Overview of Structural Analysis and Design for the APR1400

A. Reactor Containment Building

B. Auxiliary Building &
Emergency Diesel Generator Building Block

C. Foundations

D. Summary

A. Reactor Containment Building

1. Introduction
2. Regulatory Requirements
3. Codes and Standards
4. Loads and Load Combinations
5. Analysis
6. Design

A-1. Introduction

- The purpose of this presentation is to present an overview of the analysis and design of the APR1400 seismic Category I structures.

1) RCB Configuration

TS

2) Code Jurisdictional Boundary

TS

3) Description of Structures

- Classification of structures

Structure	Safety Class	Seismic Category
Reactor Containment Building - Shell and Dome - Basemat	SC-2	I
Reactor Containment Buildin - Internal Structures	SC-3	I

A-2. Regulatory Requirements

1) Regulatory Requirements

- **10 CFR Part 50 :** Domestic Licensing of Production and Utilization Facilities
- **10 CFR Part 50.34 :** Contents of Applications; Technical Information.
- **RG 1.35(Rev.3):** Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containment
- **RG 1.35.1:** Determining Prestressing Forces for Inspection of Prestressed Concrete Containments
- **RG 1.136(Rev.3):** Design Limits, Loading Combinations, Materials, Construction, and Testing of Concrete Containments
- **RG 1.142(Rev.2):** Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments)

1) Regulatory Requirements (Cont'd)

- **RG 1.199:** Anchoring Components and Structural Supports in Concrete
- **RG 1.216:** Containment Structural Integrity Evaluation for Internal Pressure Loadings Above Design Basis Pressure
- **NUREG/CR-6906 :** Containment Integrity Research at Sandia National Laboratories-An Overview
- **SECY-90-016:** Evolutionary Light-Water Reactor (LWR) Certification Issues and their Relationship to Current Regulatory Requirements

A-3. Codes and Standards

1) Codes and Standards

- **ASME Section III, Division 2, Subsection CC:** Code for Concrete Containments, ASME, 2001 Edition with the 2003 Addenda
- **ASME Section III, Subsection NE:** Class MC Components, ASME, the 2007 Edition with the 2008 Addenda
- **ACI 349:** Code Requirements for Nuclear Safety-Related Concrete Structures, ACI, 1997, including Appendix B (2001)
- **ANSI/AISC N690:** Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, including Supplement 2(2004), ANSI/AISC, 1994
- **ASTM A615:** Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement, ASTM, 2006
- **ASTM A416:** Standard Specification for Steel Strand, Uncoated Seven-Wire for Prestressed Concrete, ASTM, 2002

A-4. Loads and Load Combinations

1) Loads
2) Load Combinations

1) Loads

- **Construction Loads**
- **Test Loads**
  - ✓ Pressure Load (P_t) : P_{design} x1.15
- **Normal Loads**
  - ✓ Dead Load (D)
  - ✓ Live Load (L)
  - ✓ Thermal Load (T_o)
  - ✓ Pre-stress Load (F)
  - ✓ Pressure Load (P_v)

ASME Boundary Only.

Loads for Internal Structures and Steel Structures are described in the AB structure overview.

1) Loads (Cont'd)

- **Abnormal Loads**
  - ✓ Accident Pressure (P_a) and Temperature (T_a)
  - ✓ Pipe Break Reactions (Y_r)
  - ✓ Jet Impingement Load (Y_j)
  - ✓ Missile Impact Load (Y_m)
  - ✓ Flooding Load (Y_f)
  - ✓ Miscellaneous Abnormal Load (M_a)

1) Loads (Cont'd)

- **Severe Environmental Loads**
  - ✓ Wind Loads (W)
- **Extreme Environmental Loads**
  - ✓ Safe Shutdown Earthquake (E_s)
  - ✓ Tornado or Hurricane Load (W_t)

2) Load Combinations

Seismic Category I Structure Containment Loading Combination Table

CATEGORY	LOADING CONDITION	NO.	D[2]	L[1]	F	P_t	G	P_a	T_t	T_o	T_a	E_s	W	W_t	R_o	R_a	Y_r	Y_j	Y_m	Y_f	H	H_s	P_v	H_a	Ps
SERVICE	TEST	1	1.0	1.0	1.0	1.0	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CONSTRUCTION	2	1.0	1.0	1.0	-	-	-	-	1.0	-	-	1.0		-	-	-	-	-	-	-	-	-	-	-
	NORMAL	3	1.0	1.0	1.0	-	1.0	-	-	1.0	-	-	-	-	1.0	-	-	-	-	-	-	-	1.0	-	-
FACTORED	SEVERE ENVIRONMENTAL	4	1.0	1.3	1.0	-	1.0	-	-	1.0	-	-	1.5		1.0	-	-	-	-	-	-	-	1.0	-	-
		5	1.0	1.3	1.0	-	1.0	-	-	1.0	-	-	-	-	1.0	-	-	-	-	-	1.5	-	1.0	-	-
	EXTREME ENVIRONMENTAL	6	1.0	1.0	1.0	-	1.0	-	-	1.0	-	1.0	-	-	1.0	-	-	-	-	-	-	-	1.0	-	-
		7	1.0	1.0	1.0	-	1.0	-	-	1.0	-	-	-	1.0	1.0	-	-	-	-	-	-	-	1.0	-	-
		8	1.0	1.0	1.0	-	1.0	-	-	1.0	-	-	-	-	1.0	-	-	-	-	-	-	1.0	1.0	-	-
	ABNORMAL	9	1.0	1.0	1.0	-	1.0	1.5	-	-	1.0	-	-	-	-	1.0	-	-	-	-	-	-	-	-	-
		10	1.0	1.0	1.0	-	1.0	1.0	-	-	1.0	-	-	-	-	1.25	-	-	-	-	-	-	-	-	-
		11	1.0	1.0	1.0	-	1.25	1.25	-	-	1.0	-	-	-	-	1.0	-	-	-	-	-	-	-	-	-
	ABNORMAL / SEVERE ENVIRONMENTAL	12	1.0	1.0	1.0	-	1.0	1.25	-	-	1.0	-	1.25	-	-	1.0	-	-	-	-	-	-	-	-	-
		13	1.0	1.0	1.0	-	1.0	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	-
		14	1.0	1.0	1.0	-	1.0	-	-	1.0	-	-	1.0	-	-	-	-	-	-	-	-	-	-	1.0	-
	ABNORMAL / EXTREME ENVIRONMENTAL	15	1.0	1.0	1.0	-	1.0	1.0	-	-	1.0	1.0	-	-	-	1.0	1.0	1.0	1.0	1.0	-	-	-	-	-
	SEVERE ACCIDENT[3]	16	1.0	-	1.0	-	-	-	-	-	-	-			-	-	-	-	-	-	-	-	-	-	1.0

Note : 1. D_d is included in D.

2. Includes all temporary construction loading during and after construction of the containment, also includes L_h and C.

3. The strain shall not exceed the values given in ASME SECTION Ⅲ, Division 2, Table CC-3720-1.

A-5. Analysis

1) Containment Structure
2) Internal Structure
3) Severe Accident & UPC

1) Containment Structure

- The 3-dimensional Finite Element models (ANSYS V.14) are developed to perform the structural analysis of the containment structure. In the FE model of the containment structure, the element types are as follows:

TS

Non-Proprietary

1) Containment Structure (Cont'd)

- Global Structural Analysis

  This analysis is performed to compute all member force of the containment structure.

TS

2) Internal Structure

- The 3- dimensional FE models are developed to perform the structural analysis of the internal structure. In the FE model of the internal structure, the element types are as follows:

TS

2) Internal Structure (Cont'd)

- Global Structural Analysis

  This analysis is performed to compute all member forces of the internal structure.

TS

2) Internal Structure (Cont'd)

- Accidental Torsion
  - Accidental torsional moment : story inertia force X 5% of the building plan dimension
  - Accidental torsional moments are applied at the mass center of the each floor elevation.

TS

3) Severe Accident & UPC

- **Ultimate Pressure Capacity (UPC)**

  The purpose of this evaluation is **to assess the pressure capacity of the containment** at which the structural integrity is retained, and a failure leading to a significant release of fission products does not occur.

