Pre-Application Review Meeting

▣ Seismic Analysis of APR1400

Seismic Analysis of APR1400

- **Structure Part**
  - A. Seismic Design Parameters
  - B. SSI Analysis
  - C. Hard Rock High Frequency Response Spectrum
  - D. Summary of Structure Part

Seismic Analysis of APR1400

A. Seismic Design Parameters

1. Introduction
2. Regulatory Requirements
3. Seismic Classification
4. Design Ground Motion
5. Generic Soil Profiles

A-1. Introduction

1) Purpose of Meeting
2) Background
3) Organization

1) Purpose of Meeting

- KEPCO intends to submit an application to the NRC for Design Certification (DC) of the APR1400 standard design.
- The purpose of this meeting is to present an overview of the APR1400 standard design and the approaches used in the seismic analysis and design of the major buildings.
- The expectation from this meeting is to receive feedbacks, recommendations, and regulatory positions on seismic issues related to the APR1400 DC application.

2) Background

- In September 2010, KEPCO presented to the NRC the seismic analysis approaches through 1st Seismic Design PARM.
- After 1st Seismic PARM, many seismic related analyses have been performed including the generation of artificial time histories, site response analysis, seismic modeling, and model verification.
- Through this presentation, we will explain the seismic analysis approaches and results.

3) Organization

KEPCO/KHNP
Project Management
- Dr. S. J. Oh : Project Manager
- Dr. J. B. Jang : Structural Eng.
- Dr. K. H. Yun : Seismology

KEPCO E&C
Structure Part
- Mr. Y. K. Kim : Structural Eng.
- Mr. W. K. Jung : Earthquake Eng.
- Mr. K. Y. Yoon : 〃
- Mr. J. C. Song : 〃
- Dr. S. R. Han : 〃
- Mr. Y. S. Jang : 〃

System Part
- Mr. S. H. Jeong : Mechanical Eng.
- Mr. J. Y. Kim : 〃
- Mr. J. S. Moon : 〃

Paul C. Rizzo Associates, Inc.
Seismic Analysis
- Dr. Wen S. Tseng : Earthquake Eng.
- Dr. Kiat Lilhanand : 〃
- Mr. Don Hamasaki : 〃
- Dr. J. M. Jim Lee : 〃
- Dr. Wassim Naguib : 〃
- Dr. Julio Garcia : 〃

A-2. Regulatory Requirements

1) Regulatory Requirements
2) Computer Codes

1) Regulatory Requirements

- **10 CFR Part 50, App. S:** Earthquake Engineering Criteria for Nuclear Power Plants
- **10 CFR Part 52, Subpart B:** Standard Design Certifications, Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants
- **Reg. Guide 1.60 (Rev. 0):** Design Response Spectra for Seismic Design of Nuclear Power Plants
- **Reg. Guide 1.61 (Rev. 1):** Damping Values for Seismic Design of Nuclear Power Plants
- **Reg. Guide 1.92 (Rev. 2):** Combining Modal Responses and Spatial Components in Seismic Response Analysis

1) Regulatory Requirements (cont'd)

- **Reg. Guide 1.208 (Rev. 0):** A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion
- **Reg. Guide 1.122 (Rev. 1):** Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components
- **SRP 3.7.1 (Rev. 3):** Seismic Design Parameters
- **SRP 3.7.2 (Rev. 3):** Seismic System Analysis
- **SRP 3.7.3 (Rev. 3):** Seismic Subsystem Analysis
- **DC/COL-ISG-01:** Seismic Issues Associated with High Frequency Ground Motion in Design Certification and Combined License Applications

1) Regulatory Requirements (cont'd)

- **DC/COL-ISG-017 :** Ensuring Hazard-Consistent Seismic Input for Site Response and Soil Structure Interaction Analyses
- **NUREG/CR-6728:** Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-consistent Ground Motion Spectra Guidelines

2) Computer Codes

- **Generation of Design Time Histories matching CSDRS**
  - Computer code: OPTIME
    - ➢ Generate Artificial Time History (ATH)
    - ➢ Verified and validated following the SQA procedure
    - ➢ Applied to the design of nuclear power plants in Korea.
- **Finite Element Modeling and Eigenvalue Analysis of Structures**
  - Computer code: ANSYS Ver. 14
- **Site Response Analysis**
  - Computer code: SHAKE of Paul C. Rizzo Associates, Inc.
  - Verified and validated following the SQA procedure
  - It can handle as follows:
    - ➢ Low frequency range
    - ➢ Frequency range higher than 25 Hz
    - ➢ Soil layers up to 100 layers

2) Computer Codes (cont'd)

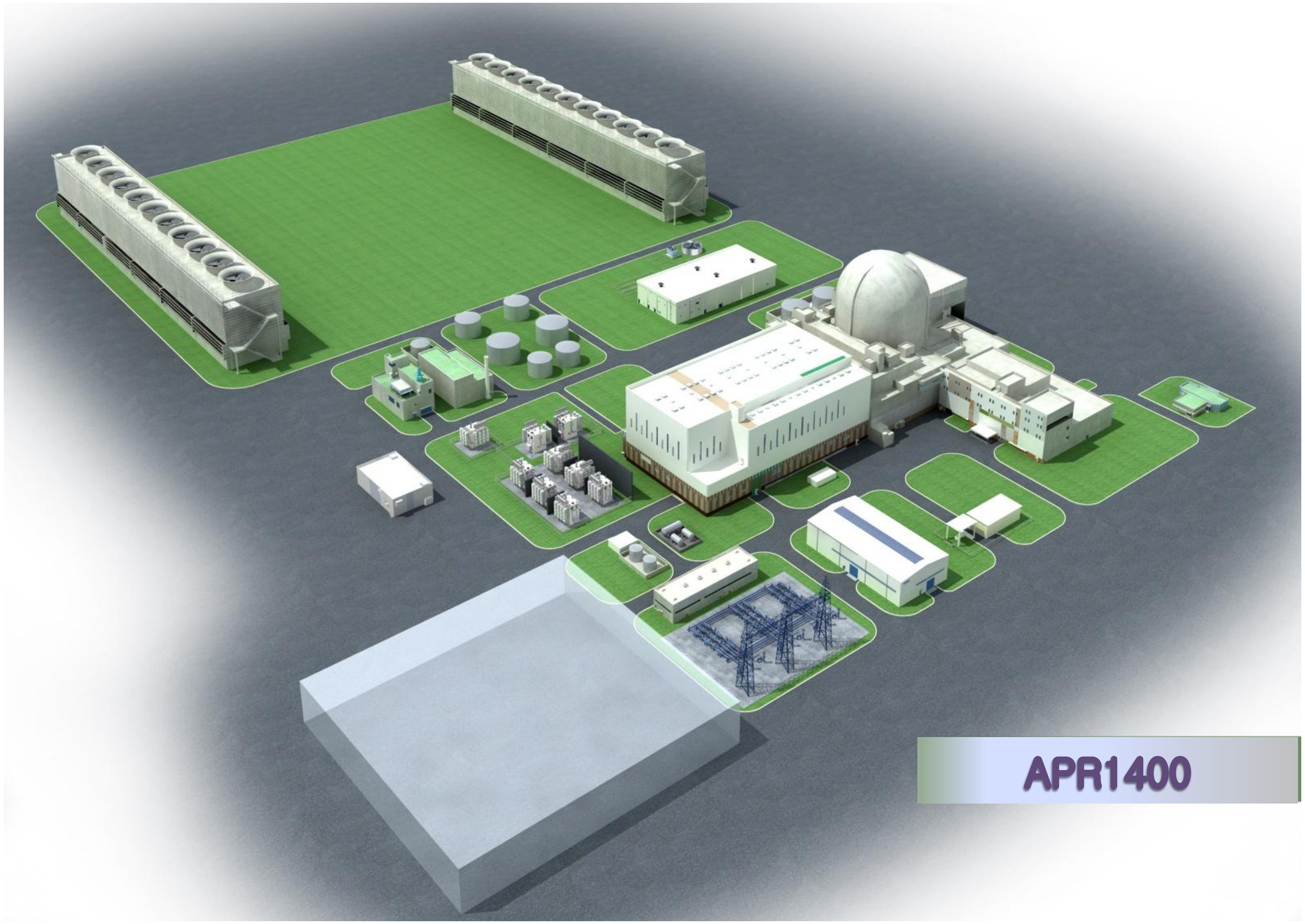
- **Soil-Structure Interaction Analysis with Coherent and Incoherent Seismic Input Motions**
  - Computer code: ACS SASSI Fast Solver NQA Ver. 2.3.0
    - Verified and validated by Ghiocel Predictive Technologies Inc.
    - Registered and in-use tested following the SQA procedure

A-3. Seismic Classification

1) Layout
2) Scope
3) Seismic Classification

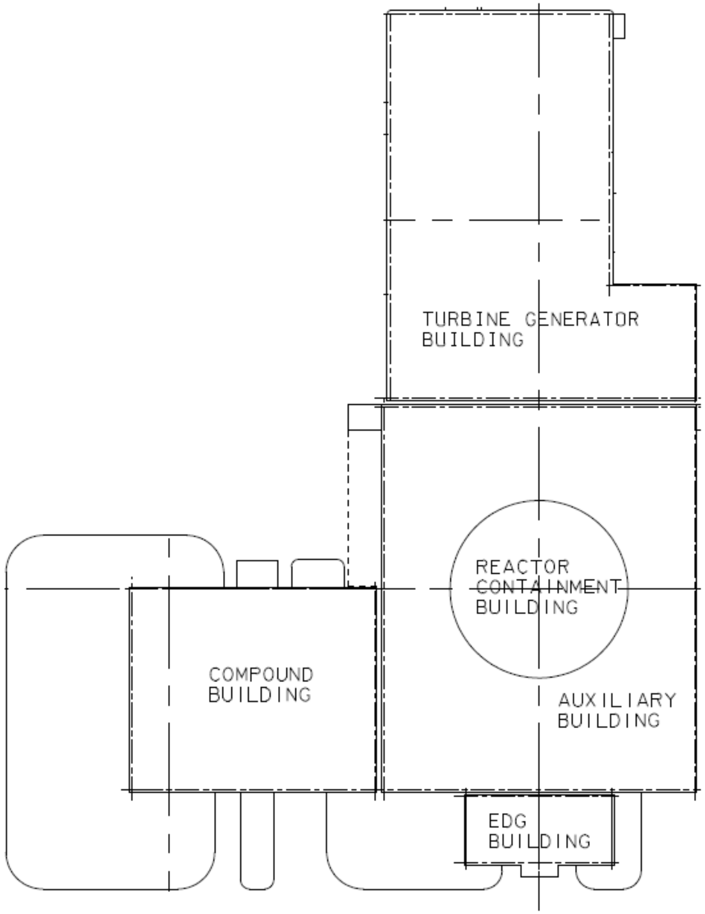
1) Layout

- **Layout : Single Unit Design**



1) Layout (cont'd)

- Site Plot Plan of Major Buildings



2) Scope

- **Seismic Analysis Scope**
  - Nuclear Island Structures
    - ➢ Reactor Containment Building (RCB)
    - ➢ Auxiliary Building (AB)
  - Emergency Diesel Generator Building (EDGB)
  - Turbine Generator Building (TGB)
  - Compound Building (CPB)

3) Seismic Classification

- **Seismic Classification of Buildings in Scope**
  - Seismic Category I
    - ➢ Reactor Containment Building
    - ➢ Auxiliary Building
    - ➢ Emergency Diesel Generator Building
  - Non-Seismic Category I
    - ➢ Turbine Generator Building
    - ➢ Compound Building

A-4. Design Ground Motion

1) Design Ground Motion
2) CSDRS
3) Recorded Seed Time Histories
4) Design Time History Generation

1) Design Ground Motion

- **Background**
  - RG 1.60 design response spectra enhanced in the high frequency range
    - ➢ Duke Engineering provided the enhanced response spectra utilizing EPRI (1986) and LLNL (1989) study.
      - ▪ Increase 30% of the spectral acceleration at 25 Hz than the design ground response spectra of Reg. Guide 1.60.
  - Recent studies on CEUS seismic hazard (2006, 2008 and 2011) are incorporated.
    - ➢ In collaboration with EPRI, CEUS GMRS were generated with 2008 USGS SSC model on in May 2011 (EPRI Product ID: 1023389).
    - ➢ KEPCO determined the new HRHF(Hard Rock High Frequency) response spectra from EPRI report for evaluation of the APR1400.

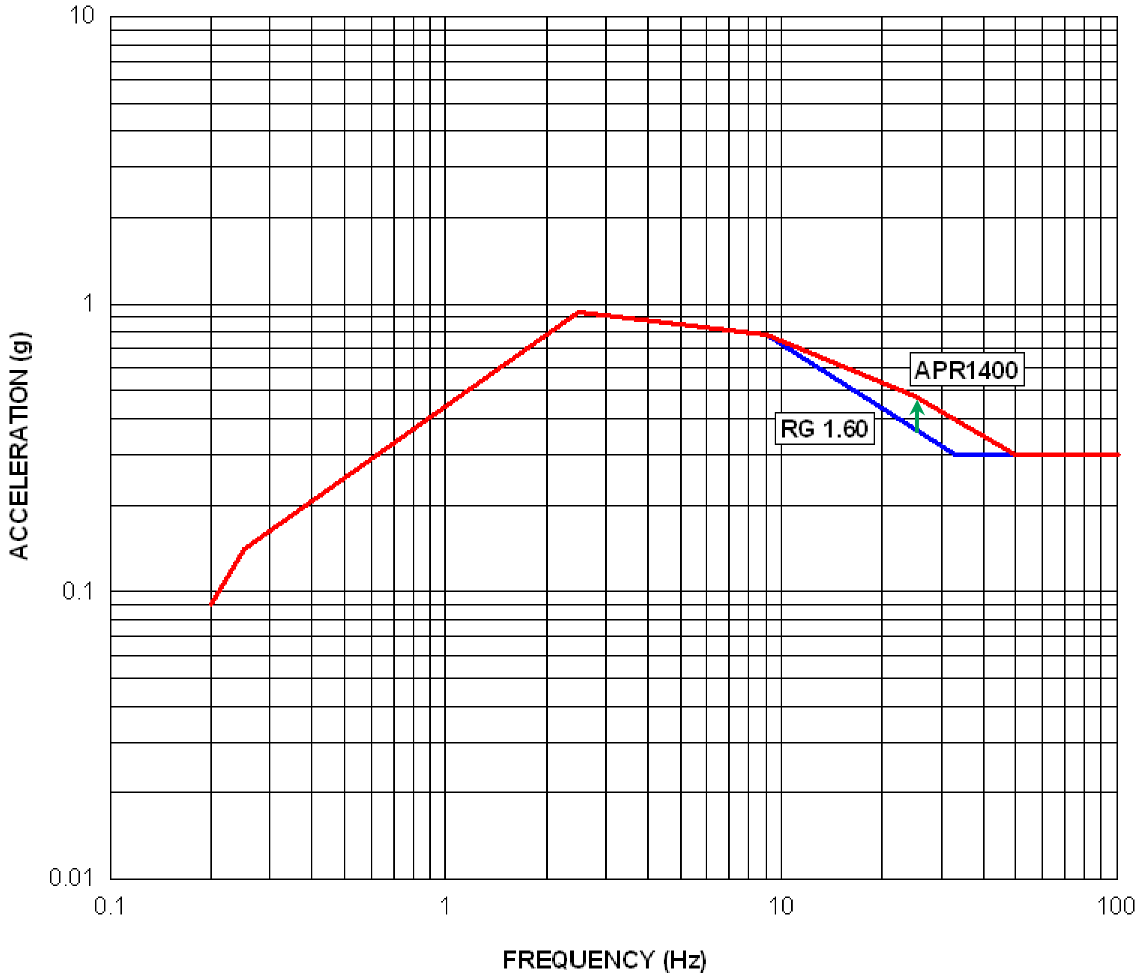
1) Design Ground Motion (cont'd)

- **Hard Rock High Frequency (HRHF) Response Spectra (RS)**
  - The SSI Analysis will be performed with the HRHF RS based on the 2008 USGS SSC model for a separate evaluation of the high frequency ground motion effects on the Structure, System, and Components (SSCs).
  - To reduce the impact on the SSCs, the ground motion Incoherency effect will be incorporated in the SSI Analysis with the HRHF RS ground motion input.
  - In the Structure Part C presentation, details of the HRHF RS and incoherency SSI analysis will be presented.

