiffness springs are modeled through the use of contact elements applied to the base of the NI Common Basemat Structure. These elements do not allow tension force transfer between the soil and the foundation. Sliding is not modeled in the static analysis. Figure 3.8-106—Elastic Displacement for Soil Case 1u, Figure 3.8-107—Elastic Displacement for Soil Case 2u, Figure 3.8-108—Elastic Displacement for Soil Case 1n2u, Figure 3.8-109—Elastic Displacement for Soil Case 3u, Figure 3.8-110—Elastic Displacement for Soil Case 4u, Figure 3.8-111—Elastic Displacement for Soil Case 5a, Figure 3.8-112—Elastic Displacement for Soil Case 5u, Figure 3.8-113—Elastic Displacement for Soil Case 2sn4u, Figure 3.8-114—Elastic Displacement for Soil Case 2n3u, and Figure 3.8-115—Elastic Displacement for Soil Case 3r3u illustrate elastic displacements, from loading, and dead load + 0.25* live load + equipment load using the springs listed in Table 3.8-13.

Tri-linear soil springs are developed for soil cases 4u and 2sn4u, as defined in Section 3.7.1, in order to mitigate unrealistic analysis results generated by the NI Common Basemat Structure static model. Seismic forces were conservatively applied using maximum ZPA accelerations from the soil structural interaction (SSI) analysis for points throughout the structure. These accelerations are applied to the building masses simultaneously, without consideration of timing. This methodology results in conservative sets of seismic forces, in some cases base shears are 20 percent to 55 percent larger than those calculated by the SSI analysis, applied to the structure. When these conservatively high forces are applied to soils represented by stiff springs the resulting overturning moment is exaggerated and skews the analysis results. The introduction of tri-linear springs to the model mitigates the exaggerated response.

Tri-linear springs development uses the linear development as the starting point. The subsurface soil is assumed to be relatively high plasticity clay. Based on the modulus degradation for clays with plasticity index in the range 50 to 70, a relationship is developed between displacement of the foundation basemat and the corresponding average reaction imposed by the underlying soil medium on the foundation basemat. Using an incremental approach, the methodology calculates the reaction at the base of the foundation basemat for a small increment of basemat displacement, using the appropriate soil spring associated with the shear modulus at this step. In the next incremental step, the solution is advanced using a reduced shear modulus consistent with the shear strain at a representative depth associated with the soil reaction from the previous step. For the two aforementioned soil cases (4u and 2sn4u) the resultant bearing pressure versus subgrade modulus values are provided in Table 3.8-14—Tri-Linear Subgrade Modulus vs. Bearing Pressures.

The results of the soil spring analyses are used in determining forces and moments in the basemat for concrete design and for determining the acceptability of the supporting soil media under static loading conditions.

A second model was developed to evaluate the soil bearing pressures, sliding and overturning due to seismic events. This model explicitly represents the nonlinearities of sliding and uplift, the transient nature of the seismic loadings, the properties of the soils, and the dynamic characteristics of the structure. This approach produces a more realistic picture of the NI Common Basemat Structure response to seismic loadings than is possible using the static model alone.

The NI Common Basemat Structure superstructure is modeled using lumped parameter systems identical to those used for the soil-structure interaction analysis. The masses, stiffnesses, and eccentricities of the buildings are mathematically computed, spatially arranged and tuned (to the fundamental frequencies of the SSI model) to correctly represent the dynamic characteristics of the NI Common Basemat structures. The basemat is modeled using shell elements and properties are provided to make this surface as rigid as practical for analytical purposes. The NI Common Basemat Structure basemat is very rigid by virtue of its thickness and many stiffened walls.

Soil is modeled with one layer of solid elements beneath the shells, representing the basemat. Properties of these solids are established in a way that ultimately allows the model to respond in agreement with the SASSI analysis fundamental modes (see Table 3.8-15—Fundamental Mode Frequencies for Dynamic Model Tuning).