- **Severe Accident Capacity**

  The purpose of this evaluation is **to assess the capability of the concrete containment under severe accident loads. (ASME service level C limits)**

3) Severe Accident & UPC (Cont'd)

- **Basic Configuration**
  - Post-tensioned cylindrical concrete shell and hemispherical dome

TS

3) Severe Accident & UPC (Cont'd)

- 3D Finite Element Model (Full Model)

TS

3) Severe Accident & UPC (Cont'd)

- **Material - Concrete**

Material Properties	Wall & Dome	Basemat
Compressive Strength	6000 psi (5600 psi at 290 °F)	5000 psi (4660 psi at 290 °F)
Splitting Tensile Strength	600 psi (560 psi at 290 °F)	500 psi (466 psi at 290 °F)
Elastic Modulus	4415.2 ksi (4265.0 ksi at 290°F)	4030.5 ksi (3893.4 ksi at 290°F)
Poisson's Ratio	0.17	
Unit Weight	145 pcf	

TS

[ ]

3) Severe Accident & UPC (Cont'd)

- **Material - Liner Plate, Reinforcing Bars, and Tendons**

Material Properties	Liner Plate ASME SA-516, Gr. 60	Reinforcing Bars ASTM A615, Gr. 60	Tendon ASTM A416, Gr. 270
Yield Strength	32 ksi	60 ksi	240 ksi
Tensile Strength	60 ksi	90 ksi	270 ksi
Elastic Modulus	29,000 ksi	29,000 ksi	28,000 ksi
Poisson's Ratio	0.3		
Unit Weight	490 pcf		

TS

3) Severe Accident & UPC (Cont'd)

- **Load Combination**
  - Ultimate Pressure Capacity
    - $1.0D + 1.0F + 1.0T_a + 1.0P_a$

TS

3) Severe Accident & UPC (Cont'd)

- **Load Combination**
  - Ultimate Pressure Capacity
    - 1.0D + 1.0F+ **$1.0T_a$ + $1.0P_a$**

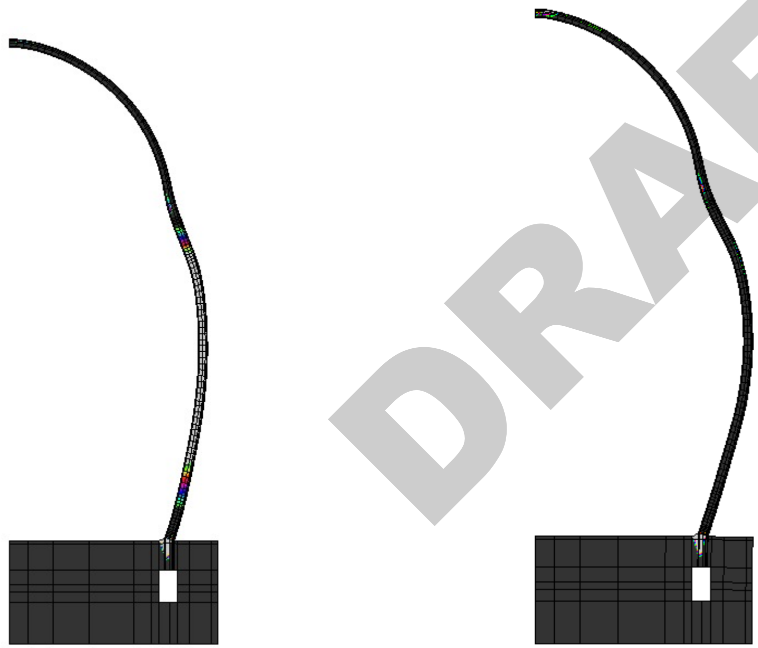
TS

3) Severe Accident & UPC (Cont'd)

- **Load Combination**

  ▪ Ultimate Pressure Capacity

    - 1.0D + 1.0F+ **$1.0T_a$ + $1.0P_a$**



(a) Pressure Only (b) Pressure & Temperature

Pressure & Heat Stress Analysis Results (1.46 MPa)

∗Temperature Effect

Temperature does not affect the ultimate pressure capacity (UPC) of the containment building if the value is less than 200 °C (392 °F)

Non-Proprietary

3) Severe Accident & UPC (Cont'd)

- **Load Combination**

  - Ultimate Pressure Capacity
    - $1.0D + 1.0F + 1.0T_a + 1.0P_a$

➤ Initial Prestress Load : Initial losses from the prestress just after stressing
: Slip at anchorages, friction, elastic shortening of concrete

➤ Final Prestress Load : Time-dependent losses from the initial prestress load
: Concrete shrinkage, creep, tendon relaxation

TS

3) Severe Accident & UPC (Cont'd)

- **Failure Criteria of UPC (RG 1.216, SRP 3.8.1)**

  - **A total tensile average strain in tendons away from discontinuities** (e.g., hoop tendons in cylinder) **of 0.8 percent**, which includes the strains in the tendons before pressurization (typically about 0.4 percent) and the additional straining from pressurization

  - **A global free-field strain for the other materials** that contribute to resist the internal pressure (i.e., liner, if considered, and rebars) **of 0.4 percent**

  - **Additional failure modes**, such as concrete shear and concrete crushing which may occur **near discontinuities**, to allow the determination of the controlling containment failure mode.

3) Severe Accident & UPC (Cont'd)

- **Analysis Results - UPC**

TS

3) Severe Accident & UPC (Cont'd)

- **Loading Condition – Severe Accident (SA)**
  – The requirements of sub-article CC-3720 of the ASME Code shall be met for the following loading conditions.

▪ Factored Load Category

- ① Dead Load + P_{g1} + P_{g2}
- ② Dead Load + P_{g1} + P_{g3}

▪ Service Load Category

- ① Dead Load + P_{g3}

P_{g1}= Pressure resulting from an accident that releases hydrogen generated from 100% fuel clad metal-water reaction

P_{g2}= Pressure resulting from uncontrolled hydrogen burning

P_{g3}= Pressure resulting from post-accident inerting assuming carbon dioxide is the inerting agent

3) Severe Accident & UPC (Cont'd)

- **Acceptance Criteria of S.A. (Leak-tightness Criteria)**
  - RG 1.216
  - **ASME CC-3720 (Factored Category)**

Liner Strain	Global (Membrane)	Local (Membrane + Bending)
Compression	0.005	0.014
Tension	0.003	0.010

- For performance assessment of containment structure, factored load category concept was introduced **to consider uncertainty which might arise during evaluation**.

TS

Non-Proprietary

3) Severe Accident & UPC (Cont'd)

- **Analysis Results – S.A.**

TS

A-6. Design

1) Characteristics of RCB
2) Shell Design
3) Liner Plate
4) Leak Chase System
5) Post Tensioning System