2) CSDRS

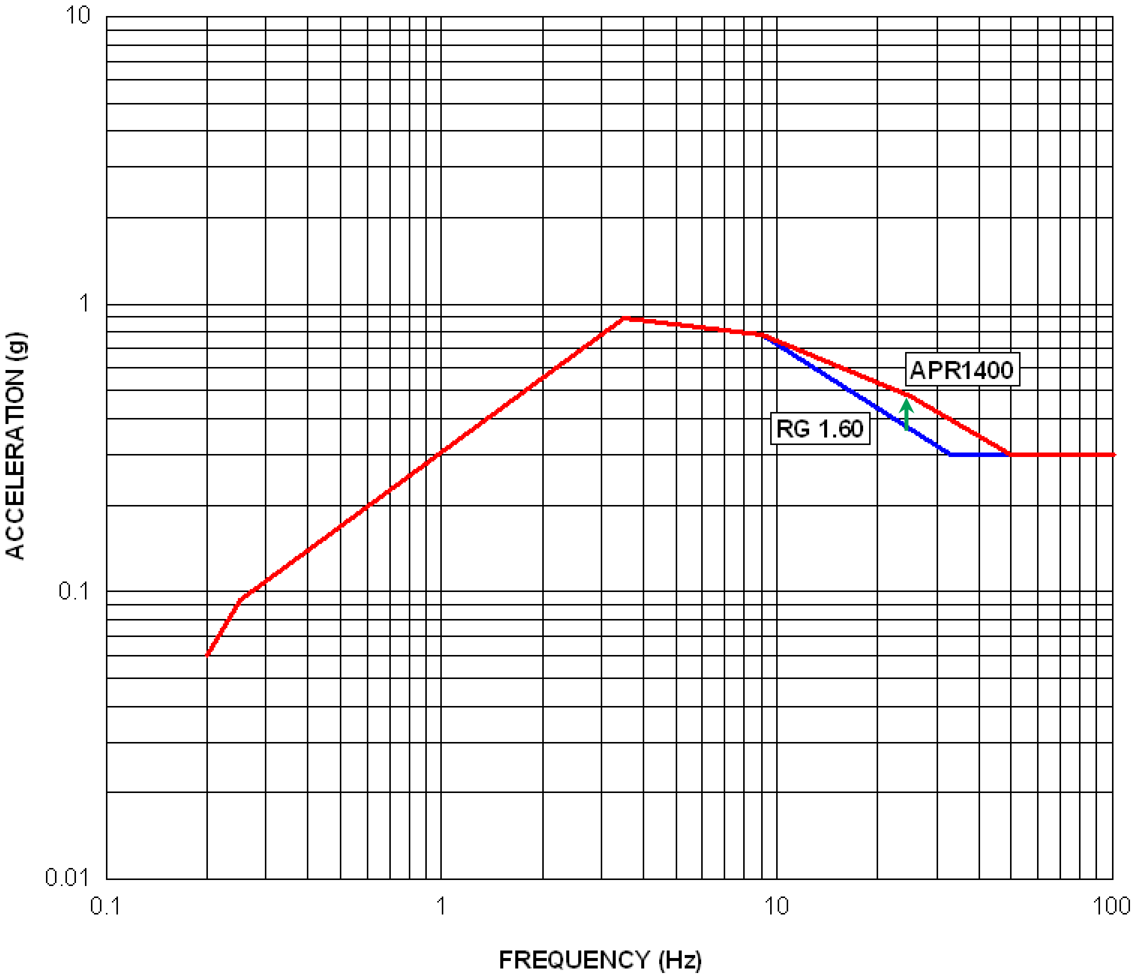
- **APR1400 CSDRS**
  - SSE PGA (0.3g) for the horizontal and vertical directions
  - RG 1.60 spectra enhanced in high frequency from 9 Hz to 50 Hz
    - ➢ Increase the Regulatory Guide 1.60 response spectral values at 25 Hz by the factor of 1.30.
    - ➢ Linearly vary, on log-log-scale, the Regulatory Guide 1.60 spectra at 9 Hz to the 1.3-times amplified spectral values at 25 Hz.
    - ➢ Linearly vary, on log-log-scale, the 1.3-times amplified spectral value at 25 Hz to the PGA value at 50 Hz.
- **Design for OBE, which is 1/3×SSE, is eliminated in accordance with 10 CFR Part 50, App. S.**

2) CSDRS (cont'd)



Horizontal Spectral Amplifications for CSDRS and RG 1.60 Spectrum (5% Damping)

2) CSDRS (cont'd)



Vertical Spectral Amplifications for CSDRS and RG 1.60 Spectrum (5% Damping)

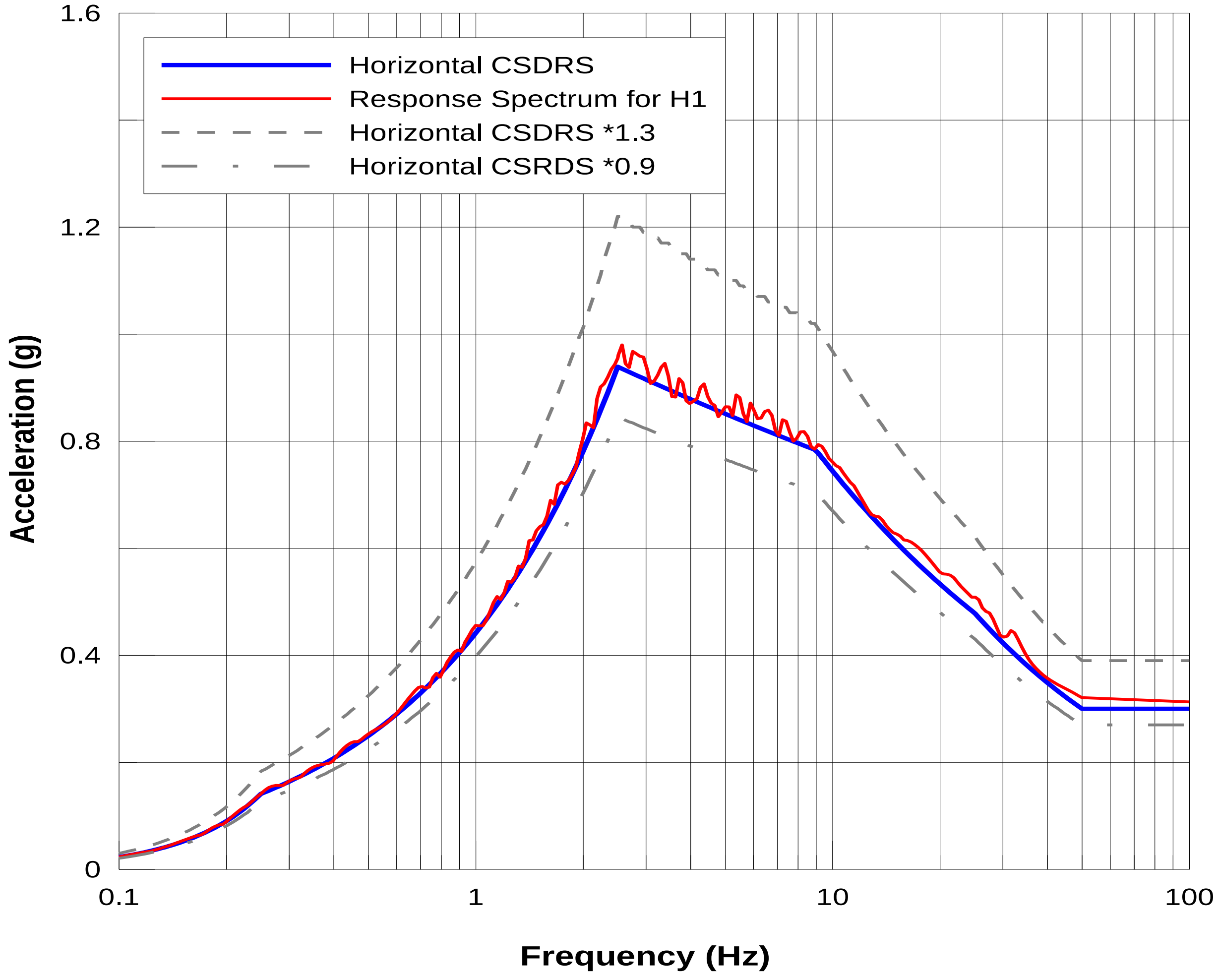
3) Seed Recorded Time Histories

- **Northridge Earthquake recorded ground motion used as the seed motion**
  - Northridge Earthquake motion used is the recorded horizontal and vertical accelerograms at the West Covina (D=52.4 km) recording station on January 17th, 1994 Northridge, California, earthquake (M=6.7).
  - The APR1400 design time histories are generated with the Initial horizontal and vertical seed-motion time-histories in conformance with SRP 3.7.1 Rev.3

4) Design Time History Generation

- **Option 1 Approach 2 of SRP 3.7.1, Rev.3 has been applied to generate design time histories**
- **The criteria are as follows:**
  - Total duration of at least 20 seconds
  - Nyquist frequency (N_f) of at least 50 Hz
  - Minimum 100 points per frequency decade for comparison of the time-history response spectra with the target response spectra from 0.1 Hz to 50 Hz
  - 5%-damped response spectrum not more than 10% below and not more than 30% above the target spectrum at any frequency
  - No more than 9 adjacent frequency points falling below the target response spectrum

4) Design Time History Generation (cont'd)



Comparison of 5%-Damped Response Spectra for H1 Component and CSDRS (Anchored at 0.3g)

4) Design Time History Generation (cont'd)

- **Strong Motion Duration computed as per SRP 3.7.1 Rev.3**
  - Minimum acceptable strong motion duration: 6 sec.
  - Calculate the Arias Intensity from 5% to 75%

4) Design Time History Generation (cont'd)

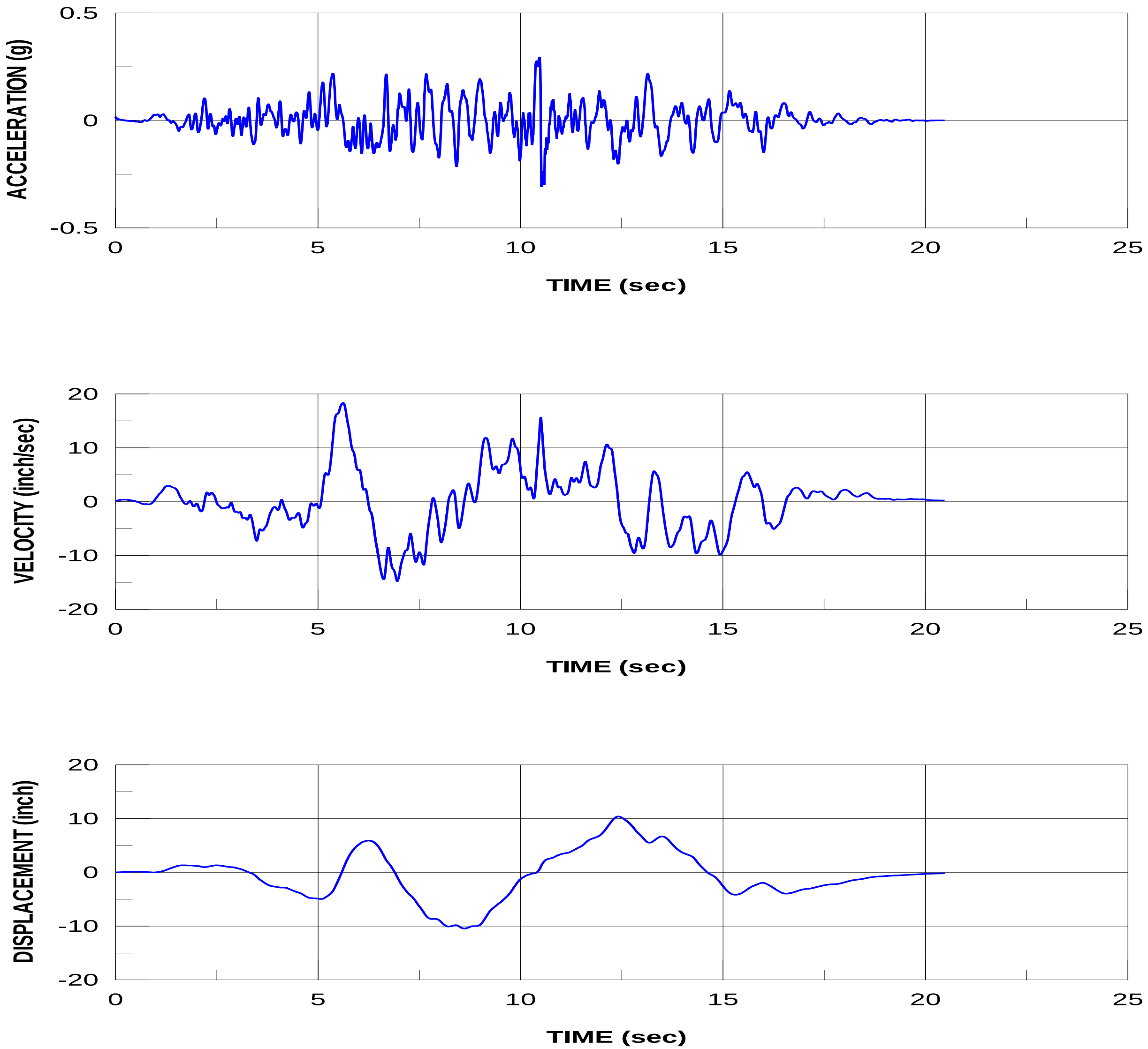
- **Cross-correlation Coefficients**
  - The biggest correlation coefficient between each pair of the 3-component time histories is 0.085 (which is less than 0.16)
- **Consistency of V/A and AD/V^2**
  - Ratios V/A and AD/V^2 is consistent with characteristic values for the magnitude and distance of the Northridge earthquake

where, A : Peak ground acceleration (A_{max})

V : Peak ground velocity (V_{max})

D : Peak ground displacement (D_{max})

4) Design Time History Generation (cont'd)



Generated Time History Plots for H1 Component (Anchored at 0.3g)

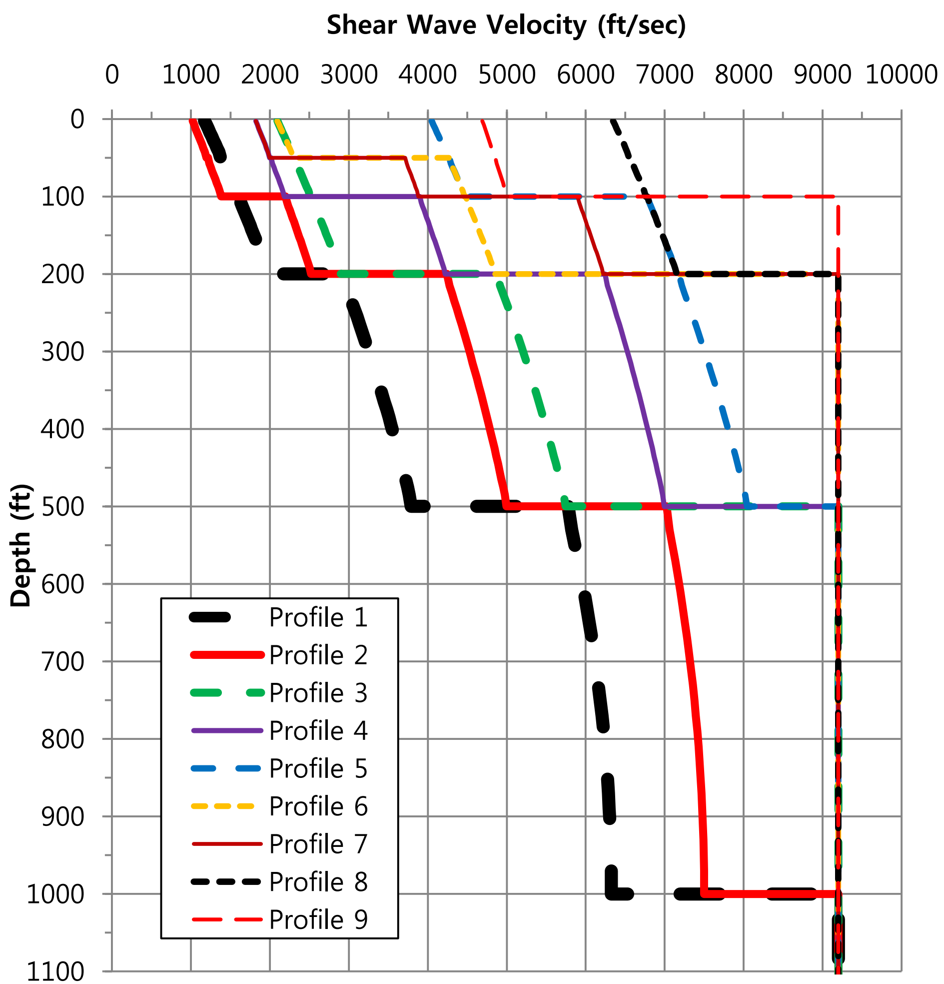
A-5. Generic Soil Profiles

1) Features of Generic Soil Profiles
2) Site Response Analysis
3) Analysis Results

1) Features of Generic Soil Profiles

- **Generic soil profiles**
  - Nine layered profiles: S01 (Soft Soil) to S09 (Hard Rock)
  - One fixed base condition: S10
- **Five categories of site layer depth to bedrock**
  - 55 ft (Embedment depth of NI)
  - 100 ft
  - 200 ft
  - 500 ft
  - 1,000 ft
- **For a layer-depth category, a generic soil-profile is defined by its soil/rock shear wave velocity profile**

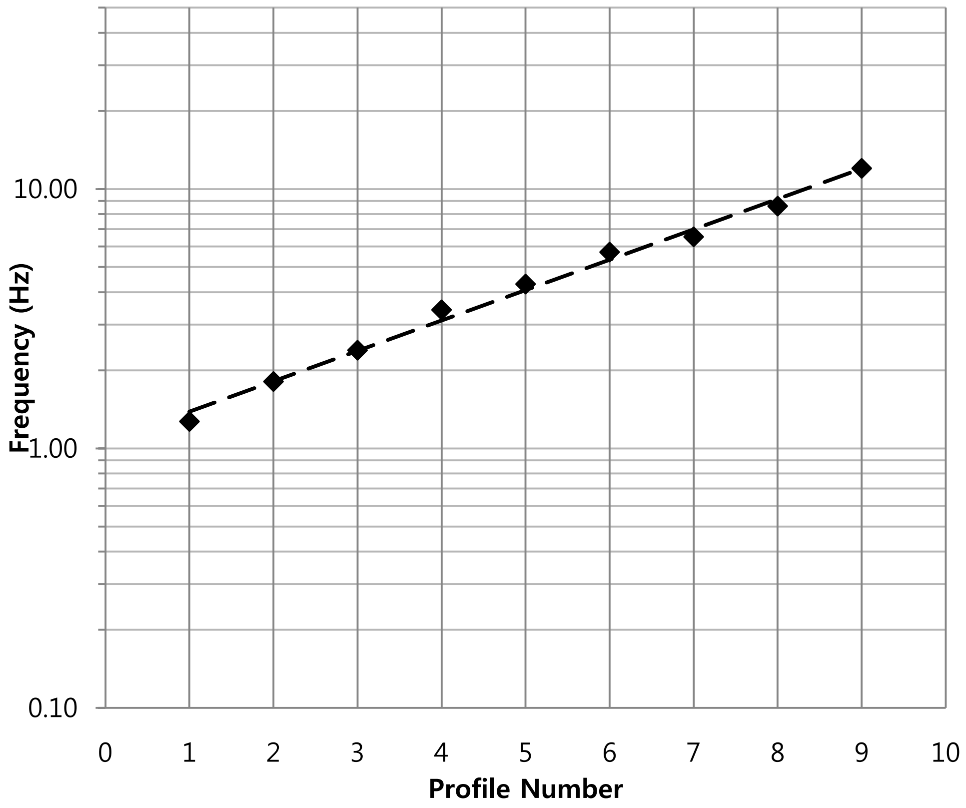
1) Features of Generic Soil Profiles (cont'd)



Generic Soil Profiles for the APR1400 Standard Design

1) Features of Generic Soil Profiles (cont'd)

- **Horizontal Fundamental Site Frequencies for Generic Soil Profiles**



Profile No.	Freq. (Hz)
1	1.27
2	1.81
3	2.39
4	3.42
5	4.30
6	5.71
7	6.54
8	8.59
9	12.01