Interaction of the basemat shells and soil elements is modeled with contact elements; tension in the soil is not allowed. Shear resistance at the interface is modeled by setting the shear coefficient to a constant value of $\mu = 0.7$, $\mu = \tan \varphi$ where $\varphi = 35°$ for soil. Passive lateral soil pressure is also modeled and the full passive pressure is assumed to mobilize at a horizontal displacement of one percent of the embedded depth (see Figure 3.8-116—Passive Soil Pressure). Horizontal springs with constants representing this curve are connected to the basemat for conservatism, as opposed to some distance up the embedded walls.

Damper elements (dashpots) are connected to the element upper and lower nodes to account for soil damping in the three principal directions. These values are derived from the SASSI analysis transfer functions. A constant 5 percent critical damping is used for the superstructure.

The model is excited by simultaneous application of three EUR seismic transients to the base of the soil elements, for soil cases 1u, 2sn4u, 2n3u, 2u, 4u and 5a representing soft, medium and hard soils. Transients are applied, one each, in the three principal building directions. The weight of the building; including the water in the in-containment refueling water storage tank (IRWST), fuel pool, and the four emergency feedwater storage tanks (because this water is always present within the NI Common Basemat Structure), and full buoyancy are the other loadings included in this analysis. Active dynamic earth pressure is small when compared to the building seismic shear and is not considered in this model.

Table 3.8-16—Dynamic Analysis Results summarizes the results of the non-linear dynamic analysis.

Section 3.8.1, Section 3.8.3, and Section 3.8.4 provide descriptions of interfacing structures that induce loads on the NI Common Basemat Structure foundation basemat. The figures in those sections illustrate the concrete shear walls and columns that transfer loads to the NI Common Basemat Structure foundation basemat. The tendon gallery beneath the NI Common Basemat Structure foundation basemat is not relied upon as a shear key to aid in resisting lateral forces on the basemat. The area under the tendon gallery is not considered in transferring vertical forces into the underlying soil media.

Detailed analysis and design procedures are described in the critical sections presented in Appendix 3E.

Section 3.8.3 provides a description of analysis and design of the RB internal structures basemat, which is located above the containment liner plate.

3.8.5.4.3 Emergency Power Generating Buildings Foundation Basemats

Horizontal shear loads are transferred from the EPGB foundation basemat to the underlying soil by friction between the bottom of the basemat, mud mat, and the soil, and by passive earth pressure.

The EPGB foundation basemat is analyzed and designed using the GT STRUDL v.29.1 finite element analysis code. The finite element model contains both the building superstructure (i.e., reinforced concrete walls and elevated slabs) as well as the foundation basemat. Analysis of the EPGB includes all applicable design loads and design load combinations described in Section 3.8.4.3. Figure 3.8-104—Emergency Power Generating Building Foundation Basemat Model illustrates the foundation basemat portion of the overall EPGB finite element model.

The GT STRUDL finite element model representing the EPGB foundation basemat consists of SBHQ6 rectangular elements, each with six degrees of freedom. This element type is capable of capturing both in-plane and out-of-plane behavior. Elastic boundary conditions are included in the finite element model in order to simulate the stiffness of the supporting soil. Basemat flexibility and SSI are addressed by inclusion of the basemat section properties and aforementioned soil spring boundary conditions in the finite element model.

The foundation basemat is included in the overall GT STRUDL finite element model used for static analysis of the foundation basemat, along with compression-only soil springs representing static soil stiffness properties of soft, medium and hard soils. Compression-only effects are included in the boundary conditions in order to capture uplift effects induced by extreme event loading (e.g., SSE). Illustrations of the complete finite element model representing the EPGB are provided in Section 3.7.2.

Detailed analysis and design procedures are described in the critical sections presented in Appendix 3E for the EPGBs.

3.8.5.4.4 Essential Service Water Building Foundation Basemats

Horizontal shear loads are transferred from the ESWB foundation basemat to the underlying soil by friction between the bottom of the basemat, mud mat, and the soil. In addition, dynamic soil pressure and passive earth pressure have been considered for the below-grade walls, reflecting the total embedment depth of nominally 22 feet.