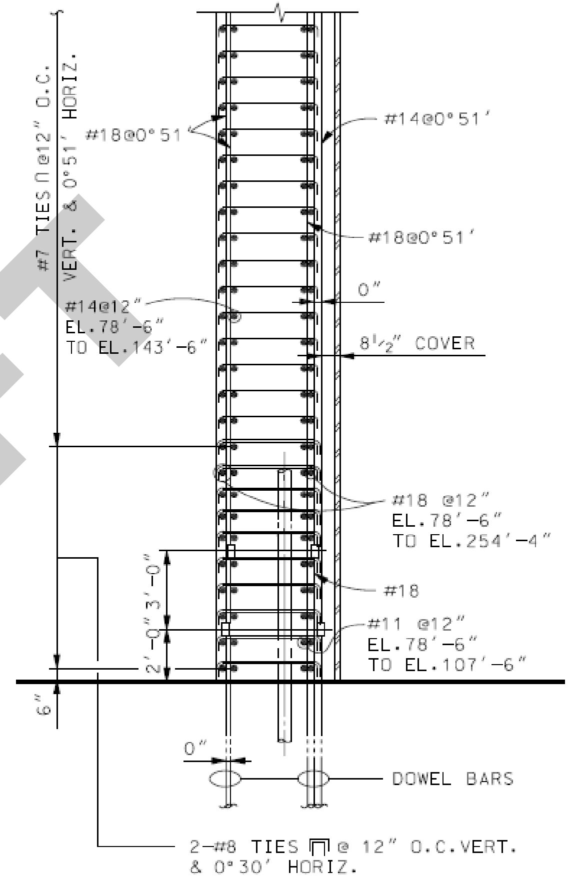
Non-Proprietary

1) Characteristics of RCB

TS

2) Shell Design

SKN 3&4 RCB Shell Wall
Construction Sample

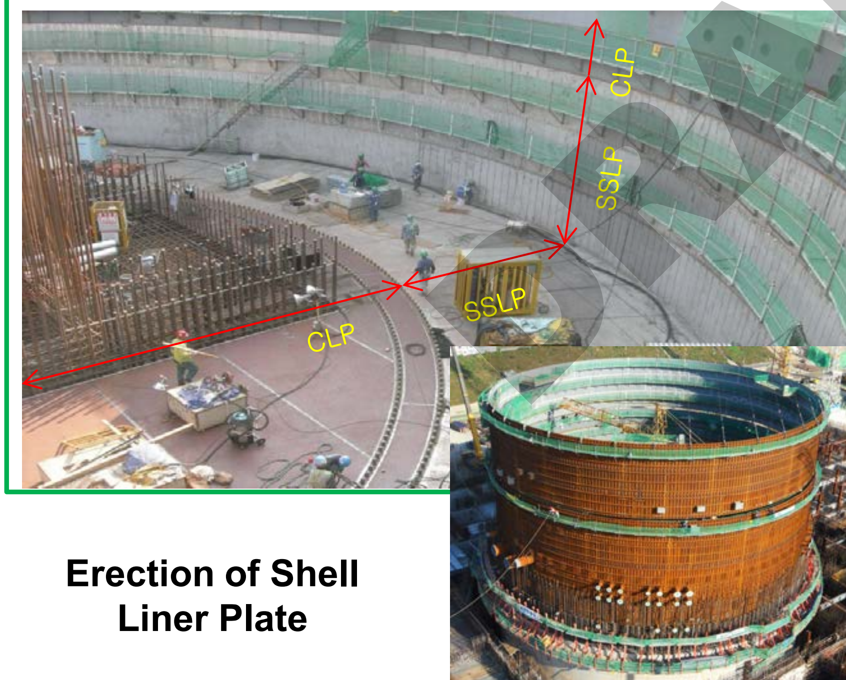


Rebar Arrangement of
Wall-Basemat Junction Area

3) Liner Plate

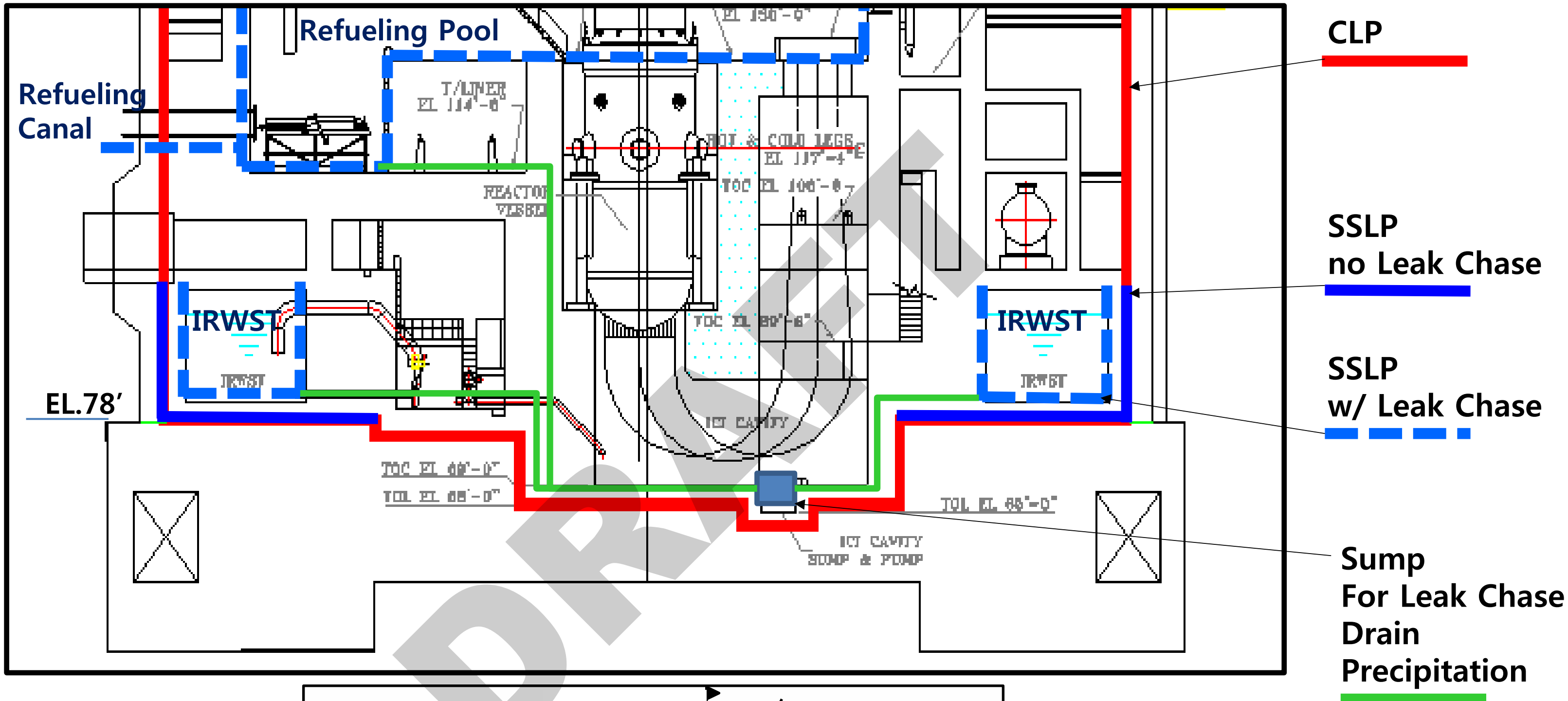
- Leak tightness for radiation in containment building
- Formwork as concrete pouring in containment wall
- 1/4" carbon steel liner plate(CLP) or stainless steel liner plate(SSLP)

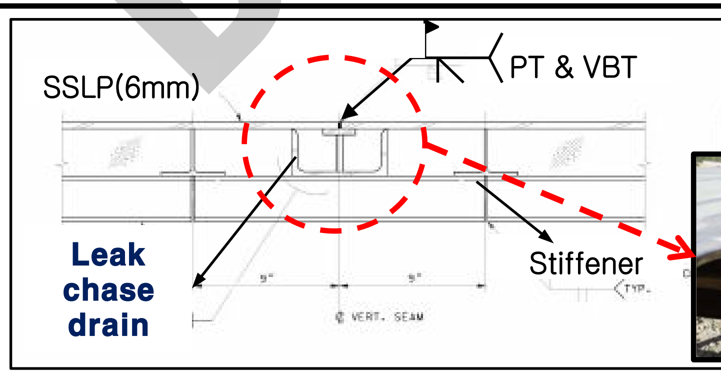
TS



Erection of Shell Liner Plate

4) Leak Chase System



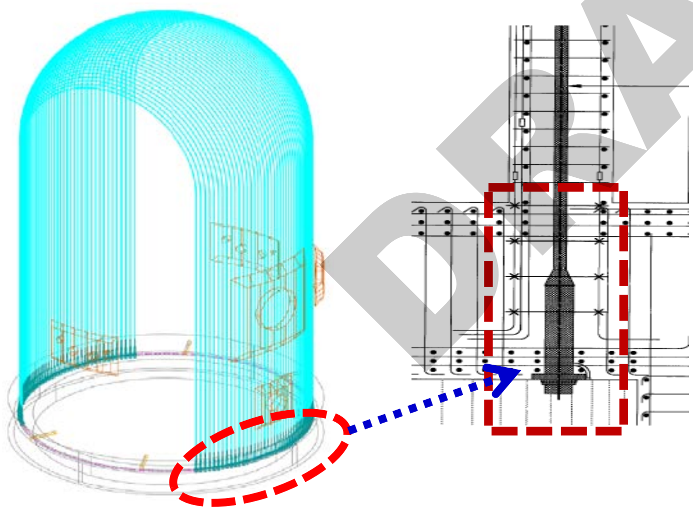


SSLP General Welding detail

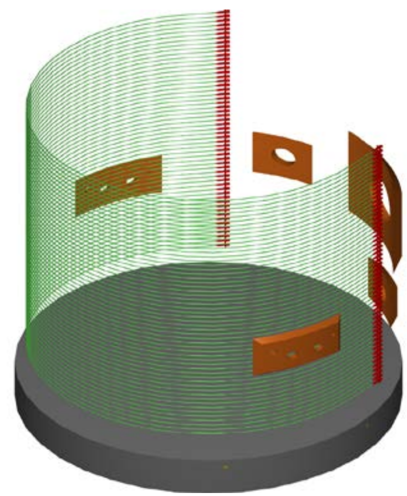
5) Post Tensioning System

- Post Tensioning System **(VSL E6-42)**
  - ✓ Orthogonally crossed at the top of the dome
  - ✓ 42 multi-strand system that uses wedge anchors
  - ✓ Unbonded type