1) Features of Generic Soil Profiles (cont'd)

- **Layer Site Category**
  - Categorized by layer thickness and depth range to bedrock

Layer Site Category	Layer Thickness and Depth Range (ft)
A	0 ~ 55
B	55 ~ 100
C	100 ~ 200
D	200 ~ 500
E	500 ~ 1,000
F	Halfspace > 1,000

1) Features of Generic Soil Profiles (cont'd)

- **Soil Profile Category**
  - Categorized by average shear wave velocity

Layer Site Category (Depth from Ground Surface)	Generic Soil Profile No.								
	1	2	3	4	5	6	7	8	9
A (0 ~ 55 ft)	P1	P1	P2	P1	P3	P2	P2	P4	P4
B (55 ~ 100 ft)	P1	P1	P2	P2	P3	P3	P3	P4	P4
C (100 ~ 200 ft)	P1	P2	P2	P3	P4	P3	P4	P4	P5
D (200 ~ 500 ft)	P2	P3	P3	P4	P4	P5	P5	P5	P5
E (500 ~ 1,000 ft)	P3	P4	P5	P5	P5	P5	P5	P5	P5
F (> 1,000 ft)	P5	P5	P5	P5	P5	P5	P5	P5	P5

No.	Velocity (ft/sec)	Soil/Rock Unit Weight (lb/ft^3)	Degradation Curve Type (EPRI)
P1	1,200	125	Sand
P2	2,000	130	Sand
P3	4,000	135	Soft Rock
P4	6,000	145	Rock
P5	9,200	155	Rock

1) Features of Generic Soil Profiles (cont'd)

- **Summary of Features**
  - Layered soil profiles to represent realistic site conditions
  - Covers wide range of sites and provides conservatism in developing standard plant seismic response parameters for design
  - A gradual transition from the lower shear wave velocity profile of the top soil-layer to the much higher shear wave velocity profile of the underlying hard rock
  - Fundamental horizontal site frequencies of the selected generic soil profiles cover a wide range of potential sites

2) Site Response Analysis

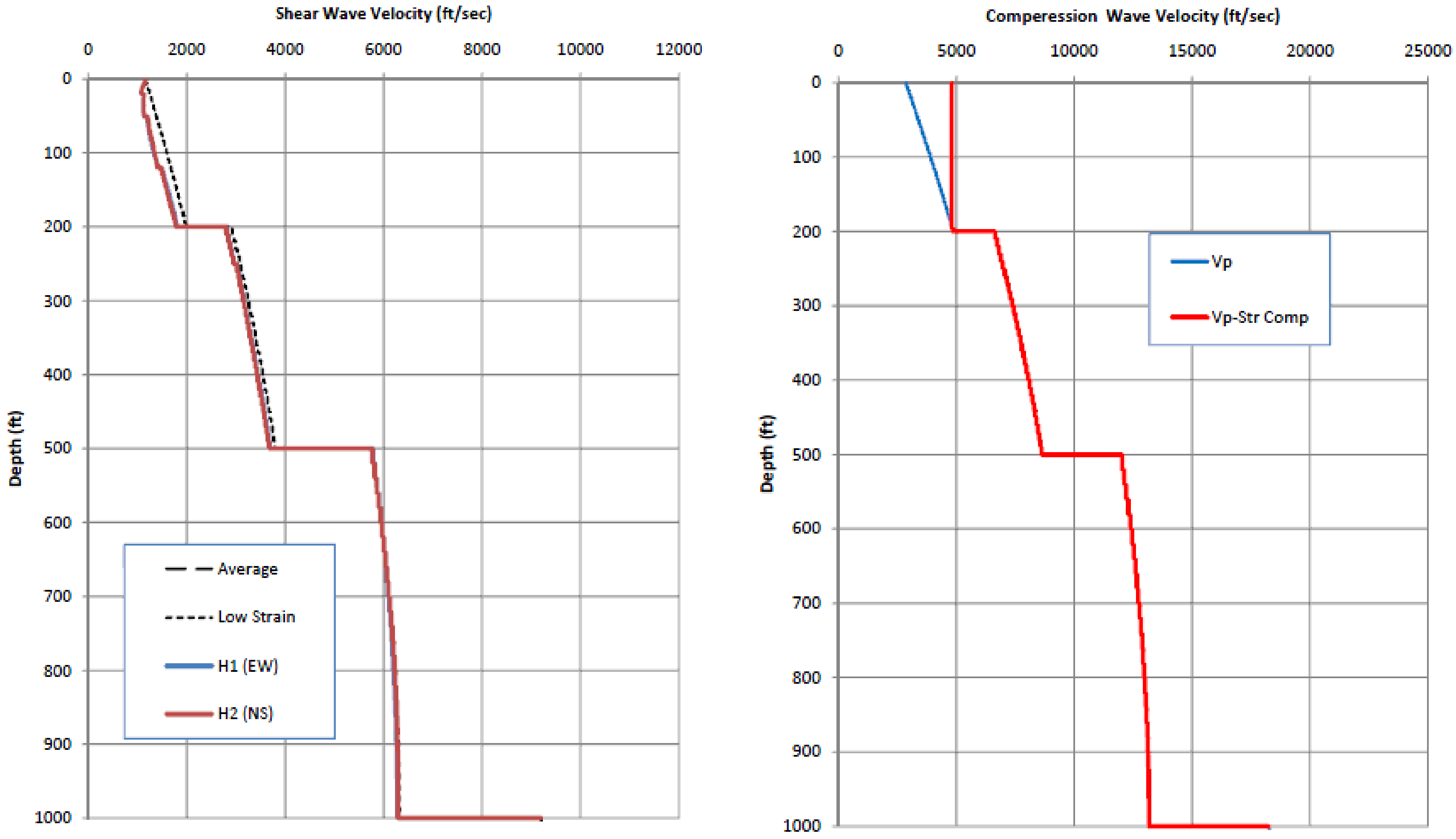
- **Purpose**
  - To generate strain-compatible seismic input motions for SSI analyses for the selected generic soil profiles
  - To calculate strain-compatible soil properties for SSI analyses
- **Analysis Code : SHAKE of Paul C. Rizzo Associates, Inc.**
  - Performed dynamic analysis of a layered soil half-space subjected to seismic input wave motions which propagate in the vertical direction
- **Seismic Input Motion**
  - Two shear wave components defined by two horizontal acceleration time histories
  - A compressional wave component defined by the vertical acceleration time history
  - Seismic input motions compatible with CSDRS applied at the free-field ground surface

2) Site Response Analysis (cont'd)

- **Soil Properties**
  - EPRI soil degradation curves (EPRI TR-102293, 1993)
    - Shear modulus reduction curves for sand and rock
    - Soil damping degradation curves for sand and rock
    - Maximum soil damping value for the horizontal site response at 15% and for the vertical site response at 10%
- **Seismic Motion Input**
  - CSDRS-compatible acceleration time histories input as control motion at the ground surface
    - H1, H2, and Vertical components input separately

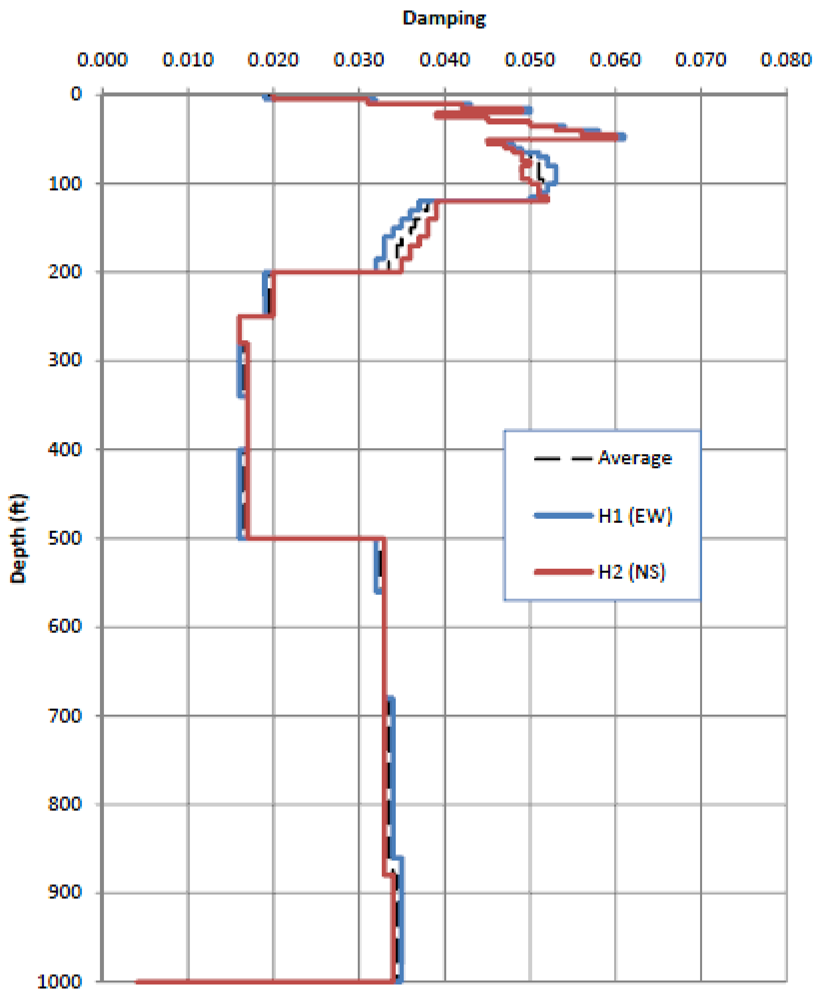
3) Analysis Results

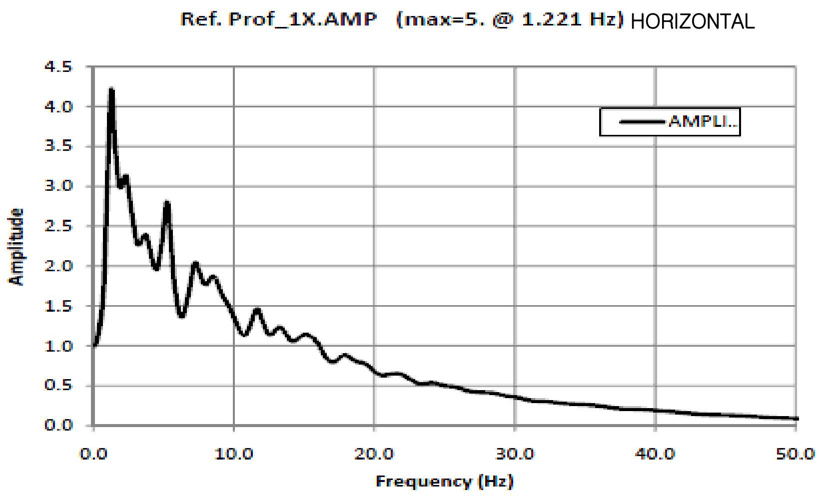
- Strain Compatible S- & P- Wave Velocity Profiles [S01]

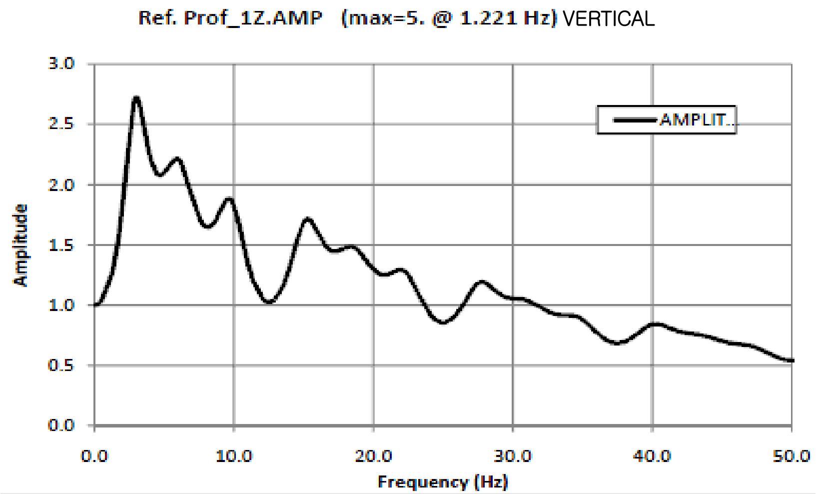


3) Analysis Results (cont'd)

- Strain Compatible Damping Profiles & TF Amplitude [S01]







Seismic Analysis of APR1400

B. SSI Analysis

B. SSI Analysis

1) Modeling
2) Verification
3) Control Point of Input Motion
4) Ground Water Level
5) Embedment
6) Concrete Cracking
7) Soil-Structure Interaction Analysis
8) Seismic Gap
9) Structure-Soil-Structure Interaction Effect
10) ISRS Development

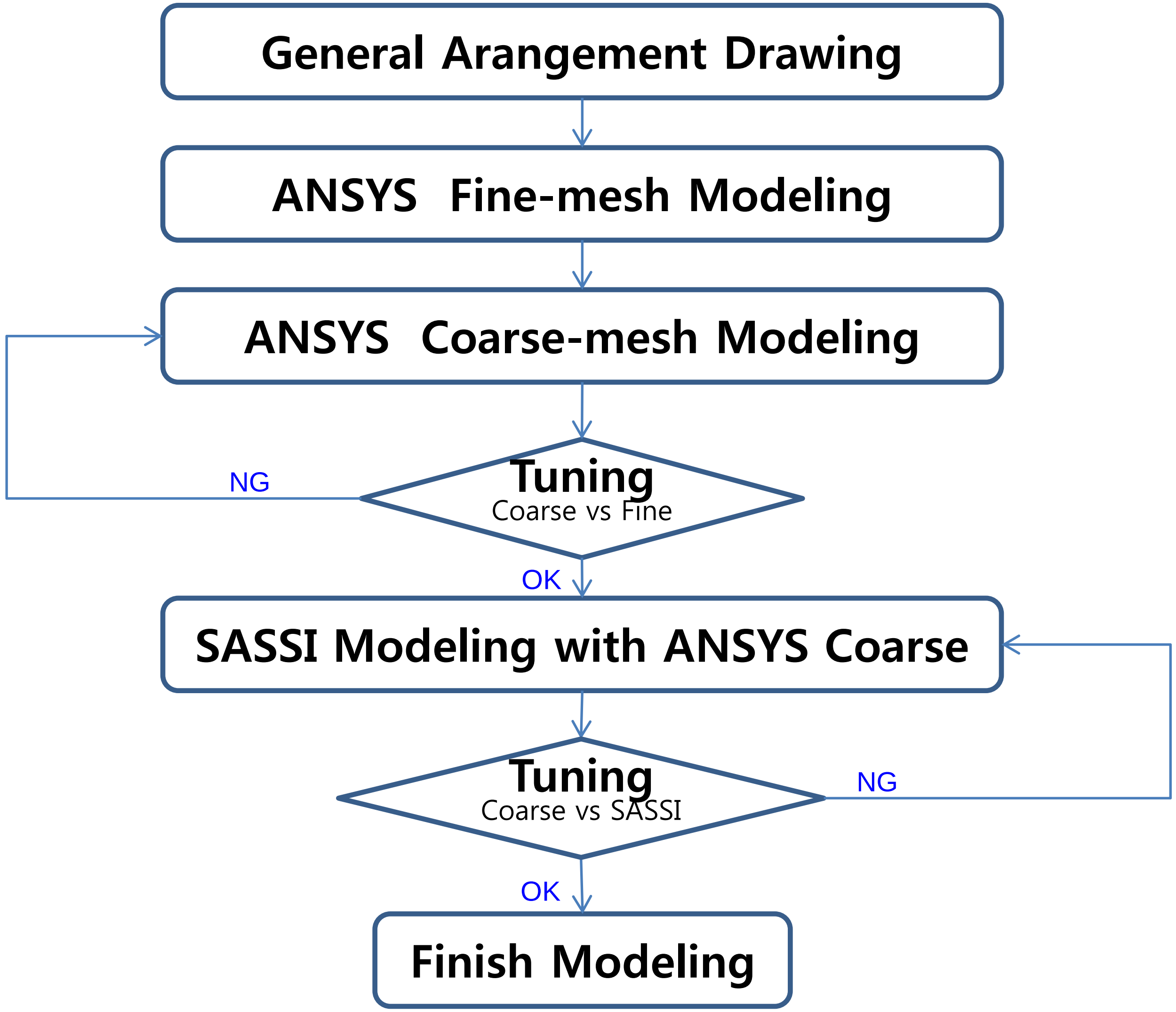
1) Modeling

- **Characteristics of NI Structure**
  - Common basemat is shared by RCB and AB.
  - RCB and AB structures are separated above basemat.
  - RCB consists of Prestressed Concrete Containment Vessel (PCCV) and Containment Internal Structure (CIS).
  - Reactor Coolant System (RCS) is incorporated into the CIS.

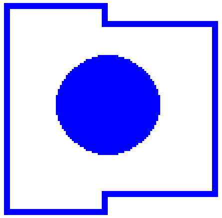
1) Modeling (cont'd)

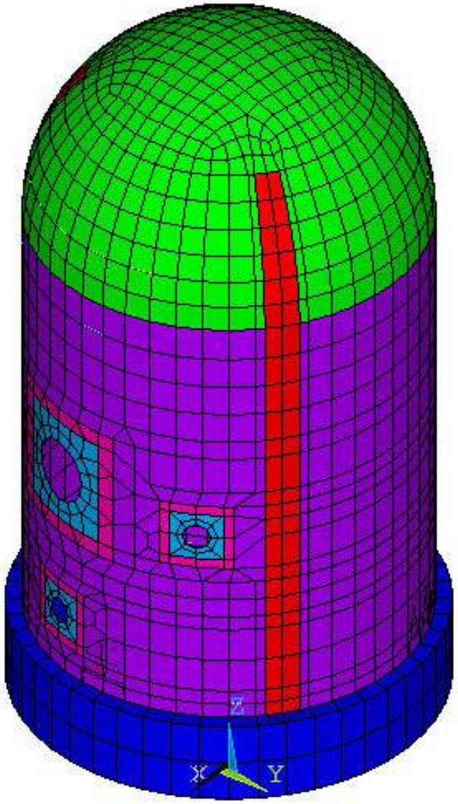
- **3-D Finite Element Modeling Process**
  - First, ANSYS fine-mesh fixed-base model is developed from the structural drawings of the NI structures.
  - Second, ANSYS coarse-mesh fixed-base model is developed and tuned to the ANSYS fine-mesh fixed-base model.
  - Thirdly, ANSYS coarse-mesh fixed-base model is converted to SASSI fixed-base model matching dynamic characteristics of the ANSYS coarse-mesh model.
  - Finally, Fixed-Base Model Validations are performed as follows:
    - ➢ ANSYS coarse-mesh model vs. ANSYS fine-mesh model
    - ➢ SASSI model vs. ANSYS coarse-mesh model
  - The 3-D FEM mesh is refined to ensure fidelity of response at least up to 50 Hz according to DC/COL-ISG-01.