Similar to the approach for the EPGB, the foundation basemat is analyzed and designed using the GT STRUDL v.29.1 finite element analysis code. The finite element model contains both the building superstructure (i.e., reinforced concrete walls, slabs, and beams) and the foundation basemat. Analysis of the ESWB includes all applicable design loads and design load combinations described in Section 3.8.4.3. Figure 3.8-105—Essential Service Water Building Foundation Basemat Model illustrates the foundation basemat portion of the overall ESWB finite element model.

The GT STRUDL finite element model representing the ESWB foundation basemat consists of SBHQ6 rectangular elements, each with six degrees of freedom. This element type is capable of capturing both in-plane and out-of-plane behavior. Elastic boundary conditions are included in the finite element model in order to simulate the stiffness of the supporting soil. Basemat flexibility and SSI are addressed by inclusion of the basemat section properties and aforementioned soil spring boundary conditions in the finite element model. Illustrations of the complete finite element model representing the ESWB are provided in Section 3.7.2.

Detailed analysis and design procedures are described in the critical sections presented in Appendix 3E for the ESWBs.

3.8.5.4.5 Design Report

Design information and criteria for Seismic Category I structures are provided in Sections 2.0, 2.4, 2.5, 3.3, 3.5, 3.8.1, 3.8.2, 3.8.3, 3.8.4, and 3.8.5. Design results are presented in Appendix 3E for Seismic Category I structure critical sections.

3.8.5.5 Structural Acceptance Criteria

Limits for allowable stresses, strains, deformations, and other design criteria for Seismic Category I concrete foundations are in accordance with ACI 349-01 and its appendices, with the exception that the shear reduction factor of 0.85 is used as allowed in ACI 349-06 (GDC 1, GDC 2 and GDC 4). Limits for concrete design include the exceptions specified in RG 1.142. In addition, the portion of the NI Common Basemat Structure foundation basemat that supports the RCB is in accordance with the ASME BPV Code and RG 1.1.36 for containment loadings as described in Section 3.8.1.

Limits for the allowable stresses, strains, deformations, and other design criteria for structural steel elements of Seismic Category I foundations are in accordance with ANSI/AISC N690-1994 (R2004), including Supplement 2 (GDC 1, GDC 2 and GDC 4).

The design of Seismic Category I foundations is generally controlled by load combinations containing SSE seismic loads. Stresses and strains are within the ACI 349-01 limits, with the exceptions previously listed. Portions of the NI Common Basemat Structure foundation basemat that support the RCB are within the limits in accordance with ASME BPV Code, Section III, Division 2.

Seismic Category I foundations are required to satisfy the factors of safety against overturning, sliding, and flotation defined in Table 3.8-11. The calculated minimum factors of safety for the NI Common Basemat Structure are provided in Table 3.8-12 – Minimum Factors of Safety Against Overturning, Sliding, and Flotation for Foundations – NI Common Basemat Structure. For the load combination containing seismic loads, the calculated minimum factors of safety are less than the values provided in NUREG-0800, for overturning and sliding of the NI Common Basemat Structure. The acceptability of these calculated values is further addressed in the following section for the NI Common Basemat Structure foundation basemat.

Acceptance criteria for soil conditions for the media supporting Seismic Category I foundations are addressed in Section 2.5.

Acceptance criteria for settlement for Seismic Category I foundations are addressed in Section 2.5.

Additional acceptance criteria for critical areas of these structures are described in Appendix 3E.

A COL applicant that references the U.S. EPR design certification will evaluate site-specific methods for shear transfer between the foundation basemats and underlying soil for soil parameters that are not within the envelope specified in Section 2.5.4.2.

3.8.5.5.1 Nuclear Island Common Basemat Structure Foundation Basemat

Appendix 3E provides details of the design of the NI Common Basemat Structure foundation basemat critical areas.

Maximum soil bearing pressures under the NI Common Basemat Structure foundation basemat are 22,000 pounds per square foot for static loading conditions, and 25,000 pounds per square foot for dynamic loading conditions.

The NI Common Basemat Structure foundation basemat for the U.S. EPR plant design can accommodate tilt settlements up to 0.5 inches in 50 feet in any direction across the basemat, as described in Section 2.5.4.10.2. Differential settlements and local settlements within the perimeter of the foundation, are not likely to affect the structure, systems, or components due to the extremely thick foundation stiffened by numerous shear walls. The combined stiffness allows the NI Common Basemat Structure foundation basemat to bridge potential foundation irregularities.