Anchorage



Tendon Gallery



Hoop Tendon Model
(Loop#1)

B. Auxiliary Building (AB) & Emergency Diesel Generator (EDG) Building Block

1. Configuration
2. Regulatory Requirements
3. Codes and Standards
4. Loads and Load Combinations
5. Analysis
6. Design

B-1. Configuration

1) AB Configuration

TS

1) AB Configuration (Cont'd)

TS

2) EDG Building Configuration

TS

Non-Proprietary

3) Description of Structures

- Emergency diesel generator (EDG) building block consists of:
  - ✓ EDG building (EDGB)
  - ✓ Diesel Fuel Oil Tank (DFOT)

- Classification of structures

Structure	Safety Class	Seismic Category
Auxiliary Building	SC-3	I
EDG Building Block	SC-3	I

B-2. Regulatory Requirements

1) Regulatory Requirements

- **10 CFR 50 Appendix A :** General Design Criteria for Nuclear Power Plants
  - ✓ **Criterion 2** - Design Bases for Protection Against Natural Phenomena
  - ✓ **Criterion 4** - Environmental and Dynamic Effects Design Bases
- **RG 1.76(Rev.1):** Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants
- **RG 1.142(Rev.2):** Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments)

1) Regulatory Requirements

- **RG 1.143 (Rev.2):** Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants

- **RG 1.199:** Anchoring Components and Structural Supports in Concrete

- **RG 1.221:** Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants

B-3. Codes and Standards

1) Codes and Standards

- **ACI 349:** Code Requirements for Nuclear Safety-Related Concrete Structures, ACI, 1997, including Appendix B (2001)
- **ANSI/AISC N690:** Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities, ANSI/AISC, 1994, including Supplement 2(2004)
- **ASCE 4:** Seismic Analysis of Safety-Related Nuclear Structures and Commentary, ASCE, 1998
- **ASCE 7:** Minimum Design Loads for Buildings and Other Structures, ASCE, 2005
- **ACI 315:** Details and Detailing of Concrete Reinforcement, ACI, 1999
- **ACI 347:** Guide to Formwork for Concrete, ACI, 2004

B-4. Loads and Load Combinations

1) Loads

2) Load Combinations

1) Loads

- **Normal Loads**
  - ✓ Dead Loads (D)
  - ✓ Live Loads (L)
  - ✓ Thermal Operating Loads (T_o)
  - ✓ Pipe, Cable Tray, Duct Supports, and Ties (R_o)
  - ✓ Crane and Trolley Loads (C)
  - ✓ Operating Pressure (P_o)
  - ✓ Miscellaneous Normal Loads (M_o)
  - ✓ Construction Loads

1) Loads (Cont'd)

- **Abnormal Loads**
  - ✓ Accident Pressure (P_a) and Temperature (T_a)
  - ✓ Accident Reactions of Pipe, Cable Tray and Duct Support and Ties (R_a)
  - ✓ Pipe Break Reactions (Y_r)
  - ✓ Jet Impingement Load (Y_j)
  - ✓ Missile Impact Load (Y_m)
  - ✓ Flooding Load (Y_f)
  - ✓ Miscellaneous Abnormal Load (M_a)

1) Loads (Cont'd)

- **Severe Environmental Loads**
  - ✓ Wind Loads (W)
  - ✓ Design Flood/Precipitation (H)
- **Extreme Environmental Loads**
  - ✓ Safe Shutdown Earthquake (E_s)
  - ✓ Tornado or Hurricane Load (W_t)
  - ✓ Probable Maximum Flood/Precipitation (H_s)

2) Load Combinations

Seismic Category I Structures Excluding Containment Structure
Reinforced Concrete – Ultimate Strength Design Load Combination Table

Loading Condition	No	Loads																						Design Strength
		Normal									Severe Environmental		Abnormal									Extreme Environmental		
		$D^{(1)}$	D_d	L	L_h	T_o	R_o	C	P_o	M_o	W	H	P_a	T_a	R_a	Y_r	Y_j	Y_m	Y_f	M_m	E_s	W_t	H_s	
Construction	1	1.1	-	1.3	1.1	-	1.3	1.3	-	1.3	1.6	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
	2	-	0.9	-	1.1	-	-	1.3	-	1.3	1.6	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
Test	3	1.1	-	1.3	1.1	1.2	1.3	1.3	1.3	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
Normal	4	1.4	-	1.7	1.4	-	1.7	1.7	1.7	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
	5	1.1	-	1.3	1.1	1.2	1.3	1.3	1.3	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
Severe Environmental	6	1.4	-	1.7	1.4	-	1.7	1.7	1.7	1.7	1.7	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
	7	1.1	-	1.3	1.1	1.2	1.3	1.3	1.3	1.3	1.3	-	-	-	-	-	-	-	-	-	-	-	-	ACI349
	8	1.4	-	1.7	1.4	-	1.7	1.7	1.7	1.7	-	1.7	-	-	-	-	-	-	-	-	-	-	-	ACI349
	9	1.1	-	1.3	1.1	1.2	1.3	1.3	1.3	1.3	-	1.3	-	-	-	-	-	-	-	-	-	-	-	ACI349
Abnormal	10	1.0	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	-	-	-	-	-	-	-	-	1.0	-	-	-	ACI349
	11	1.0	-	1.0	1.0	-	-	1.0	-	1.0	-	-	1.4	1.0	1.0	-	-	-	-	-	-	-	-	ACI349
Extreme Environmental	12	1.0	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	-	-	-	-	-	-	-	-	-	1.0	-	-	ACI349
	13	1.0	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	-	-	-	-	-	-	-	-	-	-	1.0	-	ACI349
	14	1.0	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	-	-	-	-	-	-	-	-	-	-	-	1.0	ACI349
Abnormal/ Extreme Environmental	15	1.0	-	1.0	1.0	-	-	1.0	-	1.0	-	-	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	1.0	-	-	ACI349

(1) Where a load occurs simultaneously with and reduces effects of other loads, the load factor is taken as 0.9; otherwise, the load factor is taken as zero.

(2) Hydrodynamic loads associated with seismic loads are included in E_s.

B-5. Analysis

1) Auxiliary Building
2) EDG Building Block

1) Auxiliary Building (AB)

- The 3-dimensional FE models are developed to perform the structural analysis of the AB. In the FE model of the AB , the element types are as follow:

TS

1) Auxiliary Building (Cont'd)

- Global Structural Analysis

This analysis is performed to compute all member forces of shear walls in the AB.

TS

Non-Proprietary

1) Auxiliary Building (Cont'd)

- Accidental Torsion

  - Accidental torsional moment : Story inertia force X 5% of the building plan dimension
  - Accidental torsional moments are applied at the mass center of each floor elevation.

TS

1) Auxiliary Building (Cont'd)

- Heavy Equipment Moving Load

  - Shell elements at EL. 156'-0" are subdivided so that the heavy equipment moving loads can be simulated appropriately.
  - The reaction of heavy equipment (steam generator, reactor vessel, pressurizer) are applied on the EL.156 ft. roof slab of the AB as live loads (point loads).

TS

2) EDG Building Block

- The 3-dimensional FE models are developed to perform the structural analysis of the EDG building block. In the FE model of the EDG building block, the element types are as follow:

TS

Non-Proprietary

2) EDG Building Block (Cont'd)

- Global Structural Analysis

  This analysis is performed to compute all member forces of shear walls in the EDG building block.