1) Modeling (cont'd)

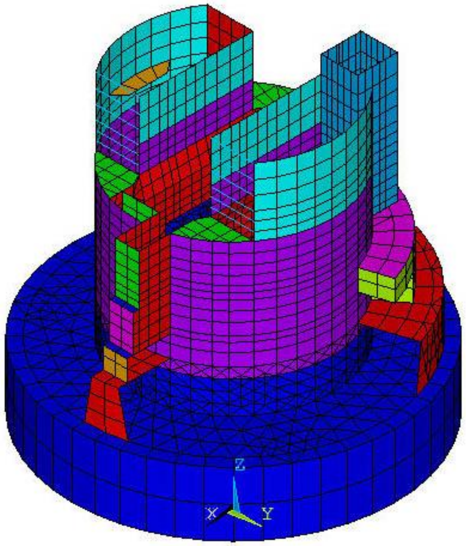


1) Modeling for RCB Coarse-mesh



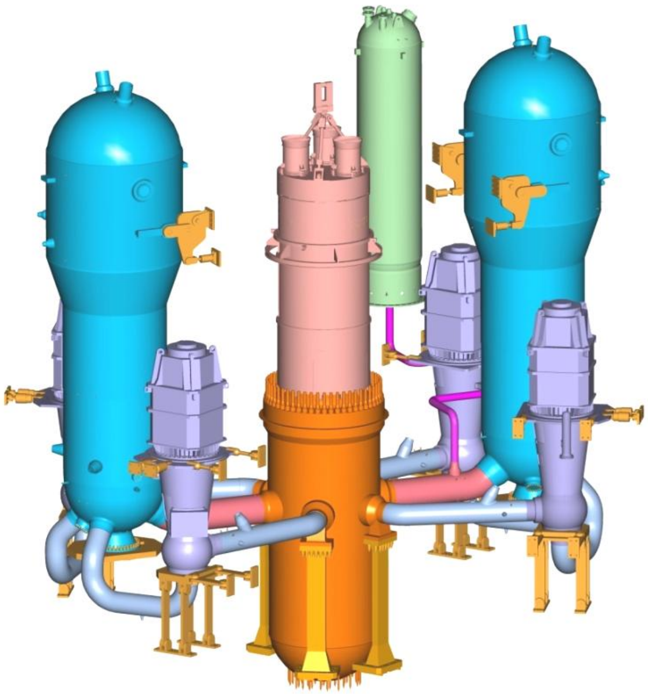


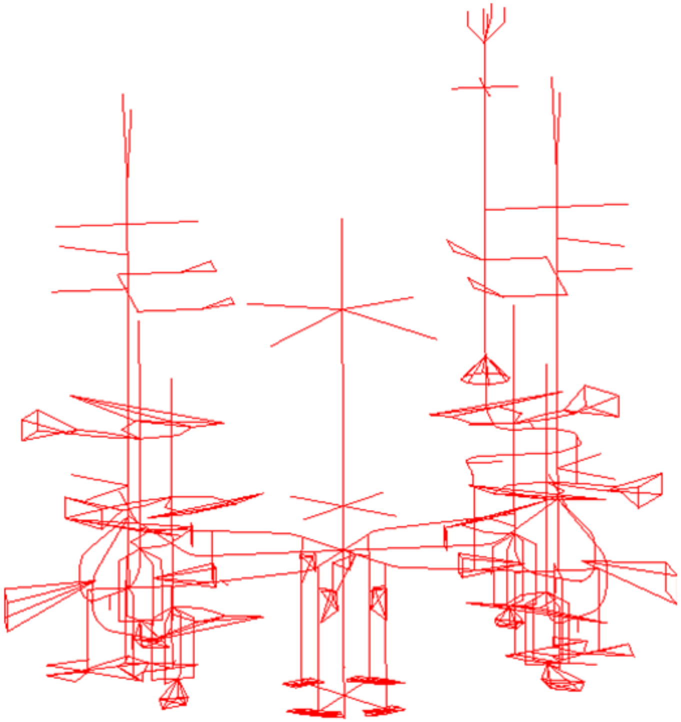
Reactor Containment Shell



Containment Internal Structure

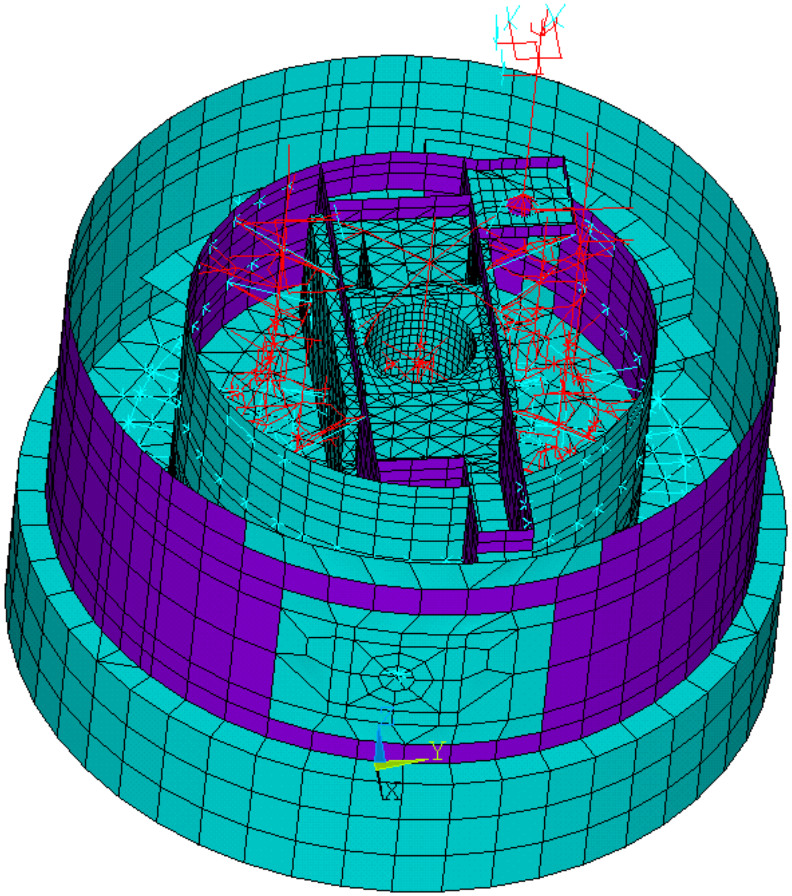
1) Modeling for RCS





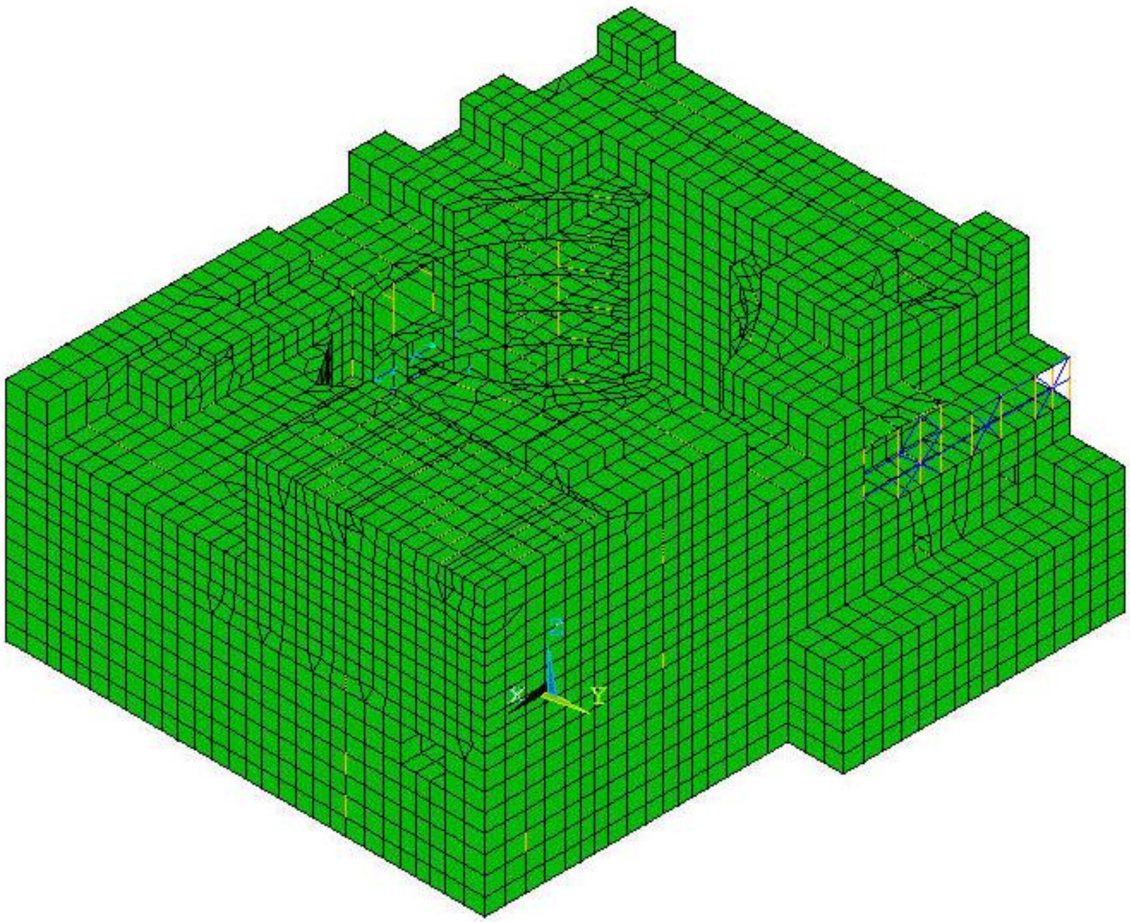
RCS Isometric View

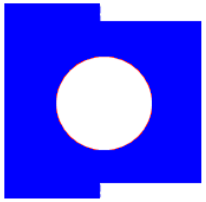
1) Modeling for RCS (cont'd)



Containment Internal Structure incorporated with RCS

1) Modeling for AB Coarse-mesh





Auxiliary Building Coarse Mesh

1) Modeling (cont'd)

- **Structural Components of RCB and AB Coarse-mesh**

Component	Data
Total No. of Node	32,778
Structural Node	23,524
Interaction Node	9,254
Total No. of Element	59,045
Solid	35,113
Beam	4,037
Shell	17,974
Spring	1,906
Matrix	15
No. of Concentrated Mass	1,452

1) Modeling (cont'd)

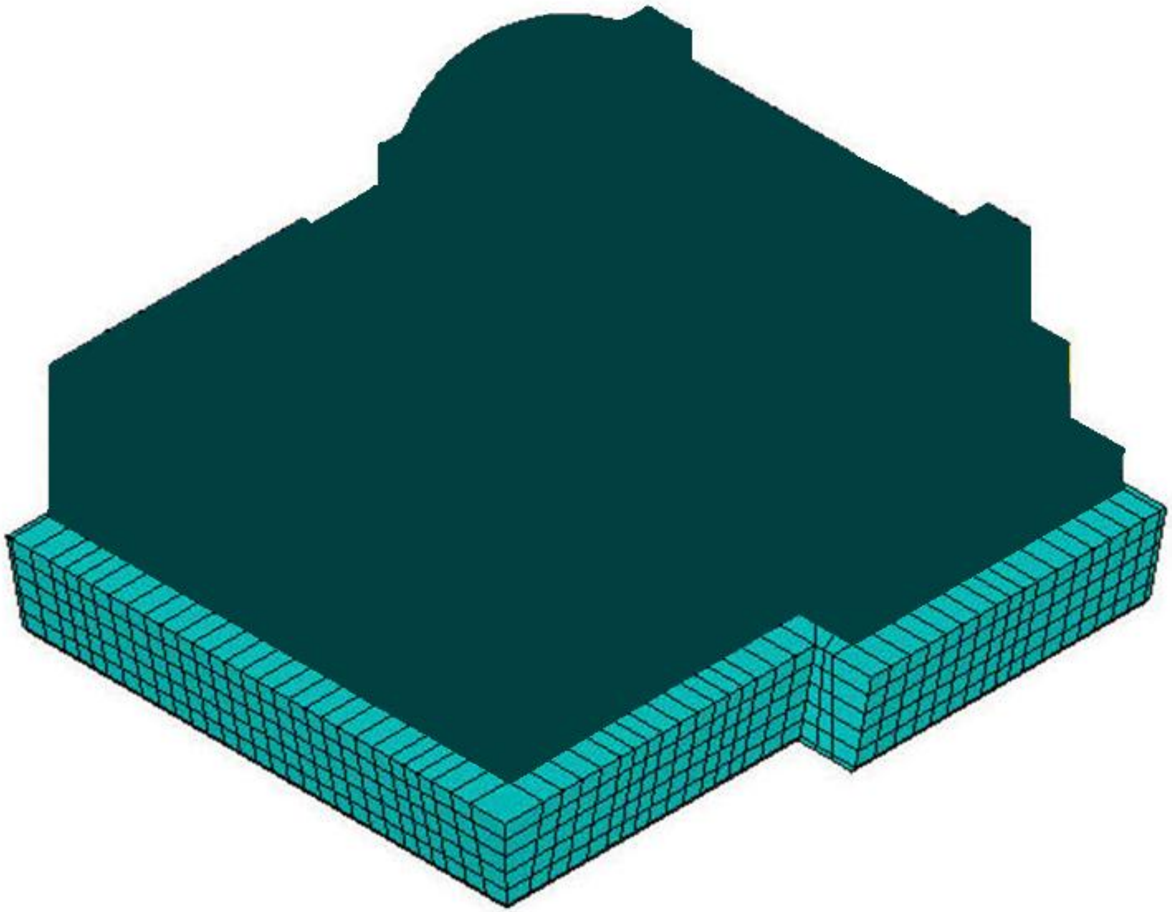
- **Excavation Volume**
  - The common basemat is a 10-ft-thick base slab with 55-ft of embedment depth to the bottom of basemat.
  - There are seismic gaps of 3 ft between AB and CPB and between AB and TGB.
  - Soil Excavation Volume

Parameter	Data
Total No. of Soil Layers	5
Layer Thickness	11 ft
No. of Interaction Nodes	9,254 (Direct Method Used)
Cut-off Frequency of Soil Model	20 ~ 120 Hz

1) Modeling (cont'd)

- **Lean Concrete under Basemat and Side Soil Backfill with SFG**
  - The 3-ft deep over-excavation beneath the bottom of the basemat and backfilled with lean concrete
  - A side excavation varying from 12 ft at the bottom to 24 ft at the surface
  - The 3 ft of side excavation between adjacent buildings and backfilled with Structural Fill Granular (SFG)

1) Modeling for RCB and AB Combined Coarse-mesh with Side Soil



2) Verification

- **Verification of ANSYS fixed-base models**
  - To verify ANSYS fixed-base models, apply 1g static lateral loads and check drift displacements following SRP 3.7.2.
  - Compare the drifts obtained from ANSYS coarse- and fine-mesh models.
  - Verify each part of the building with 1g static analyses.
    - ➢ Reactor Containment Shell
    - ➢ Containment Internal Structure
    - ➢ Auxiliary Building

2) Verification (cont'd)

- **Verification of dynamic properties of the ANSYS models by Modal Analysis**
  - To verify dynamic properties of the ANSYS models, Modal Analyses of the fixed-base coarse- and fine-mesh models are performed
  - Compare the Major Natural Frequencies, Mode Shapes, and Cumulative Modal Participation Mass Ratios between the Coarse- and Fine-mesh ANSYS Models
  - Each part of the Buildings is verified with Eigenvalue Analysis
    - ➢ Reactor Containment Shell
    - ➢ Internal Structure
    - ➢ Auxiliary Building

2) Verification (cont'd)

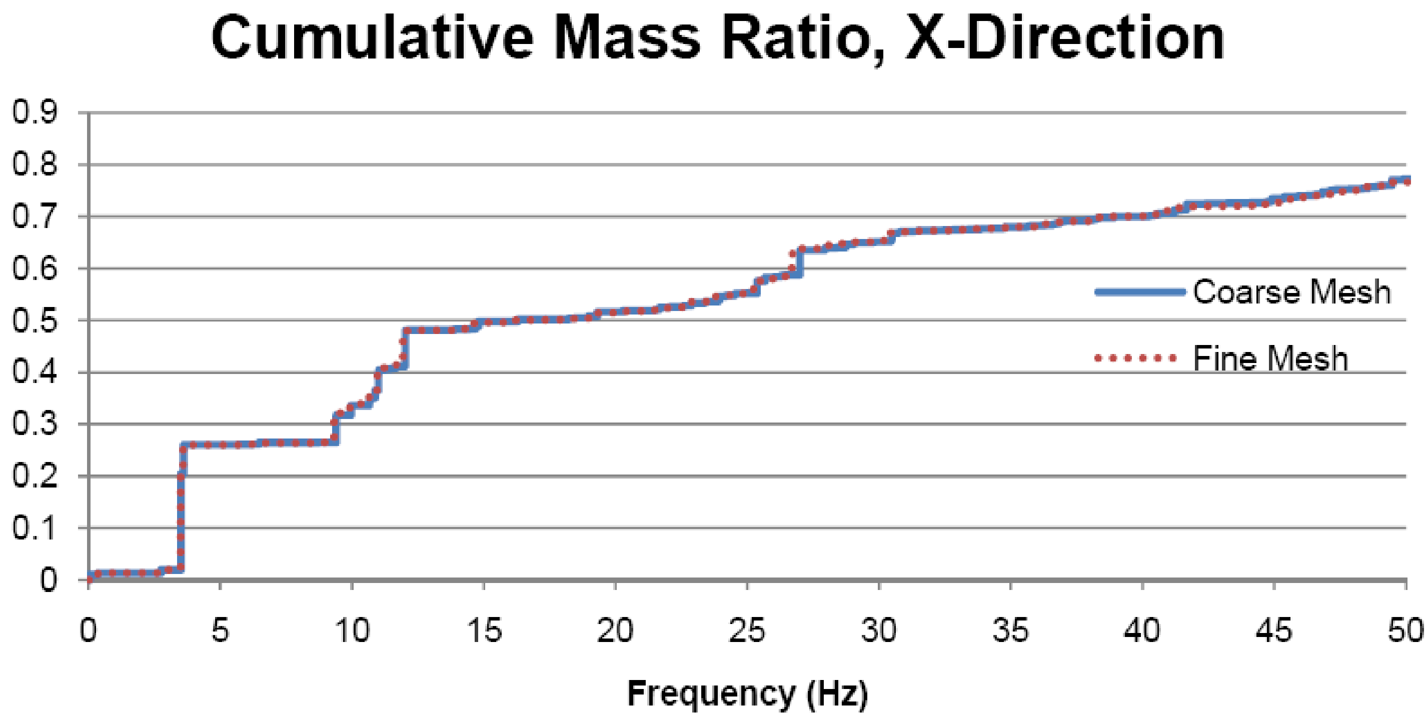
- **Eigenvalues of fine and coarse models**