For worst-case loading combinations on the NI Common Basemat Structure foundation basemat, the conservative methodology used to calculate sliding and uplift due to seismic loadings is described in Section 3.8.5.4.2. The calculated values, as provided in Table 3.8-16, are sufficiently small that they can be considered inconsequential with respect to sliding and overturning.

For worst-case loading combinations on the RB internal structures basemat above the containment liner, the minimum safety factor against sliding is 0.16 occurring for soil case 2sn4u, based solely on friction between the liner and the supporting concrete. Because friction will not prevent sliding, the surrounding concrete haunch wall is designed with sufficient capacity to resist the total base shear force. The minimum safety factor against overturning is 1.22 occurring for soil case 2sn4u.

3.8.5.5.2 Emergency Power Generating Buildings Foundation Basemats

Appendix 3E provides details of the design of the EPGB foundation basemats critical sections.

Evaluation of the EPGB foundation basemat for maximum bearing pressures under static and dynamic loading conditions, settlements, floatation, sliding, and overturning will be performed to confirm that applicable acceptance criteria are met.

3.8.5.5.3 Essential Service Water Building Foundation Basemats

Appendix 3E provides details of the design of the ESWB foundation basemats critical sections.

Evaluation of the ESWB foundation basemat for maximum bearing pressures under static and dynamic loading conditions, settlements, floatation, sliding, and overturning will be performed to confirm that applicable acceptance criteria are met.

3.8.5.6 Materials, Quality Control, and Special Construction Techniques

This section contains information relating to the materials, quality control programs and special construction techniques used in the fabrication and construction of Seismic Category I foundations.

3.8.5.6.1 Materials

Concrete, reinforcing steel, and structural steel materials for Seismic Category I foundations have been used in other nuclear facilities and are the same as described in Section 3.8.3.6 (GDC 1), except as follows:

- Materials for the portion of the foundation basemat that supports the RCB are the same as described in Section 3.8.1.6.
- Structural concrete used in the construction of Seismic Category I foundations has a minimum compressive strength of 4000 psi (f'_c) at 90 days.
- Epoxy coated reinforcing steel will be considered, on a site-specific basis, for use in foundations when groundwater may adversely affect the long-term durability of the concrete foundation. This may be waived if the groundwater level is below the foundation level due to either natural site conditions or provision of a site-specific permanent dewatering system. For epoxy coated reinforcing steel, the required splice length is increased in accordance with ACI 349-01 specifications.
- Use of waterproofing membrane, a textured geo-synthetic material, will be considered on a site-specific basis for use around foundations on sites with a high water table. Where this material is used under Seismic Category I foundations it will be embedded within the mud mat as shown in Figure 3.8-117—Geosynthetic Water Proofing Membrane.

The textured waterproofing membrane will provide adequate frictional characteristics, $\mu \geq 0.7$, at its interface with concrete. This characteristic will be demonstrated by vendor testing. The contact surface between the membrane and the concrete will be finished in accordance with manufacturer recommendations. The membrane is not a safety-related component as its failure would not result in core melt or a release of radioactivity to the environment.

A COL applicant that references the U.S. EPR design certification will evaluate and identify the need for the use of waterproofing membranes and epoxy coated rebar based on site-specific groundwater conditions.

3.8.5.6.2 Quality Control

Quality control procedures for Seismic Category I foundations are the same as described in Section 3.8.3.6 (GDC 1).

3.8.5.6.3 Special Construction Techniques

Seismic Category I foundations are constructed using proven methods common to heavy industrial construction. No special, new, or unique construction techniques are used.

Modular construction methods are used to the extent practical for prefabricating portions of reinforcing and concrete formwork. Such methods have been used extensively in the construction industry. Rigging is pre-engineered for heavy lifts of modular sections.

3.8.5.7 Testing and Inservice Inspection Requirements

Monitoring and maintenance of Seismic Category I foundations is performed in accordance with of RG 1.160 (GDC 1).