TS

2) EDG Building Block (Cont'd)

- Accidental Torsion
  - Accidental torsional moment : Story inertia force X 5% of the building plan dimension
  - Accidental torsionsl moments are applied at the mass center of the each floor elevation.

TS

B-6. Design

1) Auxiliary Building Shear Walls
2) EDG Shear Walls

1) Auxiliary Building Shear Walls

- North Wall of North MSIV House
  - ✓ Height : El.55 ft. to El.174 ft. in 5 ft. thickness
  - ✓ Max. re-bar arrangement : 2-#11@9” in each direction
  - ✓ Max. shear re-bars : #6@9”

TS

1) Auxiliary Building Shear Walls (Cont'd)

- North Wall of North AFWST
  - ✓ Dimension : El.100 ft. to El.137.5 ft. in 4 ft. thickness
  - ✓ Max. re-bar arrangement : 2-#11@9" in each direction
  - ✓ Max. shear re-bars : not required
- West Wall of MCR
  - ✓ Height : El.55 ft. to El.195 ft. in 4 ft. thickness
  - ✓ Max. re-bar arrangement : 2-#11@12" in each direction
  - ✓ Max. shear re-bars : #6@12"
- West Wall of SFP
  - ✓ Dimension : El.114 ft. to El.156 ft. in 7 ft. thickness
  - ✓ Max. re-bar arrangement : 2-#14@9" in the vertical direction
  - ✓ Max. shear re-bars : #5@12"

Non-Proprietary

1) Auxiliary Building Shear Walls (Cont'd)

- East Wall of FHA
  - ✓ Height : El.156 ft. to El.213.5 ft., in 4 ft. thickness
  - ✓ Max. re-bar arrangement : 2-#11@9" in the vertical direction
  - ✓ Max. shear re-bars : not required

TS

2) EDG Shear Walls

- West Wall
  - ✓ Max. re-bar arrangement : #11@9” in the vertical direction
- Center Wall
  - ✓ Max. re-bar arrangement : #11@9” in the vertical direction

TS

[ ]

C. Foundations

1. Configuration
2. Analysis
3. Design
4. Stability Check

C-1. Configuration

1) Description of Structures

TS

- RCB and the AB are founded on a common basemat called the nuclear island (NI) common basemat.
- The NI common basemat consists of two areas, one central circular shaped area surrounded by a rectangular shaped area.
- The circular section supports the RCB and the remaining rectangular area supports the AB.

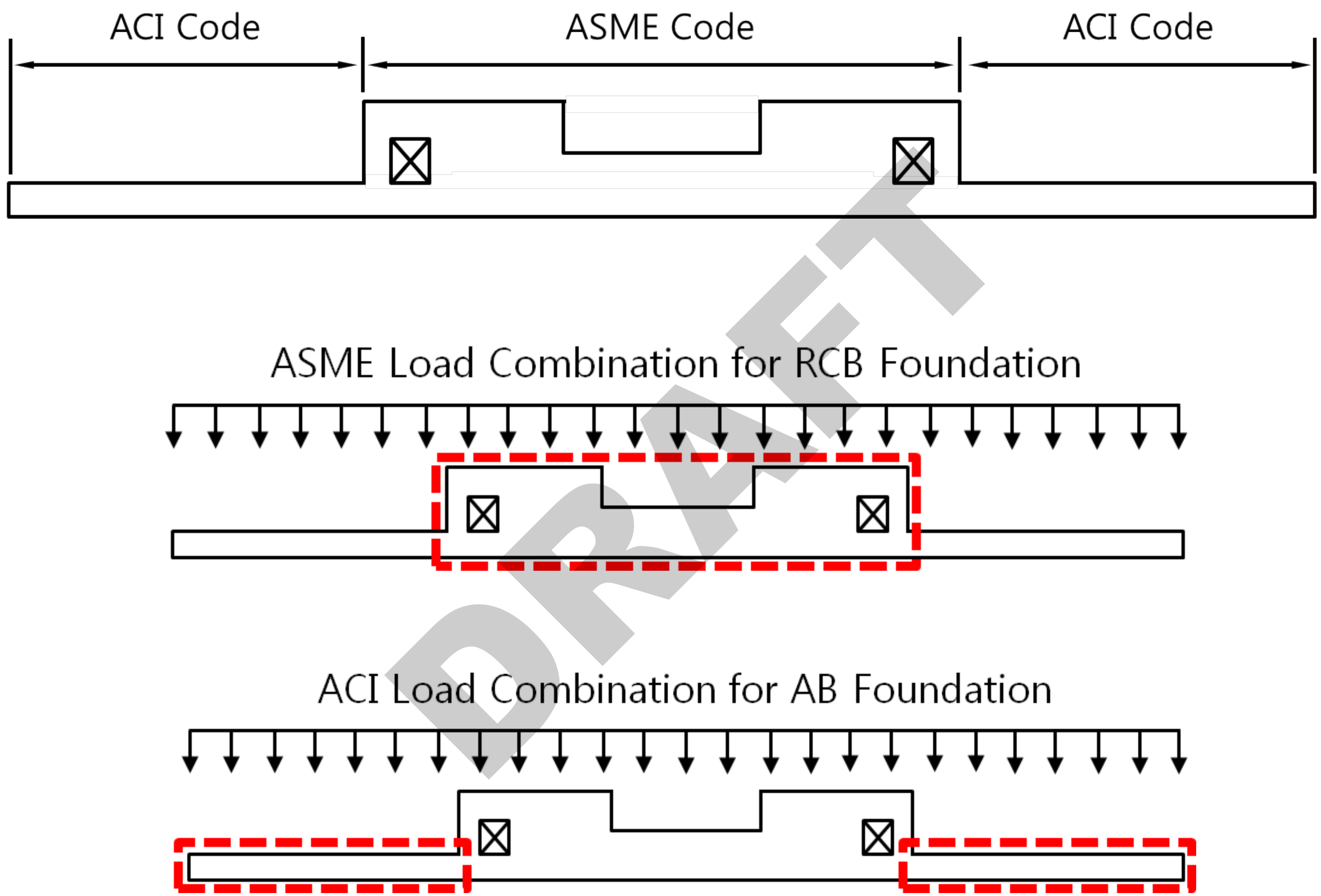
[ ]

1) Description of Structures (Cont'd)

- NI Common Basemat Plan

TS

2) Code Jurisdictional Boundary



C-2. Analysis

1) Nuclear Island(NI) Common Basemat
2) EDG Building Block Basemat

1) NI Common Basemat

- NI Common Basemat : for RCB and AB

TS

1) NI Common Basemat (Cont'd)

- Combined Model NI Common Basemat, RCB, and AB

TS

1) NI Common Basemat (Cont'd)

- **Seismic Forces from Analysis**

Seismic Excitation	Auxiliary Building (A)	RCB Shell and Dome (C)	RCB Internal Structure (I)
X-direction	$(F_x)_x$, $(F_y)_x$, $(F_z)_x$	$(F_x)_x$, $(F_y)_x$, $(F_z)_x$	$(F_x)_x$, $(F_y)_x$, $(F_z)_x$
Y-direction	$(F_x)_y$, $(F_y)_y$, $(F_z)_y$	$(F_x)_y$, $(F_y)_y$, $(F_z)_y$	$(F_x)_y$, $(F_y)_y$, $(F_z)_y$
Z-direction	$(F_x)_z$, $(F_y)_z$, $(F_z)_z$	$(F_x)_z$, $(F_y)_z$, $(F_z)_z$	$(F_x)_z$, $(F_y)_z$, $(F_z)_z$

(Fx)i, (Fy)i, and (Fz)i denote the three directional reaction forces corresponding to i (X, Y, and Z) directional seismic excitation

- **Seismic Load Cases using the 100-40-40 Method**

Auxiliary Building (A)	RCB Shell and Dome (C)	RCB Internal Structure (I)
$(Fx)_A = (F_x)_x+0.4(F_x)_y+0.4(F_x)_z$ $(Fy)_A = 0.4(F_y)_x+(F_y)_y+0.4(F_y)_z$ $(Fz)_A = 0.4(F_z)_x+0.4(F_z)_y+(F_z)_z$	$(Fx)_C = (F_x)_x+0.4(F_x)_y+0.4(F_x)_z$ $(Fy)_C = 0.4(F_y)_x+(F_y)_y+0.4(F_y)_z$ $(Fz)_C = 0.4(F_z)x+0.4(F_z)_y+(F_z)_z$	$(F_x)_I = (F_x)_x+0.4(F_x)_y+0.4(F_x)_z$ $(F_y)_I = 0.4(F_y)_x+(F_y)_y+0.4(F_y)_z$ $(F_z)_I = 0.4(F_z)_x+0.4(F_z)_y+(F_z)_z$