Reactor Containment Shell

	Natural Frequency (Hz)		Modal Mass Ratio		Direction
	Fine	Coarse	Fine	Coarse	
1st	3.50	3.51	18%	19%	X (EW)
2nd	3.59	3.61	16%	16%	Y (NS)
3rd	10.61	10.65	21%	15%	Z (Vertical)
4th	10.65	10.70	6%	11%	Z (Vertical)
5th	19.52	19.82	2%	1%	(Drumming mode)

2) Verification by Eigenvalue Analysis (cont'd)

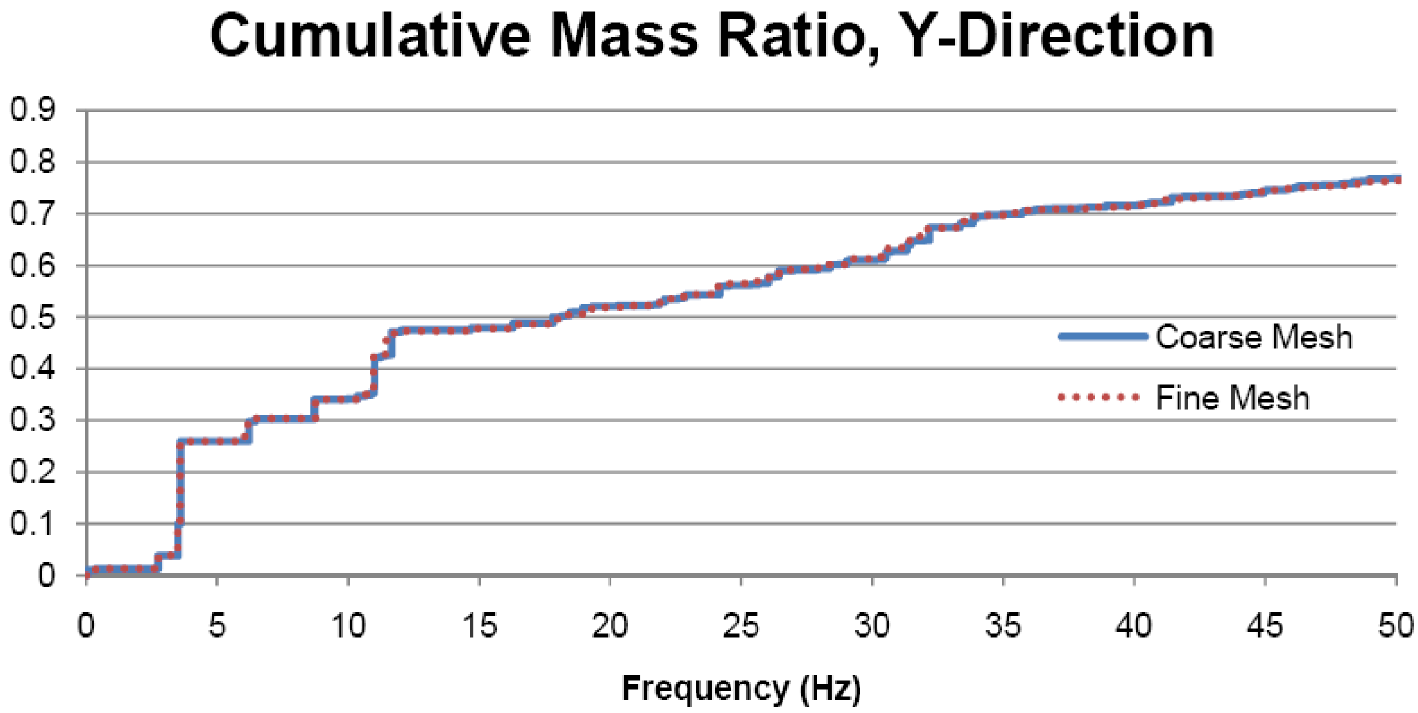
- **Reactor Containment Shell**



Comparison CMR between Coarse and Fine-mesh

2) Verification by Eigenvalue Analysis (cont'd)

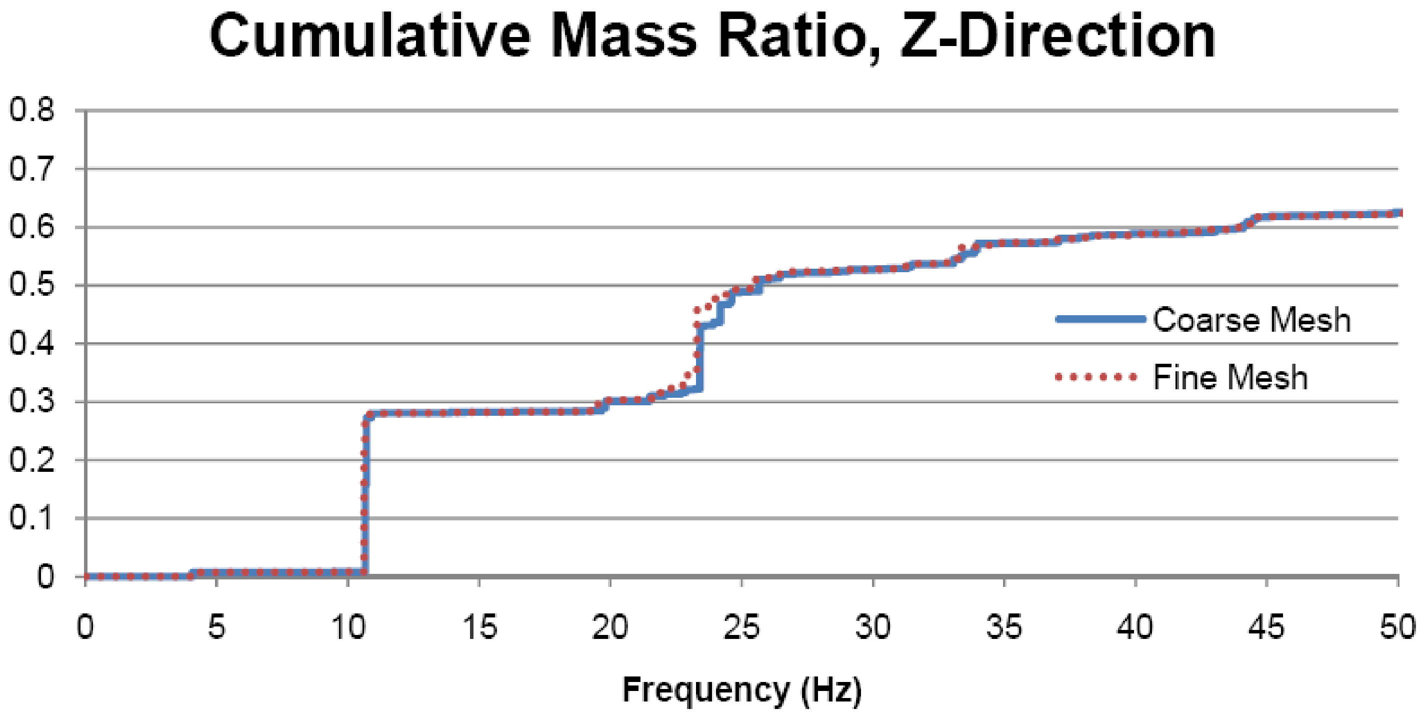
- **Reactor Containment Shell**



Comparison CMR between Coarse and Fine-mesh

2) Verification by Eigenvalue Analysis (cont'd)

- **Reactor Containment Shell**



Comparison CMR between Coarse and Fine-mesh

2) Verification (cont'd)

- Eigenvalues of fine and coarse models

Primary and Secondary Shield Walls

	Natural Frequency (Hz)		Mass Ratio		Direction
	Fine	Coarse	Fine	Coarse	
1st	6.05, 6.44	6.21, 6.45	4%	4%	Y (NS)
2nd	9.33	9.41	6%	5%	X (EW)
3rd	8.75	8.71	4%	4%	Y (NS)
4th	9.91	9.97	2%	2%	X (EW)
5th	23.29, 23.30	23.40, 23.42	11%	11%	Z (Vertical)

2) Verification (cont'd)

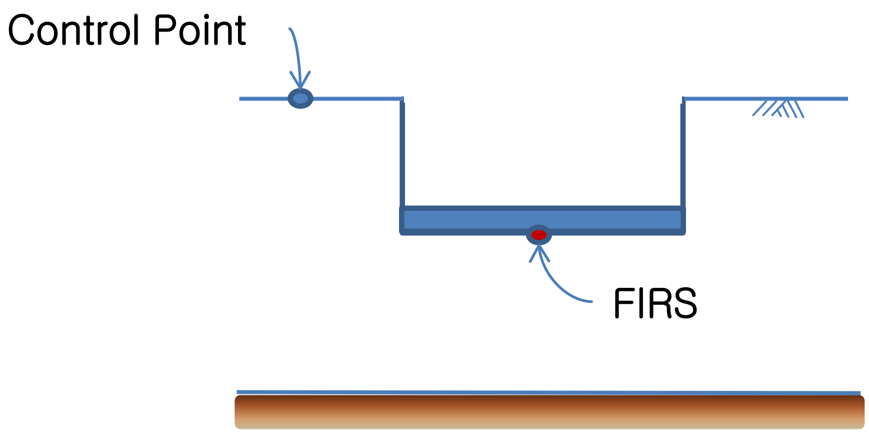
- **Eigenvalues of fine and coarse models**

Auxiliary Building

	Natural Frequency (Hz)		Mass Ratio		Direction
	Fine	Coarse	Fine	Coarse	
1st	5.14	5.16	18%	18%	EW
2nd	5.33	5.79	11%	14%	EW
3rd	5.33	5.35	37%	38%	NS
4th	5.14	5.16	12%	12%	NS
5th	10.61	10.66	20%	15%	VT
6th	10.65	10.70	6%	11%	VT

3) Control Point of Input Motion

- **Control Point**
  - At the Surface of Finished Grade in the Free Field of each soil profile
  - COL Applicant should compare FIRS (Foundation Input Response Spectrum) with the site specific GMRS (Ground Motion Response Spectrum)



4) Ground Water Level

- **Max. Design Ground Water Level in normal condition**
  - 2 ft below grade level
- **Compression Wave Velocity (Vp) of soils below water level**
  - Vp of water is set at 4,800 ft/s.
  - For design purposes, the Vp of soils below the design ground water table level is taken to be not less than 4,800 ft/s.

5) Embedment

- **Considerations of Embedment**
  - Building foundation is modeled as embedded configuration.
  - Flexibility of embedded portion of the structure is considered.
  - Direct Method is used for calculation of soil impedances and seismic input motion vectors for the excavated volume below ground surface.
  - Subtraction Method and Modified Subtraction Method are not used for the APR1400 SSI Analyses.

6) Concrete Cracking

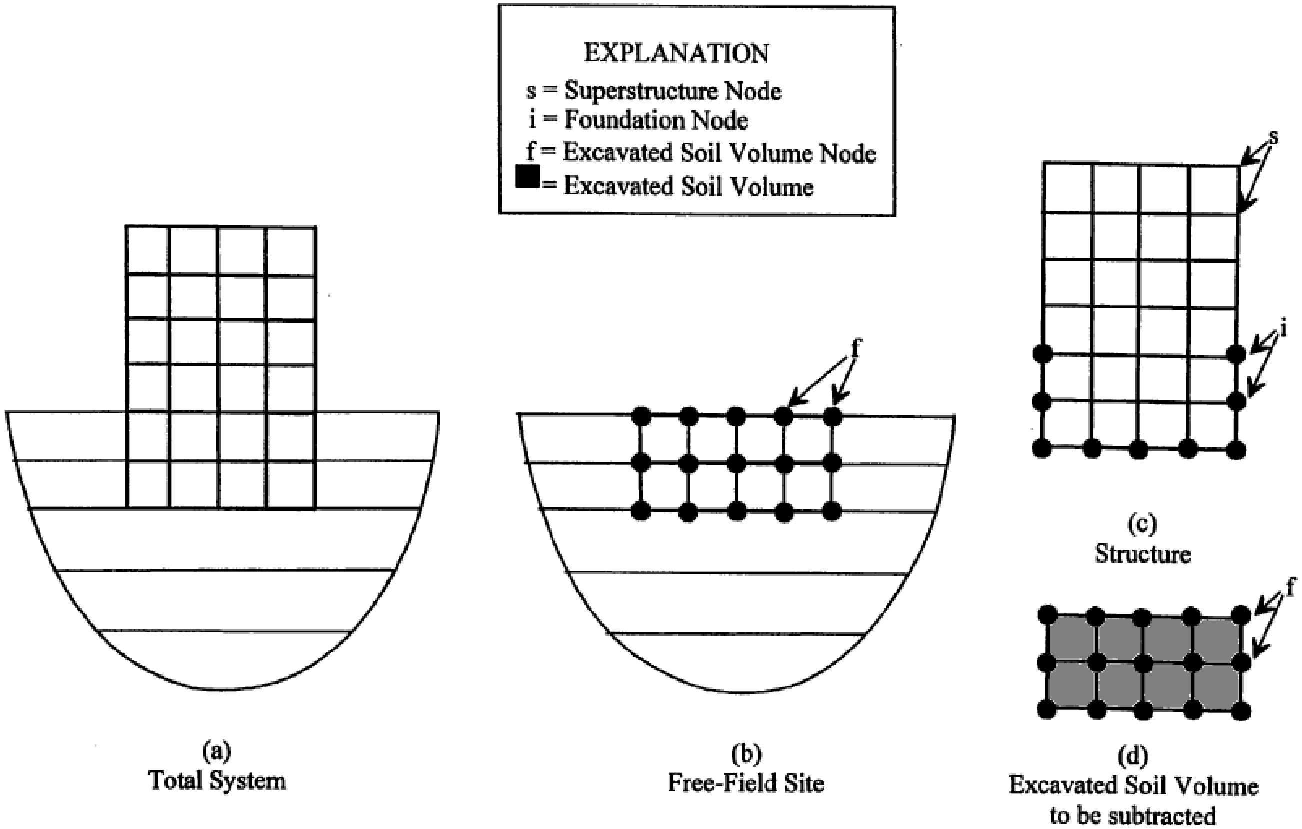
- **Bounding SSI analyses**
  - Concrete stiffness reduction factor according to guidelines of ASCE 43-05
  - Uncracked concrete stiffness reduction factor: 1.0
  - Cracked concrete stiffness reduction factor: 0.5
- **ISRS (In-Structure Response Spectrum)**
  - The enveloping ISRS is generated from the ISRS of uncracked- and cracked-concrete cases.
  - This will ensure the bounding SSI analysis.
- **OBE** and SSE damping values
  - RG 1.61, Rev. 1

	ISRS Generation	Member Force
Uncracked-Concrete	**OBE damping**	**-**
Cracked-Concrete	**SSE damping**	**SSE damping**

7) Soil-Structure Interaction Analysis

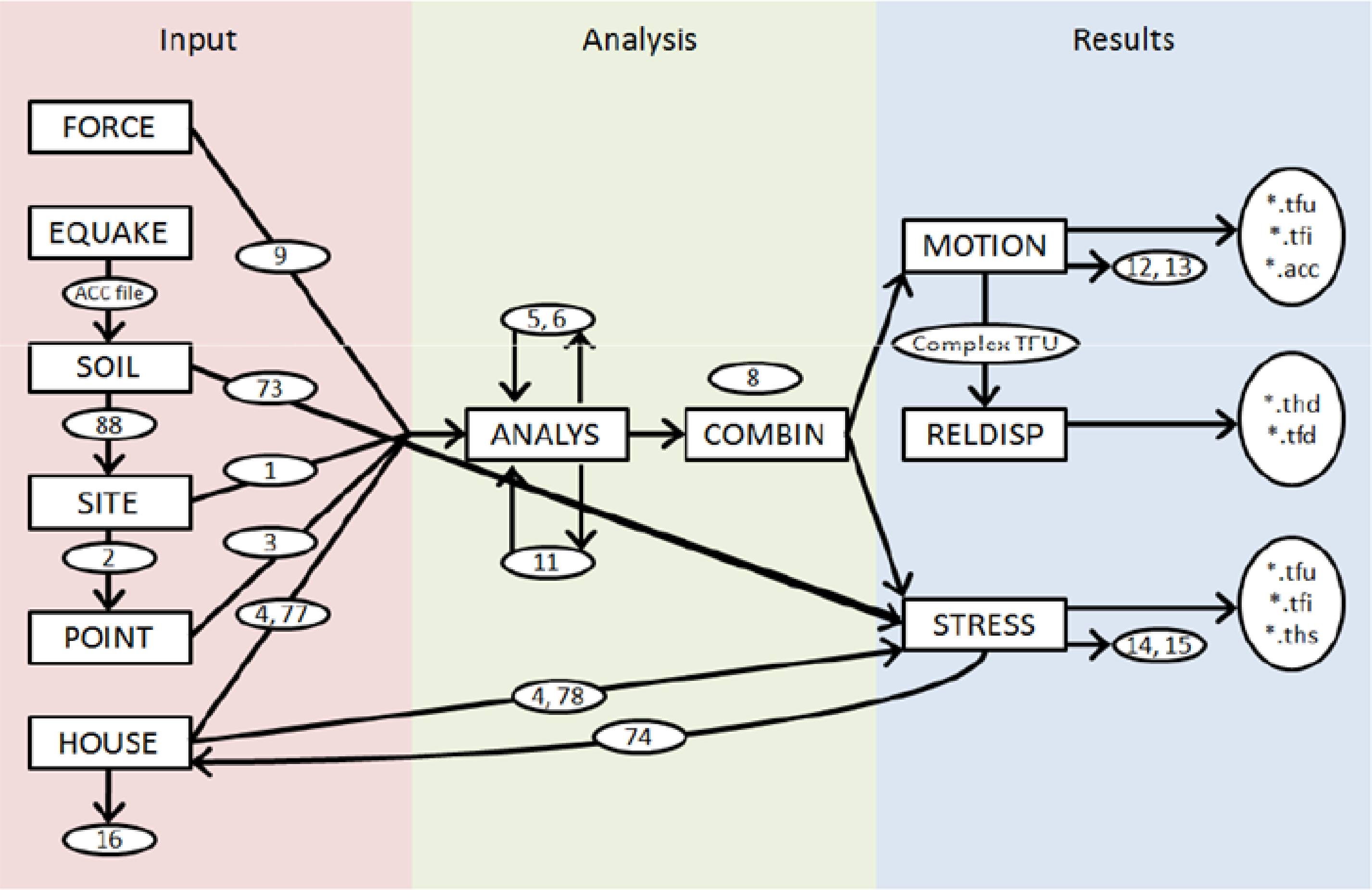
- **Dynamic Sub-Structuring Method**
  - SSI analysis of the APR1400 NI Buildings considers the actual embedded common basemat foundation configuration.
- **SSI Analysis Computer Code**
  - ACS SASSI FS NQA Ver. 2.3.0 released on Feb. 2012 by Ghiocel Predictive Technologies (GPT) is used.