Additional testing and surveillance requirements for the portion of the foundation basemat that supports the RCB are the same as described in Section 3.8.1.7.2,

Physical access is provided to perform inservice inspections of exposed portions of Seismic Category I foundations.

A COL applicant that references the U.S. EPR design certification will identify if any site-specific settlement monitoring requirements for Seismic Category I foundations are required based on site-specific soil conditions.

A COL applicant that references the U.S. EPR design certification will describe the program to examine inaccessible portions of below-grade concrete structures for degradation and monitoring of groundwater chemistry.

3.8.6 References:

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27. ASTM C937-02, "Standard Specification for Grout Fluidifier for Preplaced Aggregate Concrete," American Society for Testing and Materials, 2002.

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Table 3.8-1—Thermal Properties for Heat Transfer Analysis-Reactor Containment Building

Material Property	Concrete	Steel
Thermal conductivity (kW/m*C)	0.0023	0.041
Specific heat (J/kg*C)	1000	434

Table 3.8-2—Material Properties – Reactor Containment Building

Material	Modulus of Elasticity (ksi)	Poisson Ratio	Nominal Strength (ksi)	Unit Weight (lb/ft^3)
Concrete	4,769	0.17	f'_c=7.0	150
Post Tensioning Cable	28,000	0.30	F_{pu} =270	490
Reinforcing Bar	29,000	0.30	F_y = 60	490

Table 3.8-3—Tendon Frictional Losses

Tendon	K (per foot) Wobble Loss	μ (per radian) Curvature Loss
Hoop	0.00050	0.18
Vertical	0.00025	0.16
Dome	0.00050	0.16

Table 3.8-4—Thermal Properties – Reactor Containment Building

Specific Heat (Btu/lbm*°F)	Thermal Conductivity (BTU/hr*ft*°F)	Film Coefficient (BTU/hr*ft^2*°F)	Thermal Diffusivity (ft^2/hr)
0.24	1.33	∞ (Inside Containment) 1.41 (Outside Containment)	0.037

Table 3.8-5—Tendon Losses and Effective Forces with Time

		Hoop Tendons				Vertical Tendons				Gamma Tendons			
		T = zero[1] (plant startup)		T = 60 years[1] (plant shutdown)		T = zero[1] (plant startup)		T = 60 years[1] (plant shutdown)		T = zero[1] (plant startup)		T = 60 years[1] (plant shutdown)	
Description		Value (ksi)	% loss	Value (ksi)	% loss	Value (ksi)	% loss	Value (ksi)	% loss	Value (ksi)	% loss	Value (ksi)	% loss
Tension at lock off	$f_{p\text{-}ini}$	197.10	N/A	197.10	N/A	197.10	N/A	197.10	N/A	197.10	N/A	197.10	N/A
Loss due to friction	$\Delta f_{p\text{-}fr}$	-49.38	-25.1%	-49.38	-25.1%	-9.66	-4.9%	-9.66	-4.9%	-43.81	-22.2%	-43.81	-22.2%
Loss due to elastic shortening	$\Delta f_{p\text{-}es}$	-6.50	-3.3%	-6.50	-3.3%	-3.17	-1.6%	-3.17	-1.6%	-4.57	-2.3%	-4.57	-2.3%
Loss due to creep	$\Delta f_{p\text{-}cr}$	-13.44	-6.5%	-19.88	-10.1%	-7.28	-3.7%	-10.92	-5.5%	-12.72	-6.5%	-18.22	-9.2%
Loss due to shrinkage	$\Delta f_{p\text{-}sh}$	-3.36	1.7%	-11.20	-5.7%	-3.36	-1.7%	-11.20	-5.7%	-3.65	1.9%	-11.77	-6.0%
Loss due to steel relaxation	$\Delta f_{p\text{-}sr}$	-7.88	-4.0%	-9.86	-5.0%	-7.88	-4.0%	-9.86	-5.0%	-7.88	-4.0%	-9.86	-5.0%
Sum of all losses	$\Sigma\Delta f_p$	-80.56	-40.9%	-96.82	-49.2%	-31.35	-15.9%	-44.81	-22.7%	-72.63	-36.9%	-88.23	-44.7%
Effective Post Tension	$f_{p\text{-}eff}$	116.54	59.1%	100.28	50.8%	165.75	84.1%	-152.29	77.3%	124.47	63.1%	108.87	55.3%

Note:

1. To account for the length of the construction period and the relative ages of the RCB wall, dome and tendons, the tendon losses above assumed that at "T=zero (plant startup)," the age of the tendons is 4.0 years, the age of the RCB dome is 4.1 years, and the age of the RCB wall is 5.0 years.