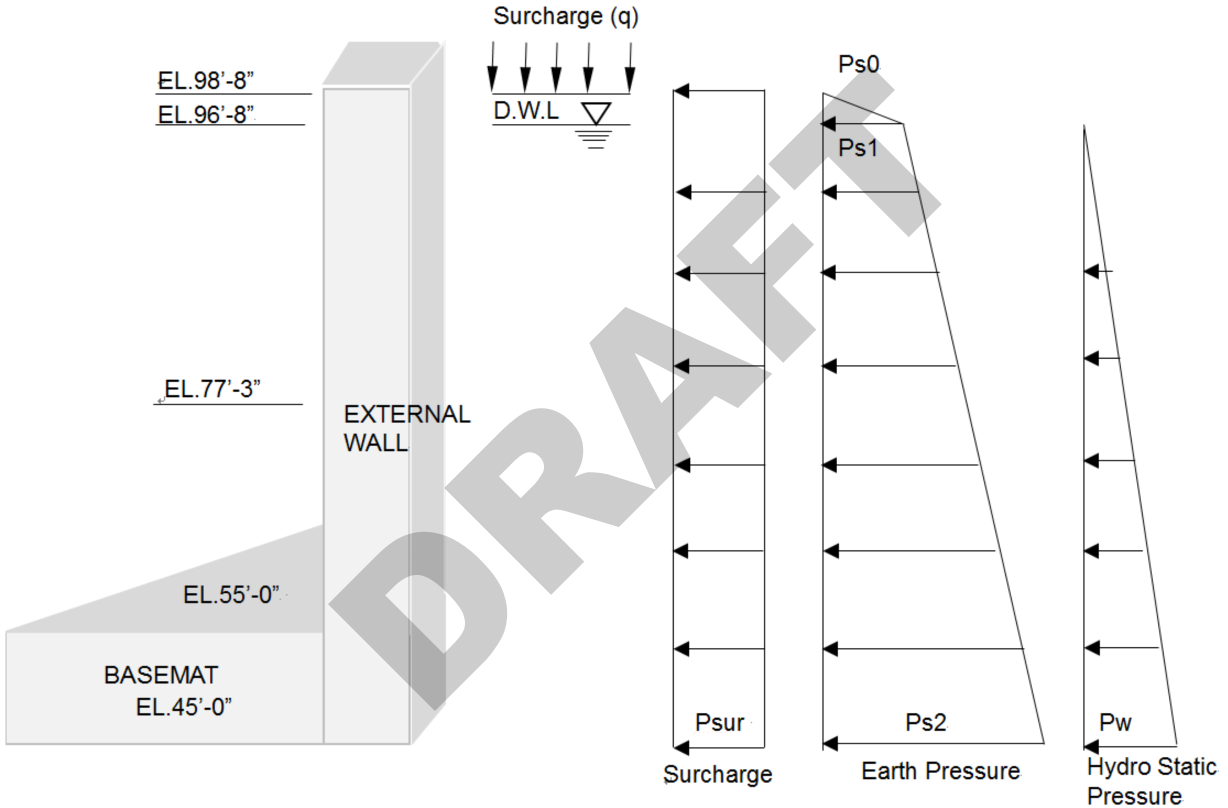
1) NI Common Basemat (Cont'd)

- **Seismic Load Combinations for NI Common Basemat**

Case	X-Directional Reaction	Y-Directional Reaction	Z-Directional Reaction
Es01	$(F_x)_A + (F_x)_C + (F_x)_I$	$(F_y)_A + (F_y)_C + (F_y)_I$	$(F_z)_A + (F_z)_C + (F_z)_I$
Es02	$(F_x)_A + (F_x)_C + (F_x)_I$	$(F_y)_A + (F_y)_C + (F_y)_I$	$-(F_z)_A - (F_z)_C - (F_z)_I$
Es03	$(F_x)_A + (F_x)_C + (F_x)_I$	$-(F_y)_A - (F_y)_C - (F_y)_I$	$(F_z)_A + (F_z)_C + (F_z)_I$
Es04	$(F_x)_A + (F_x)_C + (F_x)_I$	$-(F_y)_A - (F_y)_C - (F_y)_I$	$-(F_z)_A - (F_z)_C - (F_z)_I$
Es05	$-(F_x)_A - (F_x)_C - (F_x)_I$	$(F_y)_A + (F_y)_C + (F_y)_I$	$(F_z)_A + (F_z)_C + (F_z)_I$
Es06	$-(F_x)_A - (F_x)_C - (F_x)_I$	$(F_y)_A + (F_y)_C + (F_y)_I$	$-(F_z)_A - (F_z)_C - (F_z)_I$
Es07	$-(F_x)_A - (F_x)_C - (F_x)_I$	$-(F_y)_A - (F_y)_C - (F_y)_I$	$(F_z)_A + (F_z)_C + (F_z)_I$
Es08	$-(F_x)_A - (F_x)_C - (F_x)_I$	$-(F_y)_A - (F_y)_C - (F_y)_I$	$-(F_z)_A - (F_z)_C - (F_z)_I$

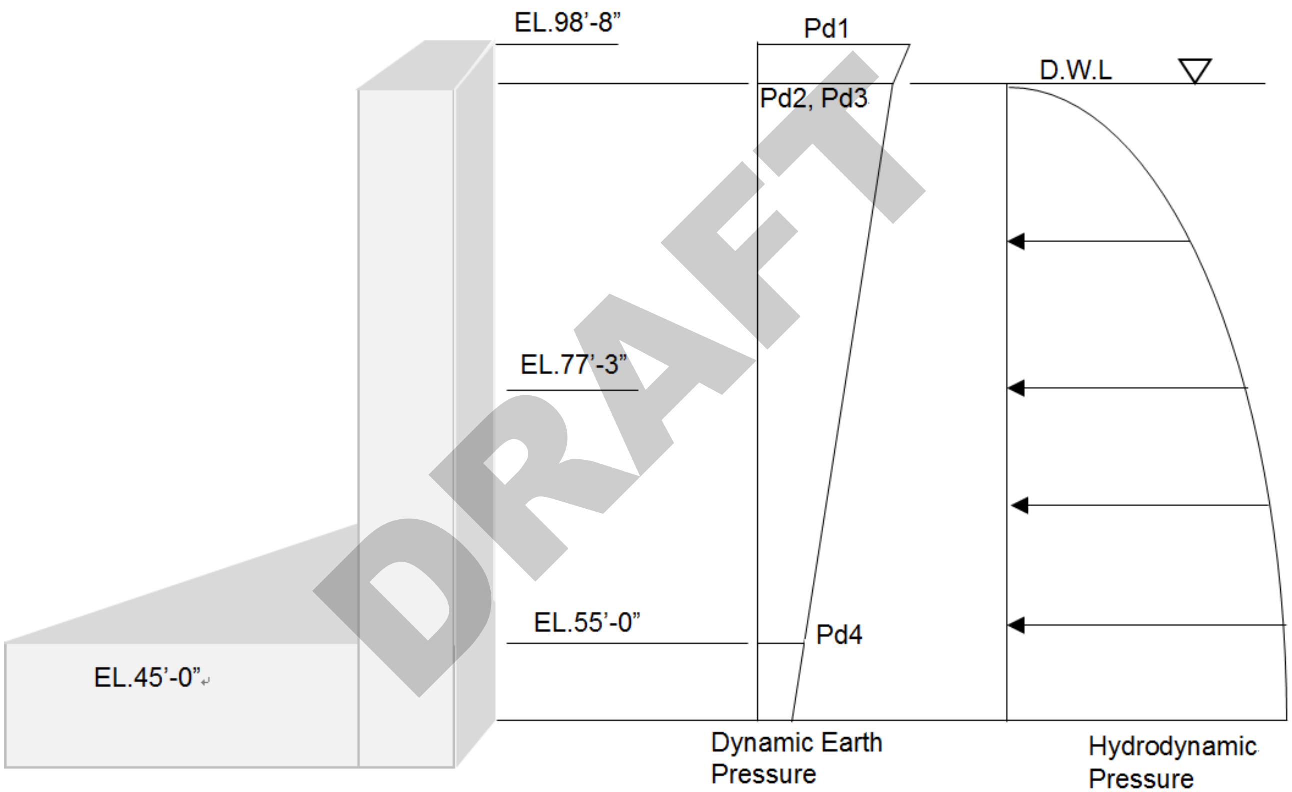
1) NI Common Basemat (Cont'd)