7) Soil-Structure Interaction Analysis (cont'd)



Concept of SASSI Direct Method

7) Soil-Structure Interaction Analysis (cont'd)

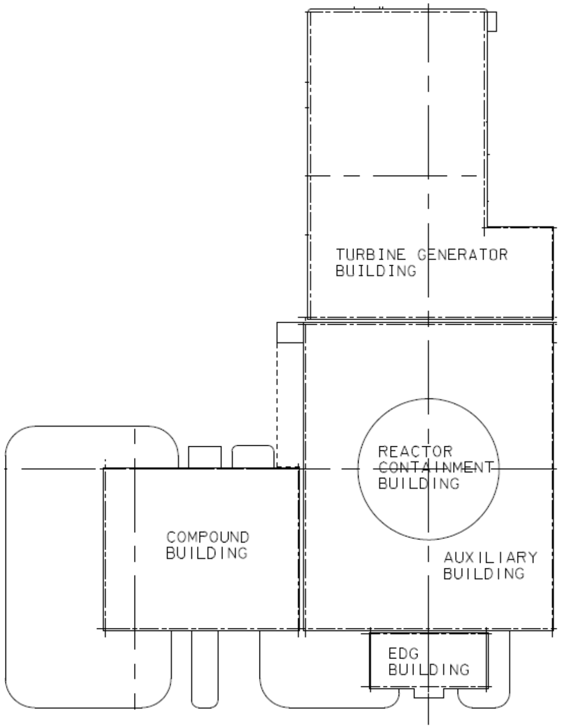


SSI Analysis Procedure of ACS SASSI

8) Seismic Gap

- **Seismic Gap between Buildings**

Buildings	Gap (ft)
AB to EDGB	3
AB to CPB	3
AB to TGB	3



- **Seismic Gap Check**
  - Check with relative displacements (relative to the free-field input motion) between buildings)

9) Structure-Soil-Structure Interaction Effect

- **Modeling**
  - Two adjacent buildings together
- **SSSI Analysis Model**
  - The structures are assumed to be surface-supported due to model size limitation of the SASSI code.
  - The SASSI model for two structures is too big to be analyzed as embedded structures.
- **SSSI Effect on Seismic Response**
  - The results of SSSI analysis are compared with those of the corresponding SSI analysis for each building considered as a surface-supported structure.

10) ISRS Development

- **Criteria**
  - Reg. Guide 1.61 and 1.122
  - SRP 3.7.2
- **ISRS of the APR1400**
  - Enveloping results for all nine soil cases and the fixed-base case
  - Enveloping results for the uncracked- and cracked-concrete conditions
  - Generated for 0.1 to 100 Hz
  - Spectrum broadening to account for uncertainty: 15% on both side of peak
  - Damping values: 2, 3, 4, 5, 7, and 10%
  - Frequency-dependent damping value in accordance to RG 1.61

Seismic Analysis of APR1400

C. Hard Rock High Frequency Response Spectrum

C. Hard Rock High Frequency Response Spectrum

1) HRHF RS for CEUS
2) Comparison between EPRI program and NRC/EPRI/DOE project
3) Coherency Functions
4) Evaluation of SSCs

1) HRHF RS for CEUS

- **Recent studies on CEUS seismic hazard:** increased the high frequency motion for rock sites
  - Program on Technology Innovation: Sensitivity of Performance-Based Approaches for Determining the Safe Shutdown Earthquake Ground Motion for New Plant Sites(EPRI, 2006)
  - Assessment of Seismic Hazard at 34 US Nuclear Plant Sites(EPRI, 2008)

1) HRHF RS for CEUS (cont'd)

- **New CEUS GMRS**
  - EPRI Product ID: 1023389, May 2011: "Evaluation of seismic hazard at Central and Eastern US nuclear power plant sites"
  - Its objective was to calculate the site-specific seismic hazards at 60 CEUS sites using up-to-date seismic source characterization (SSC) model and ground motion equations.
  - Site-specific hazard was calculated at 60 CEUS sites using the 2008 USGS Seismic Source Model.

1) HRHF RS for CEUS (cont'd)

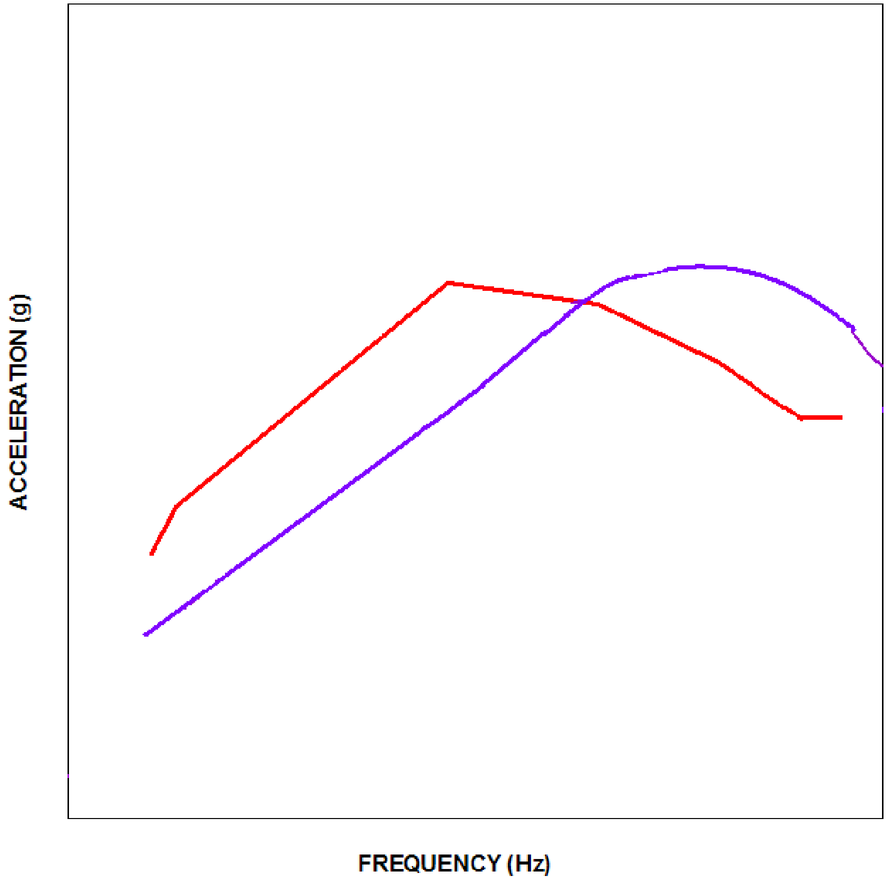
– EPRI program

- Ground motion equations were developed by the EPRI (2004) specifically for the CEUS. These consist of estimates of mean log spectral acceleration for seven structural frequencies (0.5, 1, 2.5, 5, 10, 25, and 100 Hz) and estimates of logarithmic standard deviation.
- Based on the hazard calculations at each of the 60 sites, the GMRS was calculated following Reg. Guide 1.208.
- Seismic hazard results are presented in the form of GMRS and UHRS for an annual frequency of exceedence of 10^{-5}.

KEPCO determined HRHF RS from EPRI program (May, 2011).

1) HRHF RS for CEUS (cont'd)

- **Evaluation of Standard Plant Design**
  - Using CEUS rock spectra presented in the May 2011 EPRI Report



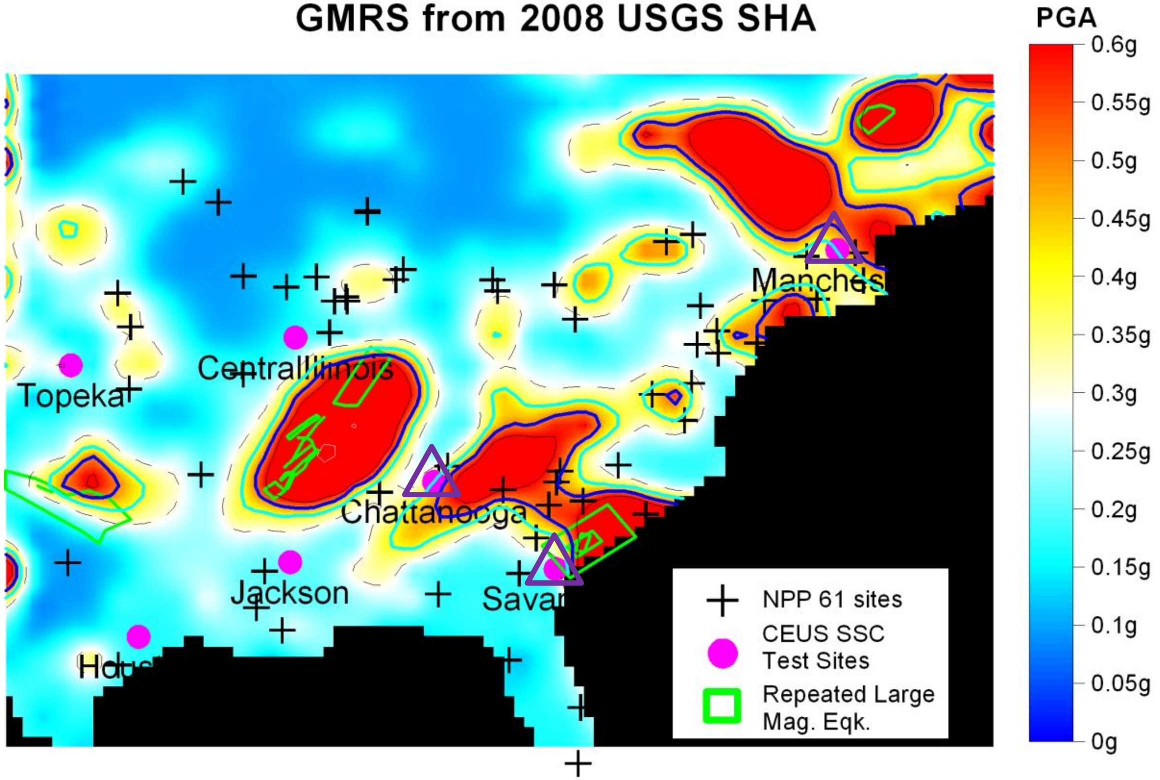
2) Comparison between EPRI program and NRC/EPRI/DOE project

- NRC/EPRI/DOE have recently updated Seismic Source Characterization (SSC) model for CEUS (2011).
  - PSHA was conducted for three frequencies (1hz, 10hz, PGA) at seven test sites by using 2004/2006 EPRI Ground-Motion attenuation relations.
  - Comparison was made between the PSH levels resulting from the new 2011 CEUS SSC, 2008 USGS, and COLA models at the seven test sites.
- The performance-based GMRS levels for 2008 USGS model for the three test sites are all above or similar to those for 2011 CEUS SSC model.
- Quantitative level of site coverage for APR1400 HRHF RS can be evaluated once the result of R2.1 seismic reevaluation project is available.

2) Comparison between EPRI program and NRC/EPRI/DOE project

- Spectral values of performance-based GMRS at 3 frequencies were calculated for the 3 test sites just near the high seismicity region (PGA= ~ 0.4g) by using the PSHA curves for 2008 USGS and 2011 CEUS SSC model from the 2011 NRC/EPRI/DOE CEUS SSC report

Basemap : PGA Map of Performance-based GMRS from 2008 USGS SHA



Contour line
—— : 0.6g
—— : 0.5g
—— : 0.4g
---- : 0.3g

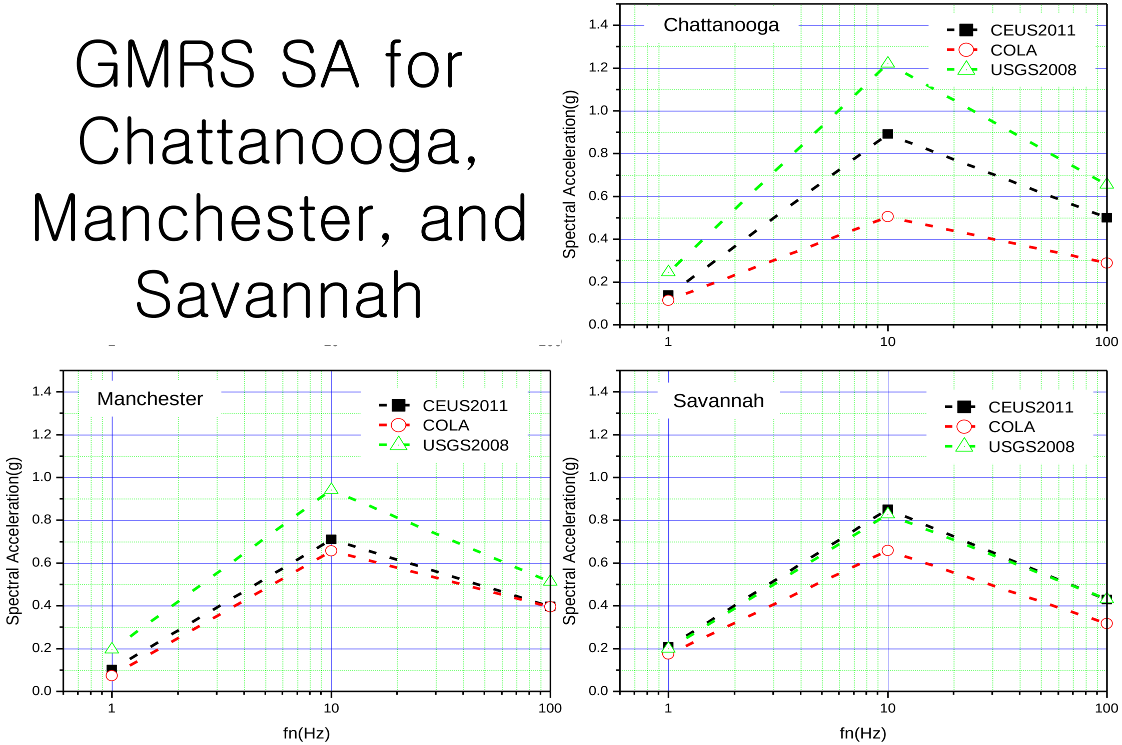
O : high seismicity region with 12 NPP sites in it

△ : 3 test sites near the high seismicity region
- Chattanooga
- Manchester
- Savanna

2) Comparison between EPRI program and NRC/EPRI/DOE project

- The other 4 test sites are not considered because they are all in the low seismicity region (PGA < ~ 0.3g) that are less relevant to site coverage of APR1400
- Comparison of spectral values of performance-based GMRS for 2008 USGS and 2011 CEUS SSC model at 3 test sites near a high seismicity region

GMRS SA for Chattanooga, Manchester, and Savannah



3) Coherency Functions

- Implementation of incoherent input motion by using INCOH code.
- Incoherent ground motion vector input to ACS SASSI FS Rev. 2.3.0.
  - Coherency model proposed by Abrahamson (2007) for hard rock sites will be used.
  - SSI responses for at least seven principal coherency modes will be combined by the SRSS combination rule to obtain the seismic response to incoherent motion input.
  - Sensitivity to SSI responses due to higher principal coherency modes will be evaluated in accordance with SRP guidelines.
  - Alternatively, SASSI-Simulation method option can be considered based on DC/COL-ISG-01.

3) Coherency Functions (cont'd)

- Methodology
  - Coherency function
    - Empirical coherency function developed by Abrahamson (2007): Hard rock site

$$|\gamma(f,\xi)| = \left[1+\left(\frac{f}{a_1 f_c(\xi)}\tanh(a_3\xi)\right)^{n_1}\right]^{-1/2}\left[1+\left(\frac{f}{a_2 f_c(\xi)}\tanh(a_3\xi)\right)^{n_2(\xi)}\right]^{-1/2}$$

4) Evaluation of SSCs

- If analysis results considering the incoherent-motion SSI analysis are larger than the results from the design basis SSI analysis, then seismic capacities of the structures, systems, and components (SSCs) will be examined as follows:
  - NI (RCB, AB) structures
  - RCS
  - Mechanical and electrical equipment/components
- Identification and evaluation of HF sensitive mechanical & electrical equipment/components
  - Screening procedure and justification of HF sensitive equipment/components following the relevant EPRI White Paper
  - Justification for screened-out equipment/components
  - Evaluation of screened-in equipment/components

Seismic Analysis of APR1400

D. Summary of Structure Part

Summary of Structure Part

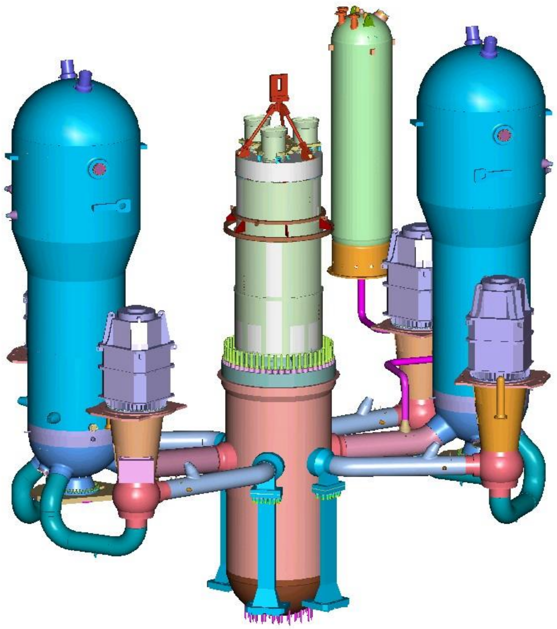
- Seismic analysis of the APR1400 is being performed in accordance with the NRC's guidelines and requirements.
- The CSDRS increased by 30% of the spectral acceleration at 25 Hz as compared to DGRS of Reg. Guide 1.60.
- To consider the high frequency contents of CEUS, the HRHF RS was determined from EPRI report.
- The recorded Northridge earthquake (1994) as the seed motion and Approach 2 of Option 1 methodology in SRP 3.7.1 are applied to the artificial time history.
- Nine soil profiles and one fixed-base condition are applied as the generic soil profile.