Table 3.8-6—Containment Ultimate Pressure Capacity

Section Evaluated	Pressure Capability (psig)		Failure Mode/Limiting Condition
	72°F[1]	395°F[2]	
Cylinder (Hoop)	277	260	Membrane Failure. 0.8% strain away from discontinuities
Dome	201	189	Membrane Failure. 0.8% strain away from discontinuities
Dome Ring	199	187	Membrane and Flexural Failure
Base of Cylinder Wall (Gusset)	302	284	Flexural Failure (Concrete Compression)
Reinforcing around Equipment Hatch Opening (Vertical Section Critical)	241	227	Flexural Failure
Equipment Hatch Cover	-	119	ASME Service Level C Limit.

Notes:

1. Average Normal Operating Temperature.
2. Maximum Design Basis Temperature.

Table 3.8-7—ISI Schedule for the U.S. EPR

	Test Pressure	
Year	**U.S. EPR ISI**	**RG 1.90**
0	1.15*P_d and P_a	1.15*P_d
1	P_a	P_N
3	P_a	1.15*P_d
7	P_a	1.15*P_d
Thereafter	P_a	P_a

Notes:

1. At year 0, the baseline measurements will be taken following the SIT, at a test pressure of P_a.

   P_N – Normal operating pressure or zero.

   P_d – Containment design pressure.

   Pa – Maximum calculated DBA pressure.

Table 3.8-8—Materials for Structural Steel Shapes and Plates
Sheet 1 of 2

ASTM Designation	Minimum F_y	Minimum F_u
A36	36 ksi	58 to 80 ksi
A53 (Type E or S) (Gr. B)	35 ksi	60 ksi
A106		
Grade A	30 ksi	48 ksi
Grade B	35 ksi	60 ksi
Grade C	40 ksi	70 ksi
A167	27 to 39 ksi	73 to 94 ksi
A240		
Austenitic	25 to 70 ksi	70 to 125 ksi
Duplex	58 to 80 ksi	87 to 116 ksi
Ferritic or Martensitic	25 to 90 ksi	55 to 115 ksi
A242	42 to 50 ksi	63 to 70 ksi
A276		
Austenitic	25 to 125 ksi	70 to 145 ksi
Austenitic-ferritic	65 to 105 ksi	90 to 125 ksi
Ferritic	30 to 60 ksi	60 to 75 ksi
Martensitic	30 to 100 ksi	60 to 125 ksi
A312	25 to 62 ksi	70 to 115 ksi
A333		
Grades 3, 7	35 ksi	65 ksi
Grades 4, 6	35 ksi	60 ksi
A441	40 to 50 ksi	60 to 70 ksi
A479		
Austenitic	25 to 125 ksi	70 to 145 ksi
Austenitic-ferritic	65 to 85 ksi	90 to 118 ksi
Ferritic	25 to 55 ksi	60 to 70 ksi
A276 (Martensitic)	40 to 100 ksi	70 to 130 ksi
A500 (round)		
Grade A	33 ksi	45 ksi
Grade B	42 ksi	58 ksi
Grade C	46 ksi	62 ksi
Grade D	36 ksi	58 ksi
A500 (square & rectangular)		
Grade A	39 ksi	45 ksi
Grade B	46 ksi	58 ksi
Grade C	50 ksi	62 ksi
Grade D	36 ksi	58 ksi