- Surcharge, Earth Pressure, Hydrostatic Pressure



1) NI Common Basemat (Cont'd)

- Dynamic Earth Pressure and Hydrodynamic Pressure



Non-Proprietary

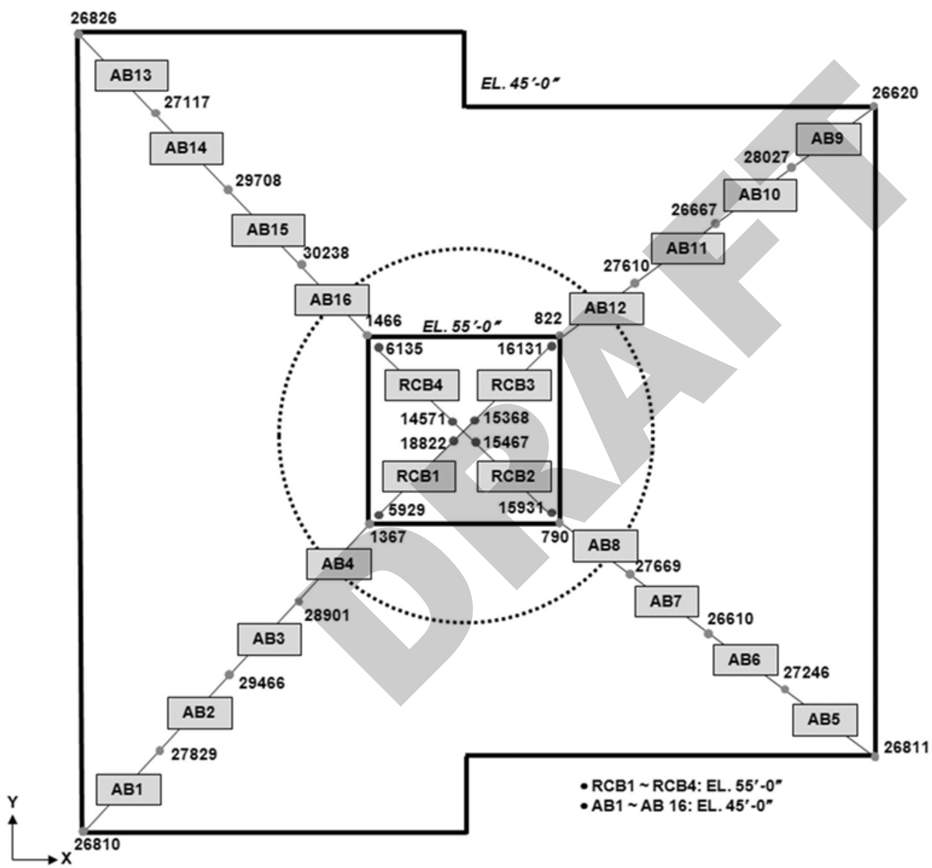
1) NI Common Basemat (Cont'd)

- **Load Combinations for NI Common Basemat**

Position	Condition	Load Case	Load Combination
RCB Basemat	Test	LC01	1.0D+1.0L+1.0Lh+1.0F+1.0Pt
	Normal	LC02	1.0D+1.0L+1.0Lh+1.0F
	Severe	LC03	1.0D+1.3L+1.3Lh+1.0F
	Abnormal	LC04	1.0D+1.0L+1.0Lh+1.0F+1.5Pa
AB Basemat	Test	LC05	1.1D+1.3L+1.1Lh+1.0F+1.0Pt
	Normal	LC06	1.4D+1.7L+1.4Lh+1.0F
	Abnormal	LC07	1.0D+1.0L+1.0Lh+1.0F+1.4Pa
RCB and AB Basemat	Abnormal /Extreme	LC08	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es01
		LC09	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es02
		LC10	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es03
		LC11	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es04
		LC12	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es05
		LC13	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es06
		LC14	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es07
		LC15	1.0D+1.0L+1.0Lh+1.0F+1.0Pa+1.0Yr +1.0Es08

1) NI Common Basemat (Cont'd)

- **Settlement Check Points (Static)**



1) NI Common Basemat (Cont'd)

- **Differential Settlement Between Buildings(Static)**

Basemat / Differential Settlement	Max. Settlement (in.)		
	S1	S4	S8
NI Basemat	4.063	0.853	0.187
TGB Basemat	3.972	1.103	0.205
Differential Settlement	0.091	0.250	0.018

- **Bearing Pressure of NI Common Basemat**

Case	Max. Bearing Pressure (ksf)		
	S1	S4	S8
Static Case	12.074	12.321	13.397
Dynamic Case	18.084	19.357	29.572

2) EDG Building Block Basemat

- Basemat : for the EDGB and the DFOT

TS

Non-Proprietary

2) EDG Building Block Basemat (Cont'd)

- Combined Model, EDGB and DFOT

TS

Non-Proprietary

2) EDG Building Block Basemat (Cont'd)

- **Seismic Forces from Superstructure Analysis**

Seismic Excitation	EDGB & DFOT
X-direction	$(F_x)_x$, $(F_y)_x$, $(F_z)_x$
Y-direction	$(F_x)_y$, $(F_y)_y$, $(F_z)_y$
Z-direction	$(F_x)_z$, $(F_y)_z$, $(F_z)_z$

(Fx)i, (Fy)i, and (Fz)i denote the three directional reaction forces corresponding to i (X, Y, and Z) directional seismic excitation

- **Seismic Load Cases using the SRSS Method**

$$R = \pm\sqrt{\sum_i R_i^2}$$

R is any response of interest and Ri (i=1, 2, 3) is the two horizontal components and one vertical component of earthquake motion.

- **Surcharge, Earth Pressure, Hydrostatic Pressure, Dynamic Earth Pressure, and Hydrodynamic Pressure**

Same method as that of the NI common basemat

Non-Proprietary

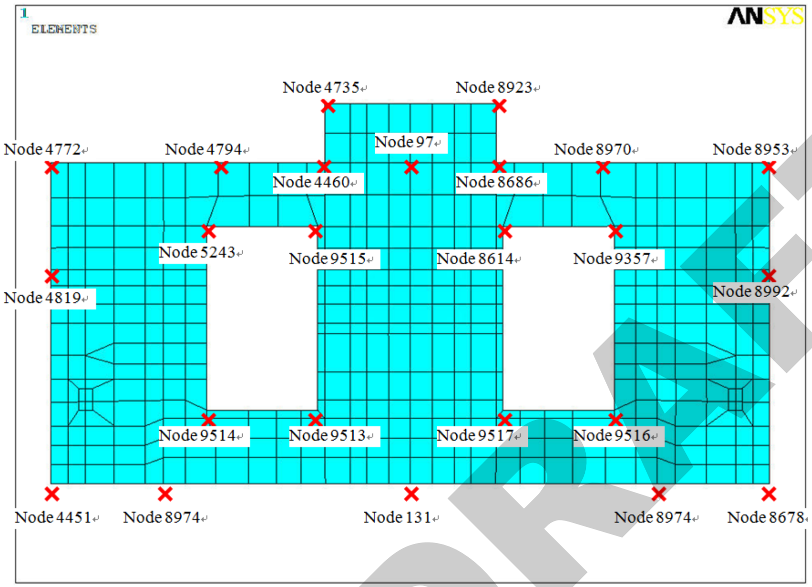
2) EDG Building Block Basemat (Cont'd)