Summary of Structure Part

- The 3-D finite element model is used to obtain the seismic response in the high frequency.
- The SSI analysis of the structure is performed in the embedded condition.
- The ISRS are enveloped for both the uncracked- and cracked-concrete condition.
- The control point is defined at the free-field ground surface.
- The spatial wave incoherency analysis will be used to reduce the high frequency response due to the HRHF RS.

Seismic Analysis of APR1400

- System Part
  - A. Overview of Seismic Analysis
  - B. Seismic Analyses for RCS, RI and Core
  - C. Summary of System Part



Seismic Analysis of APR1400

A. Overview of Seismic Analysis

A. Overview of Seismic Analysis

1) Regulations and Guides
2) Code and Standard

1) Regulations and Guides

- **<u>10 CFR Part 50 Appendix A, General Design Criteria 2:</u>**

  Design Bases for Protection against Natural Phenomena

- **<u>10 CFR Part 50 Appendix S:</u>** Earthquake Engineering Criteria for Nuclear Power Plants
  - OBE elimination
    - ➢ Safe Shutdown Earthquake (SSE) : 0.3g
    - ➢ Operating Basis Earthquake (OBE) : 0.1g

1) Regulations and Guides (cont'd)

- **RG 1.29 (Rev.04):** Seismic Design Classification
- **RG 1.61 (Rev.01):** Damping Values for Seismic Design
- **RG 1.92 (Rev.02):** Combining Modal Responses and Spatial Components in Seismic Response Analysis
- **RG 1.122 (Rev.01):** Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components
- **SRP 3.2.1 (Rev.3):** Seismic Classification
- **SRP 3.7.2 (Rev.3):** Seismic System Analysis
- **SRP 3.7.3 (Rev.3)** Seismic Subsystem Analysis

2) Code and Standard

- **ASME Code Section III, Division 1 Appendices**

  Nonmandatory Appendix N: Dynamic Analysis Methods

  - One or more acceptable steps for seismic dynamic analysis.

Seismic Analysis of APR1400

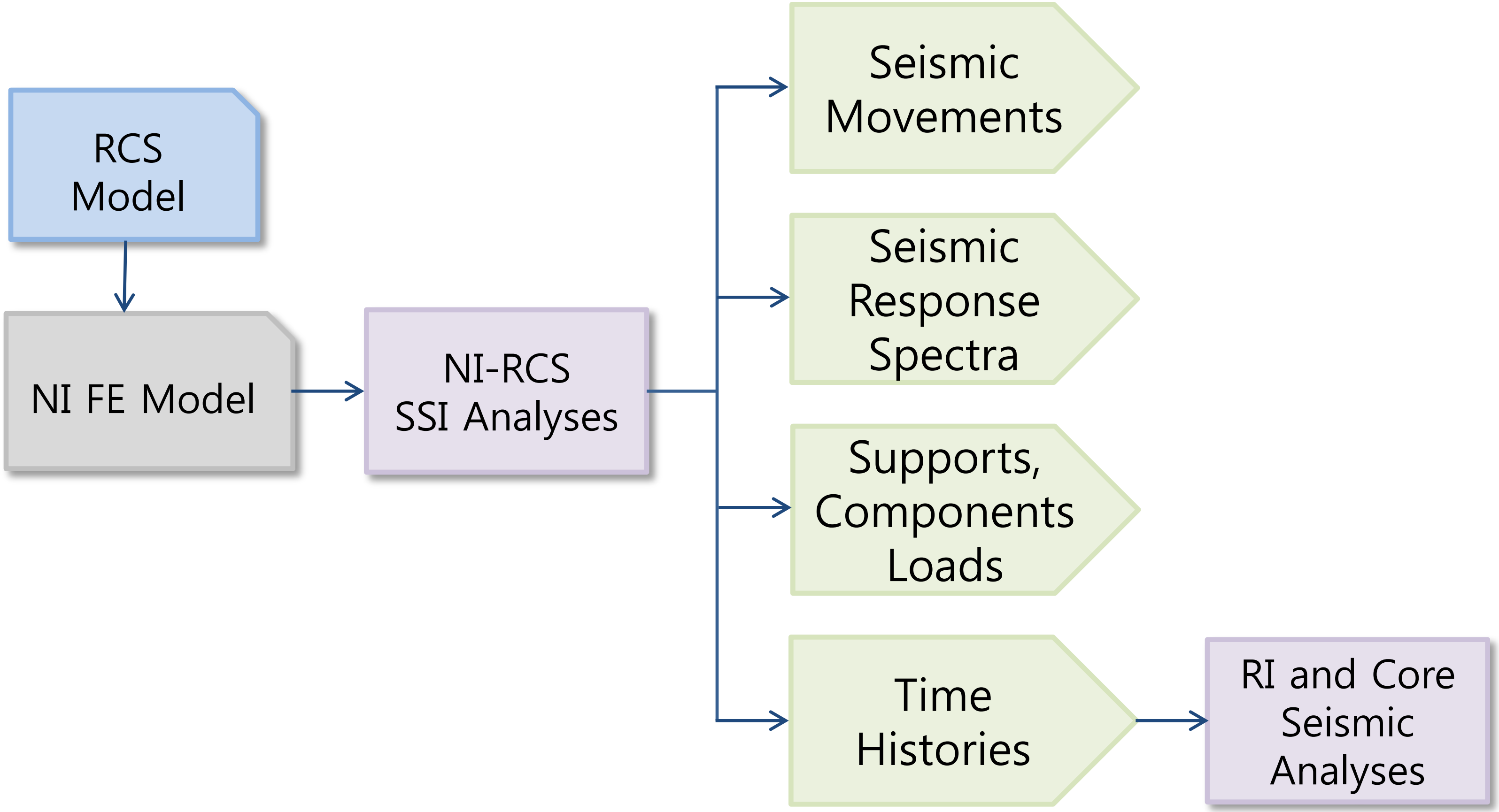
B. Seismic Analyses for RCS, RI and Core

1. Seismic Analysis for RCS
2. Seismic Analysis for RI
3. Seismic Analysis for Core

B-1. Seismic Analysis for RCS

1) Procedure of RCS Seismic Analysis
2) Analytical Modeling of RCS
3) Methods of RCS Seismic Analysis
4) Damping for RCS Seismic Analysis
5) Outputs of RCS Seismic Analysis

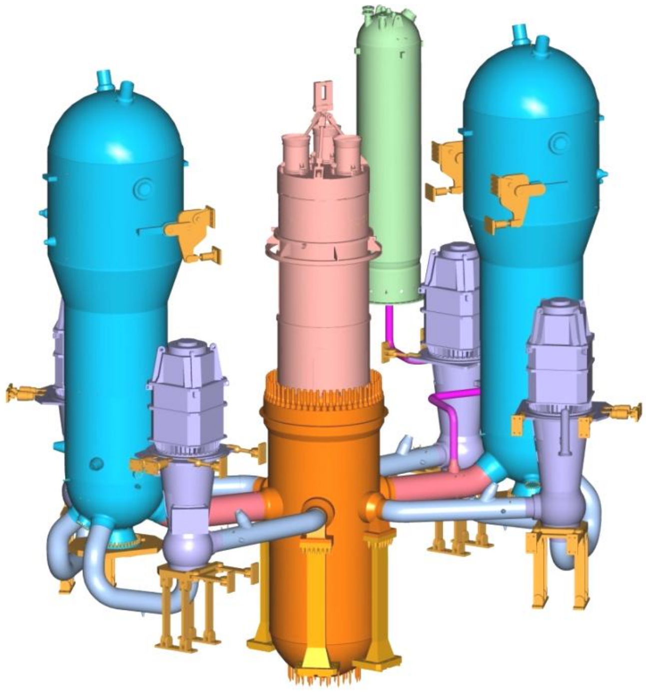
1) Procedure of RCS Seismic Analysis



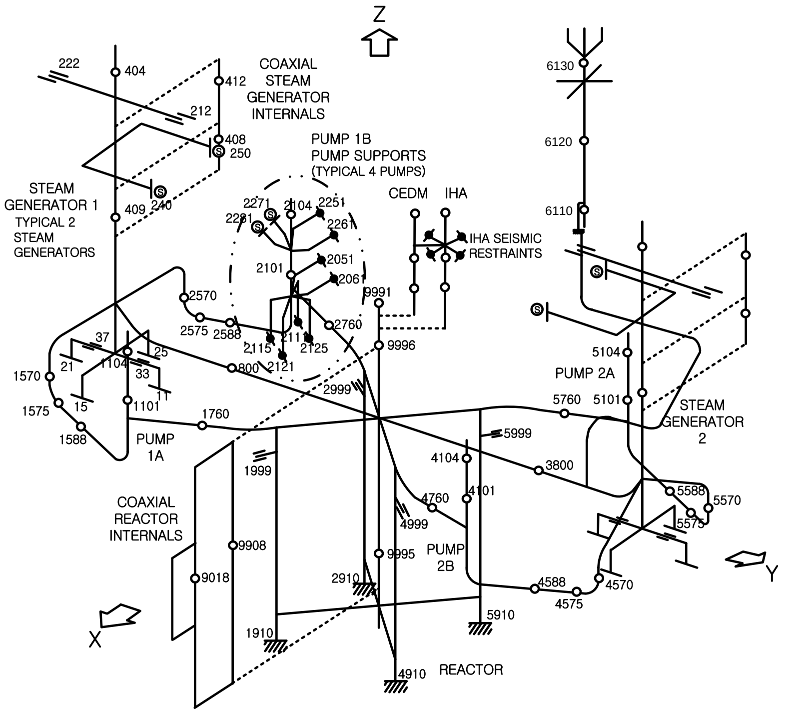
1) Procedure of RCS Seismic Analysis (cont'd)

- **RCS Seismic Model**

Reactor Coolant System

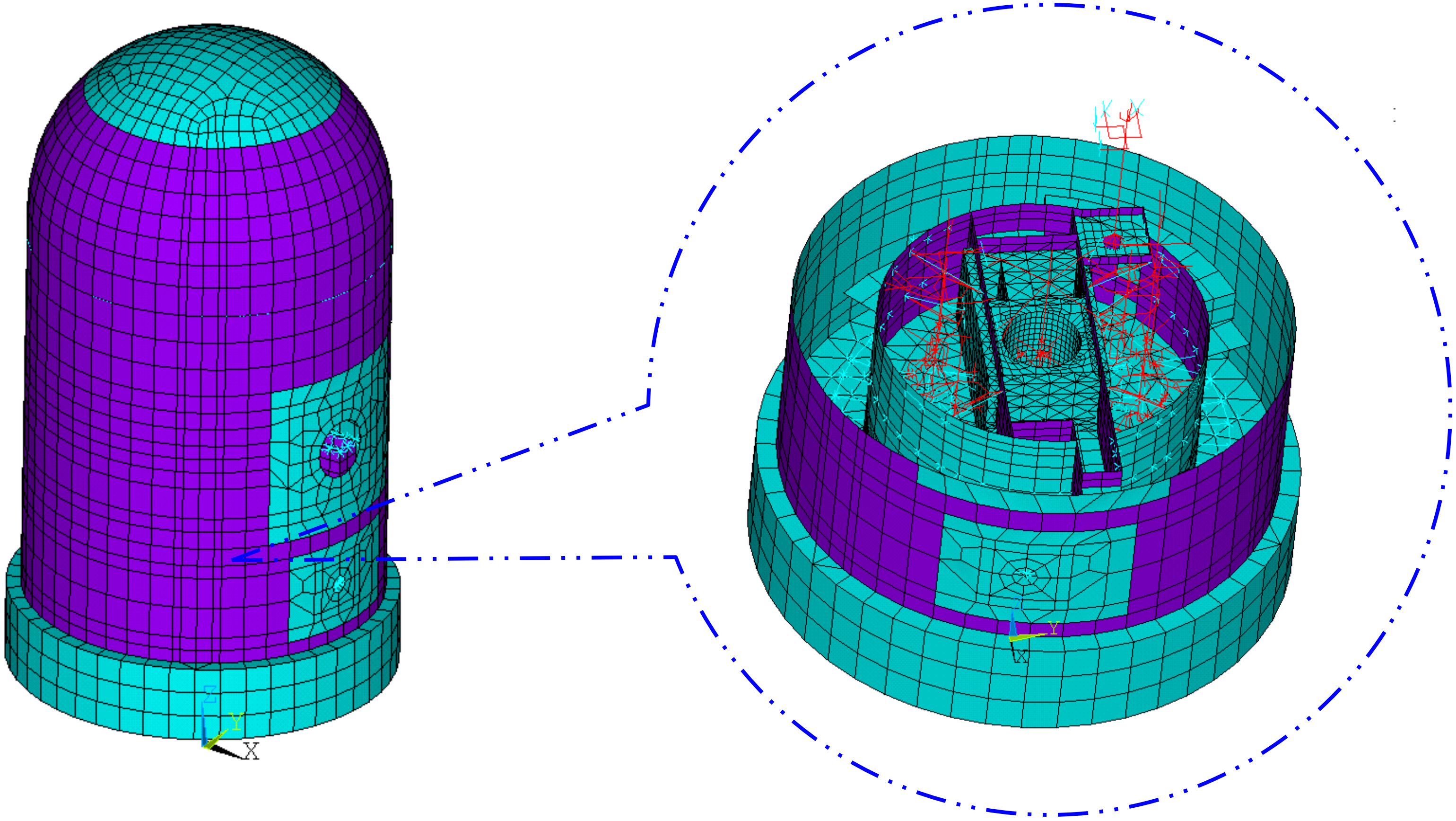


RCS Seismic Model



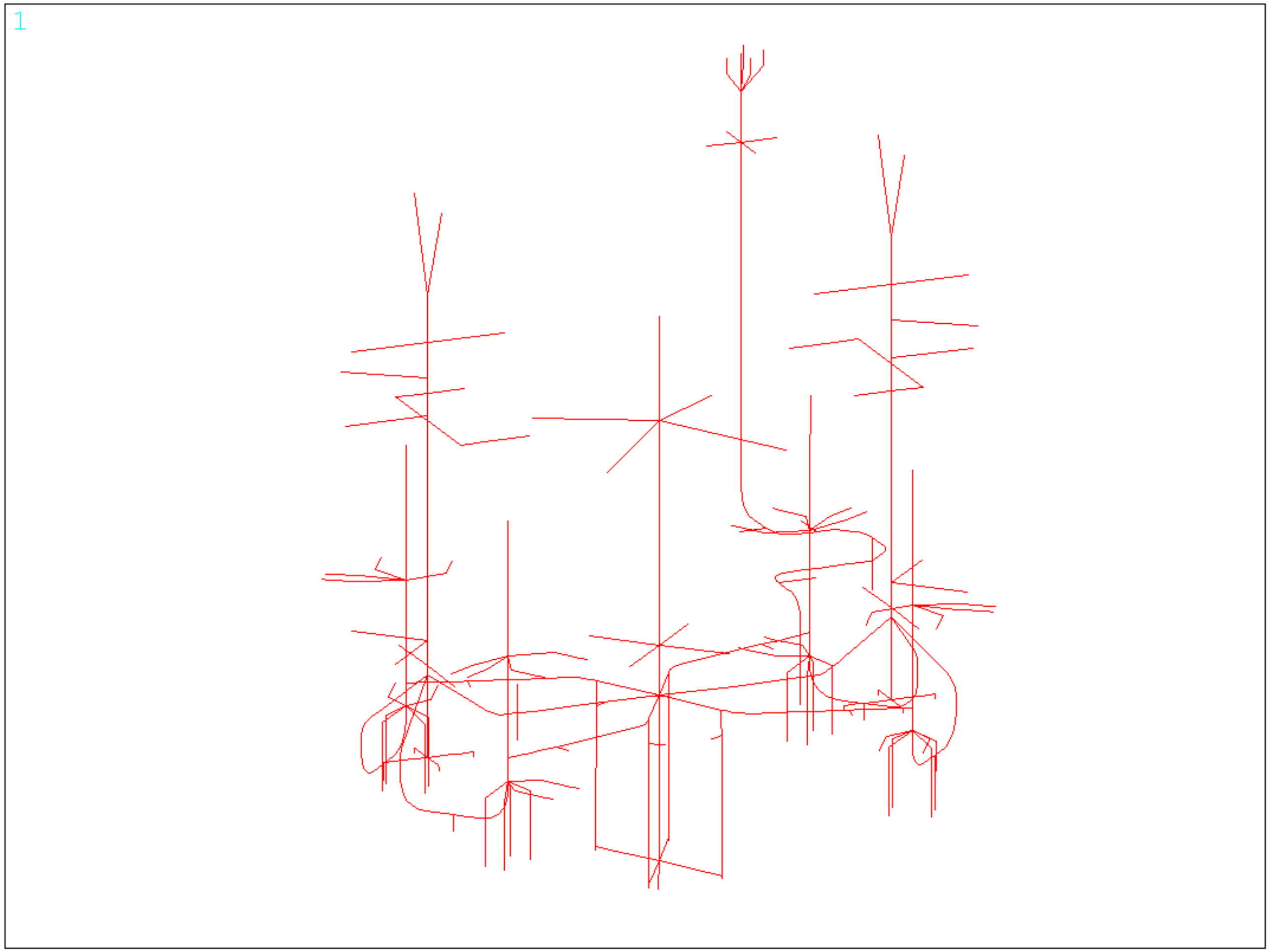
1) Procedure of RCS Seismic Analysis (cont'd)