Table 3.8-8—Materials for Structural Steel Shapes and Plates
Sheet 2 of 2

ASTM Designation	Minimum F_y	Minimum F_u
A501	36 ksi	58 ksi
A514	90 to 100 ksi	100 to 130 ksi
A515	32 to 38 ksi	60 to 90 ksi
A516	30 to 38 ksi	55 to 90 ksi
A537	40 to 60 ksi	65 to 100 ksi
A570	30 to 55 ksi	49 to 70 ksi
A572	42 to 65 ksi	60 to 80 ksi
A588	42 to 50 ksi	63 to 70 ksi
A607 Class I Class II	 45 to 70 ksi 45 to 70 ksi	 60 to 85 ksi 55 to 80 ksi
A618 Grade Ia, Ib & II Grade III	 46 to 50 ksi 50 ksi	 67 to 70 ksi 65 ksi
A633 (Grades A, C, & D)	42 to 60 ksi	63 to 100 ksi
A709	36 to 50 ksi	58 to 80 ksi
A913	50 to 70 ksi	65 to 90 ksi
A992	50 to 65 ksi	65 ksi

Table 3.8-9—Structural Bolting Materials

ASTM Designation	Minimum F_y (ksi)	Minimum F_u (ksi)
A193		
Grade B5	80 ksi	100 ksi
Grade B6	85 ksi	110 ksi
Grade B6X	70 ksi	90 ksi
Grade B7	75 to 105 ksi	100 to 125 ksi
Grade B7M	75 to 80 ksi	100 ksi
Grade B16	85 to 105 ksi	100 to 125 ksi
A307		
Grade A	-	60 ksi
Grade B	-	60 to 100 ksi
Grade C	36 ksi	58 to 80 ksi
A320		
Class 1 & 1A	30 ksi	75 ksi
Class 2	50 to 100 ksi	90 to 125 ksi
Grade L7M	80 ksi	100 ksi
Other grades	105 ksi	125 ksi
A325	81 to 92 ksi	105 to 120 ksi
A354		
Grade BC	99 to 109 ksi	115 to 125 ksi
Grade BD	115 to 130 ksi	140 to 150 ksi
A449	58 to 92 ksi	90 to 120 ksi
A490	130 ksi	150 to 170 ksi
A540		
Grade B21	100 to 150 ksi	115 to 165 ksi
Grade B22	100 to 150 ksi	115 to 165 ksi
Grade B23	100 to 150 ksi	115 to 165 ksi
Grade B24	100 to 150 ksi	115 to 165 ksi
Grade B24V	130 to 150 ksi	145 to 165 ksi
A564		
Type 630	75 to 170 ksi	115 to 190 ksi
Type 631	140 to 150 ksi	170 to 185 ksi
Type 632	160 to 175 ksi	180 to 200 ksi
Type 634	155 ksi	170 ksi
Type 635	150 to 170 ksi	170 to 190 ksi
Type XM-12	75 to 170 ksi	115 to 190 ksi
Type XM-13	85 to 205 ksi	125 to 220 ksi
Type XM-16	185 to 220 ksi	205 to 235 ksi
Type S45503	185 to 220 ksi	205 to 235 ksi
Type XM-25	75 to 170 ksi	125 to 180 ksi

Table 3.8-10—Structural Bolting Nut and Washer Materials

Item	ASTM Designation
Nuts	A194 (all grades) A563 (all grades) F1852
Washers	F436

Note:

1. Use of A563 nuts conforms to Appendix X1 of ASTM A563, which provides guidance on the suitability of A563 nuts for specific bolting materials.

Table 3.8-11—Minimum Required Factors of Safety Against Overturning, Sliding, and Flotation for Foundations

Load Combination	Minimum Factors of Safety		
	Overturning	Sliding	Flotation
D + H + W	1.5	1.5	-
D + H + Wt	1.1	1.1	-
D + H + E’	1.1	1.1	-
D + Fb	-	-	1.1

Table 3.8-12—Minimum Factors of Safety Against Overturning, Sliding, and Flotation for Foundations – NI Common Basemat Structure

Load Combination	Minimum Factors of Safety		
	Overturning	Sliding	Flotation
D + H + W	261 (E-W) 492 (N-S)	25.0 (E-W) 72.5 (N-S)	-
D + H + Wt	216 (E-W) 274 (N-S)	24.1 (E-W) 66.5 (N-S)	-
D + H + E’	See 3.8.5.4.2	See 3.8.5.4.2	-
D + Fb	-	-	4.9