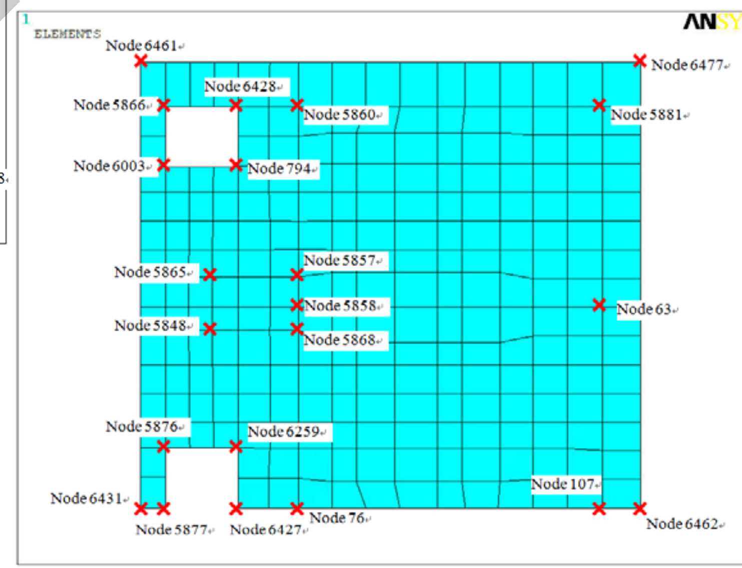
- **Load Combinations for NI Common Basemat**

Load Case	LC No.		Loading Combination
LC04	1	LC04 = 1.4D + 1.7L	Normal
LC06	2	LC06A = 1.4D + 1.7L +1.7 WINDS	Severe Environmental including Wind Load
	3	LC06B = 1.4D + 1.7L +1.7 WINDN	Severe Environmental including Wind Load
	4	LC06C = 1.4D + 1.7L +1.7 WINDE	Severe Environmental including Wind Load
LC15a+	5	LC15A = 1.0D + 1.0L + 1.0Es	Abnormal/Extreme Environmental
LC15a-	6	LC15B = 1.0D + 1.0L - 1.0Es	Abnormal/Extreme Environmental
LC15b+	7	LC15C = 0.9D + 1.0L + 1.0Es	Abnormal/Extreme Environmental
LC15b-	8	LC15D = 0.9D + 1.0L - 1.0Es	Abnormal/Extreme Environmental

2) EDG Building Block Basemat (Cont'd)

- Settlement Check Points (Static)





2) EDG Building Block Basemat (Cont'd)

- **Differential Settlement Between Buildings(Static)**

	Max. Settlement (inches)		
	Soil 01	Soil 04	Soil 08
NI Basemat	3.959	0.821	0.172
EDGB Basemat	1.670	0.537	0.059
Differential Settlement	2.289	0.284	0.113

	Max. Settlement (inches)		
	Soil 01	Soil 04	Soil 08
NI Basemat	3.959	0.821	0.172
DFOT Room Basemat	1.860	0.582	0.047
Differential Settlement	2.099	0.239	0.125

- **Bearing Pressure of Basemat**

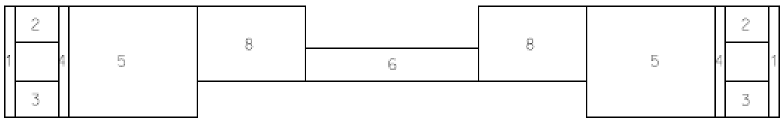
	Load Case	Max. Soil Pressure (ksf)		
		Soil 1	Soil 4	Soil 8
EDGB	Static Case	4.83	5.08	8.10
	Dynamic Case	7.61	8.06	14.02
DFOT	Static Case	5.38	5.51	6.41
	Dynamic Case	4.22	4.21	5.19

C-3. Design

1) Reactor Containment Building Basemat
2) Auxiliary Building Basemat
3) EDG Building Block Basemat
4) Stability Check

Non-Proprietary

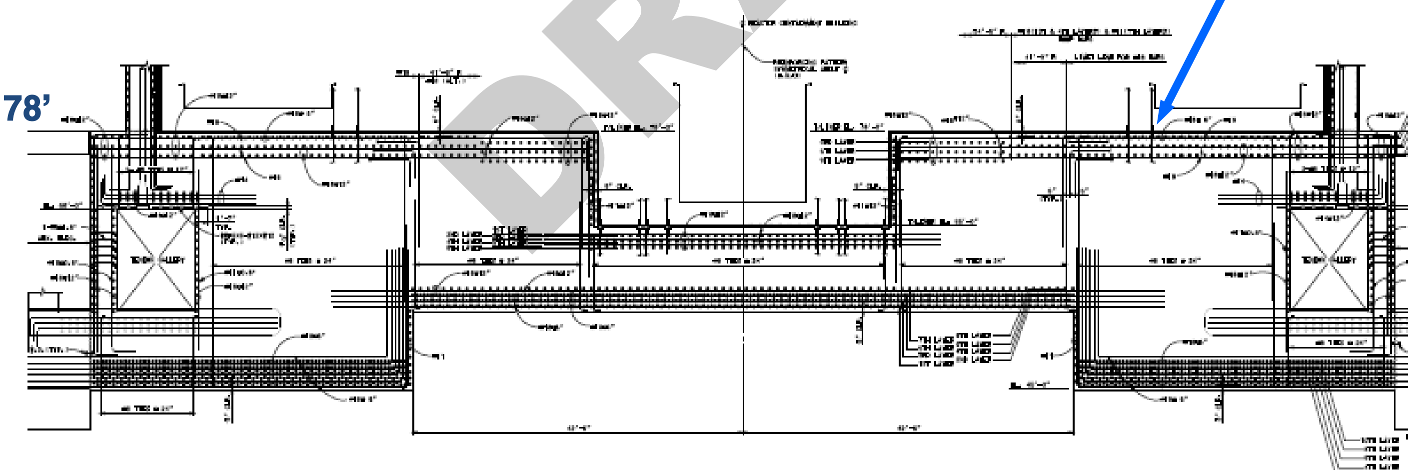
1) Reactor Containment Building Basemat



(a) Basemat Cross Section for E-W Direction

Design Sections for Basemat Reinforcement

SKN 3&4 RCB Basemat EL.78’



Reinforcement Arrangement of RCB Basemat

DRAFT

2) Auxiliary Building Basemat

- AB Area of NI Common Base Mat
- Reinforced concrete structure
- Maximum dimension : 348 ft by 353 ft in 10 ft thickness
- Orthogonal reinforcing bars at top and bottom
- Maximum top and bottom re-bar arrangement

  : 3 # 18@ 12” in each direction
- Maximum shear reinforcement : 2 # 18@ 12”

3) EDG Building Block Basemat

- Max. top and bottom re-bar arrangement : 2 # 11 @ 12” in each direction with shear re-bar #5 @ 12”

4) Stability Check

- Overturning, sliding, and buoyancy shall be checked in accordance with NUREG-0800, Section 3.8.5.

Load Combination	Overturning & Uplift	Sliding	Floatation
$D+H_e+W$	1.5	1.5	–
$D+H_e+E_s$	1.1	1.1	–
$D+H_e+W_t$	1.1	1.1	–
$D+H_s$	–	–	1.1

Where, D = Dead load

E_s = SSE Seismic Force

W= Wind load , W_t = Tornado load

H_e = Static and dynamic lateral and vertical earth pressure including buoyant effect

H_s = Buoyant force of the design basis flood

- Seismic load governs over wind load; stability checks are not considered under wind load
- The earth pressure effect is conservatively neglected.

4) Stability Check (Cont'd)

- Stability check results for overturning, sliding and buoyancy in calculation

Load Combination	Overturning	Sliding	Floatation	Result
$D+H_e+E_s$	**1.36** > 1.1	**1.51** > 1.1	–	OK
$D+H_s$	–	–	**3.39** > 1.1	OK

D. Summary

Summary

- Structural analysis and design of the APR1400 is performed in accordance with the NRC's guidelines and requirements.
- The concrete basemat and shell and dome structures in the RCB are designed in accordance with ASME CC and ACI 349.
- The concrete basemats, shear walls, and slabs in AB and the EDG Building block are designed in accordance with ACI 349.
- The combustible gas loads are evaluated as beyond design-basis-conditions. These loads are not considered as design loads under design basis conditions.
- During the severe accident scenario, the liner plate strains at the cylindrical wall base, mid-height wall, and penetrations do not reach the strain limit presented in ASME CC-3720 (factored category).
- The UPC of the APR1400 RCB is 158 psig in accordance with RG Guide 1.216 (2013).