Table 3.8-13—Static Spring Distribution

Label	Soil Case	Recommended Springs and Distribution		Min/Max Spring
		K_o (k/ft^3)	Distribution (b = I = ~52.4m)	
Cc	1u	11.2	$K(x,y)=K_o\,[4.07 - 3.50*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.57\ K_o$, $1.99\ K_o$
F	2u	62.0	$K(x,y)=K_o\,[3.74 - 3.12*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.62\ K_o$, $1.88\ K_o$
I	1n2u	55.8	$K(x,y)=K_o\,[3.74 - 3.12*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.62\ K_o$, $1.88\ K_o$
Jj	3u	166	$K(x,y)=K_o\,[3.41 - 2.74*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.67\ K_o$, $1.78\ K_o$
K	4u	390	$K(x,y)=K_o\,[3.12 - 2.42*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.70\ K_o$, $1.68\ K_o$
L	5a	5190	$K(x,y)=K_o\,[2.01 - 1.15*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.86\ K_o$, $1.33\ K_o$
LI	5u	721	$K(x,y)=K_o\,[2.58 - 1.80*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.78\ K_o$, $1.51\ K_o$
N	2sn4u	260	$K(x,y)=K_o\,[3.33 - 2.65*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.68\ K_o$, $1.75\ K_o$
O	2n3u	166	$K(x,y)=K_o\,[3.46 - 2.80*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.66\ K_o$, $1.79\ K_o$
P	3r3u	194	$K(x,y)=K_o\,[3.41 - 2.75*\mathrm{sqrt}(1 - x^2/2I^2 - y^2/2b^2)]$	$0.66\ K_o$, $1.77\ K_o$

Table 3.8-14—Tri-Linear Subgrade Modulus vs. Bearing Pressures

Soil Case	Bearing Pressure (ksf)	Subgrade Modulus (kcf)
4u	0.0 - 95	390
	95 - 375	224
	>375	116
2sn4u	0 - 65	260
	65 - 255	164
	>255	78

Table 3.8-15—Fundamental Mode Frequencies for Dynamic Model Tuning

Soil Case	Concentrated Springs & Stick Model (Equivalent to SASSI Analysis)			Non-Linear Dynamic Model (Distributed Springs under Shell)			Non-Linear Dynamic Model (Solid elements under Shell)		
	Fx (Hz)	Fy (Hz)	Fz (Hz)	Fx (Hz)	Fy (Hz)	Fz (Hz)	Fx (Hz)	Fy (Hz)	Fz (Hz)
2n3u	2.18	2.09	3.84	2.24	2.28	3.82	2.13	2.18	3.81
2u	1.38	1.32	2.41	1.42	1.45	2.40	1.38	1.41	2.41
2sn4u	2.75	2.66	5.15	2.80	2.83	5.17	2.70	2.73	5.17
4u	3.12	3.02	5.84	3.16	3.17	5.91	3.18	3.17	6.15
5a	4.14	3.98	8.91	4.15	3.99	9.12	4.04	3.90	8.99

Table 3.8-16—Dynamic Analysis Results

Soil Case Name	Maximum Bearing Pressure		Maximum Sliding-X		Maximum Sliding-Y		Maximum Uplift-Z	
	Bearing Pressure	Time	Sliding -X-East-West	Time	Sliding -Y-North-South	Time	Uplift -Z	Time
	ksf	sec	inch	sec	inch	sec	inch	sec
5a	18	7.64	0.0011	4.82	0.0011	5.975	-0.0004	4.18
4u	22	9.035	0.0201	12.055	0.0189	4.85	0.0497	1.775
2u	19	11.59	0.0174	7.7	0.0118	5.83	0.0175	4.325
2n3u	23	4.935	0.0314	12.92	0.0195	7.665	0.1992	9.14
2sn4u	25	1.84	0.0586	5.32	0.0390	5.385	0.2191	1.815
1u	16	10.45	0.0073	9.75	0.0057	7.03	-0.0031	2.48