- **Coupled RCB-RCS Seismic Model**



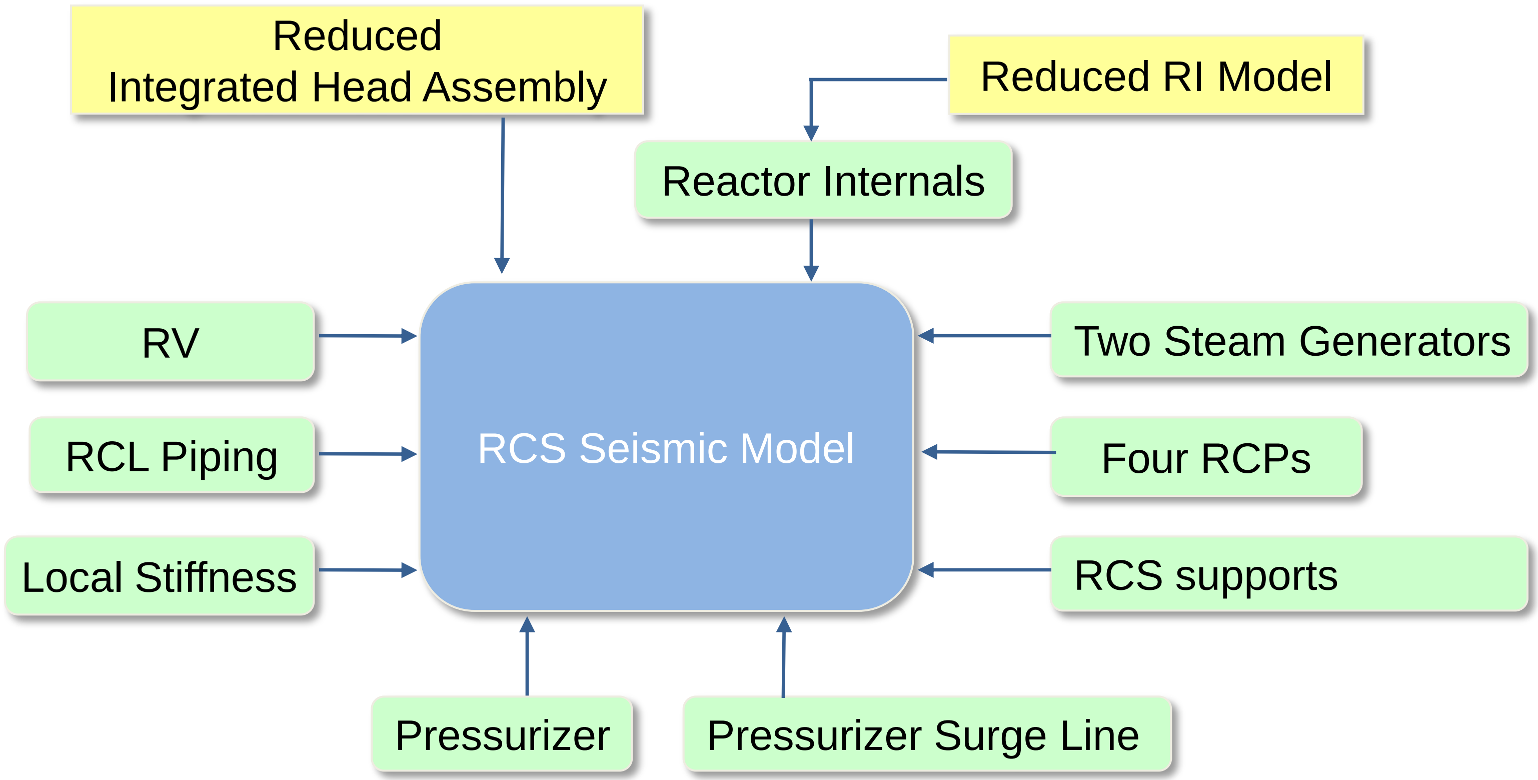
1) Procedure of RCS Seismic Analysis (cont'd)

- RCS Seismic Model Isometric View



2) Analytical Modeling of RCS

- **Components of RCS Seismic Model**



2) Analytical Modeling of RCS (cont'd)

- **RCS Seismic Model**
  - 3D lumped mass and beam model
  - Modeling parameters
    - Geometry of components and supports
    - Component stiffness
    - Support stiffness
    - Component and support masses
  - Distribution of Mass
    - Maintain total mass
    - Maintain center of gravity
    - Maintain second moment of inertia

2) Analytical Modeling of RCS (cont'd)

- **Determination of stiffness**
  - Beam section properties for simple geometry
    - Cross section and shear areas
    - Moment of inertia of area
    - Young's modulus
  - Local stiffness
    - RV Inlet and Outlet Nozzles
    - RV Lower Key
    - SG Upper Key
    - SG Snubber Lug
    - PZR Shear Key

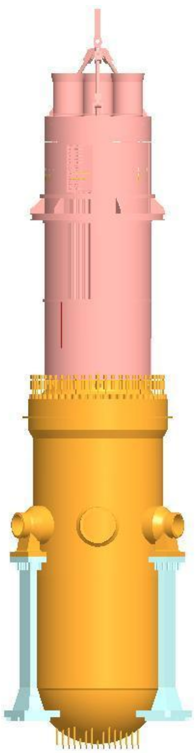
2) Analytical Modeling of RCS (cont'd)

- **Supports**
  - Linear Supports
    - Snubbers are modeled as in locked condition (SG, RCP, and PZR surge line)
    - Gaps in the RCS support systems are in closed condition

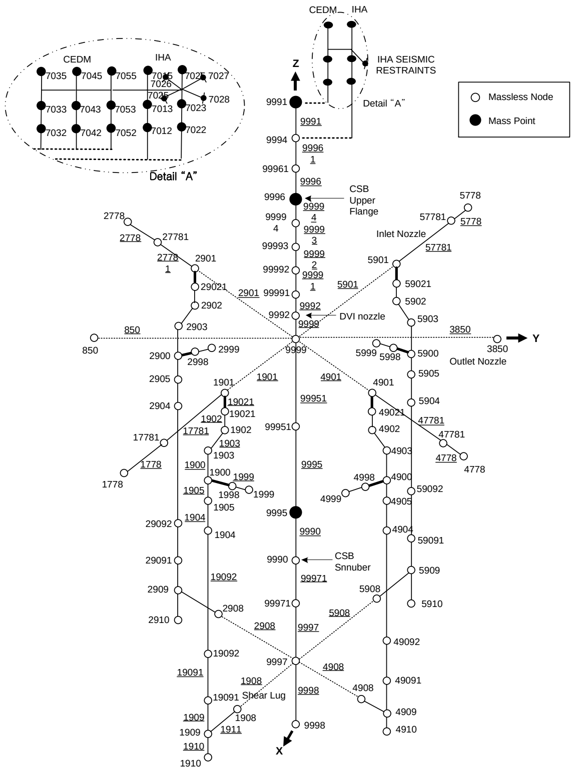
2) Analytical Modeling of RCS (cont'd)

- **RV Seismic Model**

Reactor Vessel



Reactor Vessel Model

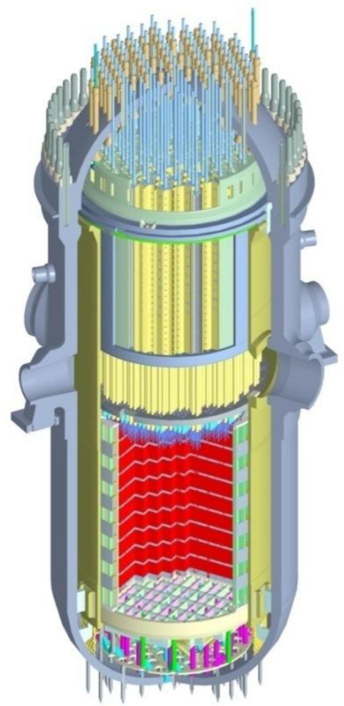


RV, IHA and CEDM : 18 MPs, 52 DDOFs

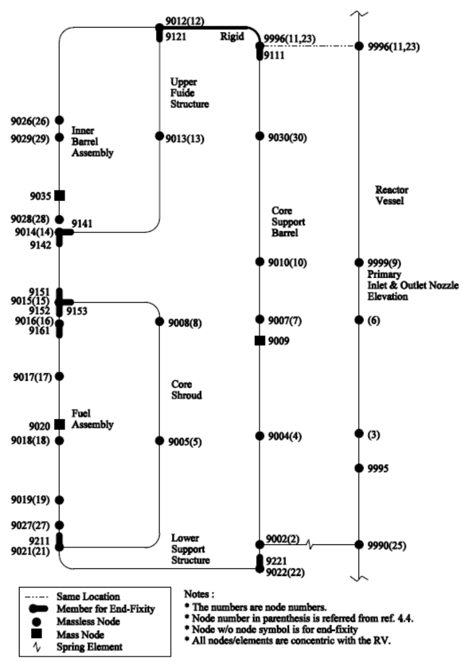
2) Analytical Modeling of RCS (cont'd)

- **RI Seismic Model**

Reactor Internals



Reduced Reactor Internals Model



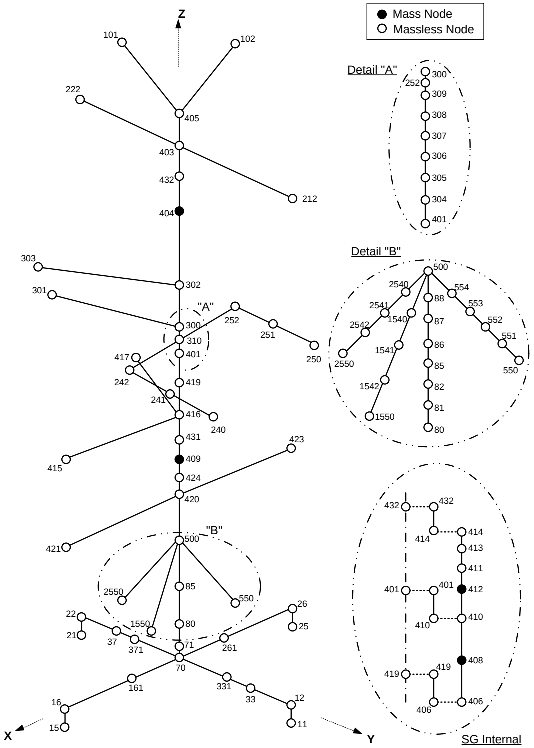
Reduced RI : 3 MPs, 9 DDOFs

2) Analytical Modeling of RCS (cont'd)

- **SG Seismic Model**

Steam Generator

Steam Generator Model

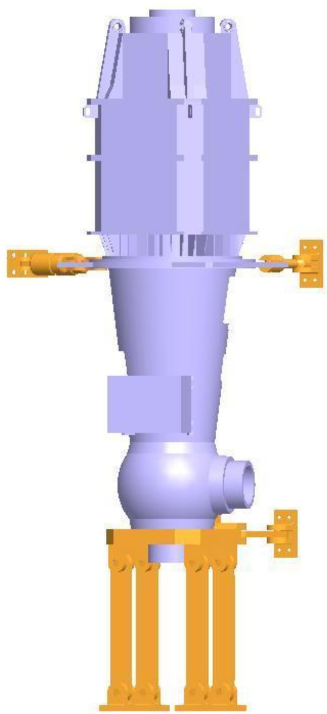


SG with Internals : 4 MPs/SG, 10 DDOFs/SG

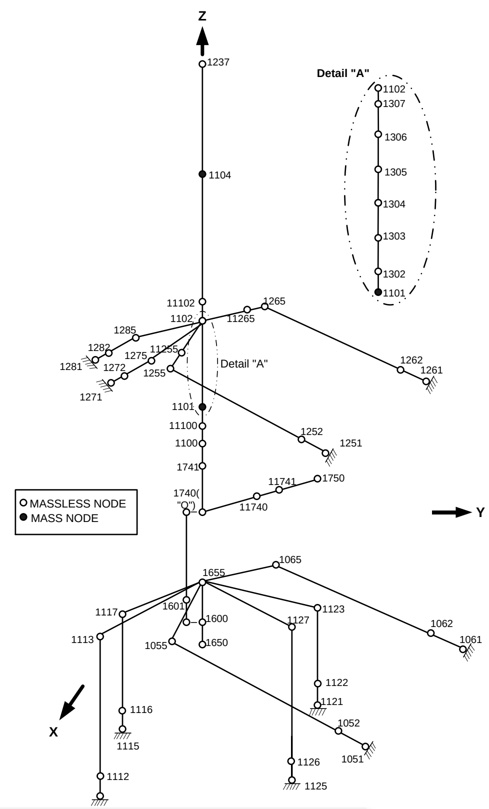
2) Analytical Modeling of RCS (cont'd)

- **RCP Seismic Model**

Reactor Coolant Pump



Reactor Coolant Pump Model

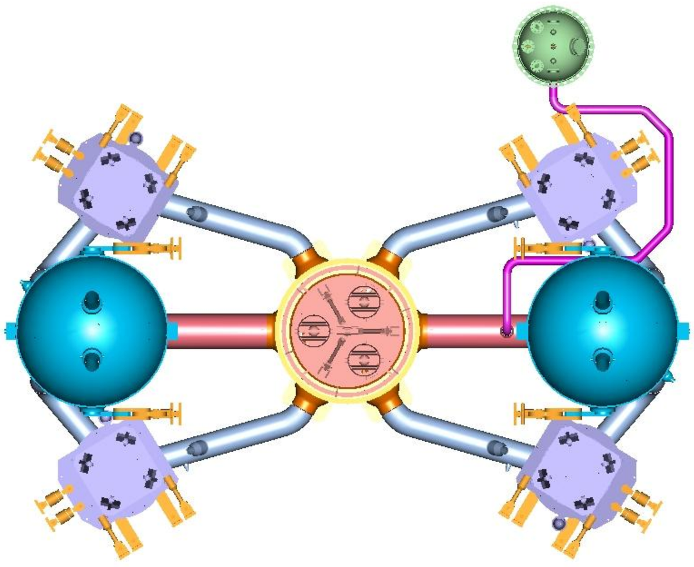


RCP with Motors : 2 MPs/RCP, 6 DDOFs/RCP

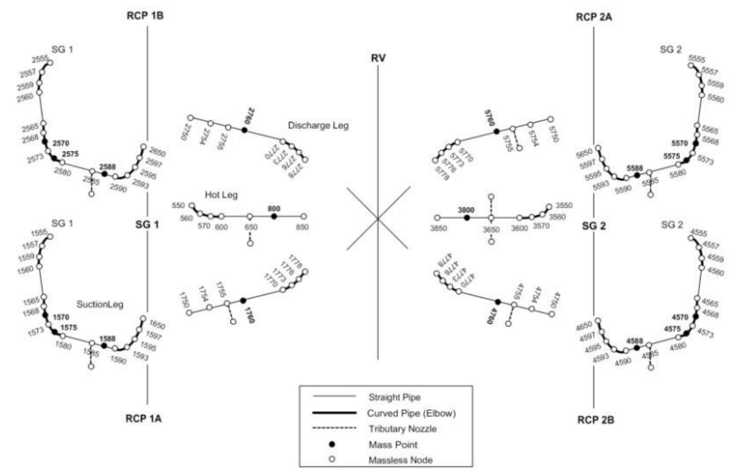
2) Analytical Modeling of RCS (cont'd)

- **RCL Piping Seismic Model**

RCL Piping



RCL Piping Model



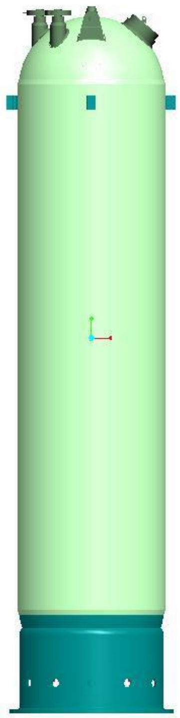
Hot Legs : 1 MP/HL, 3 DDOFs/HL

Cold Legs : 4 MPs/CL, 12 DDOFs/CL

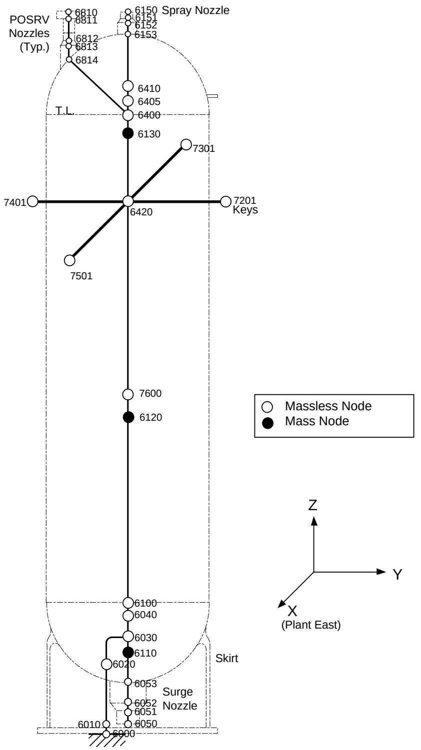
2) Analytical Modeling of RCS (cont'd)

- **PZR Seismic Model**

Pressurizer



Pressurizer Model



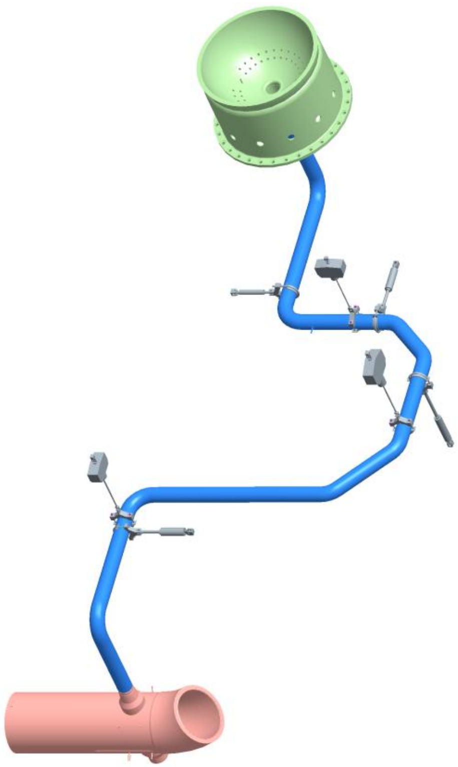
Pressurizer : 3 MPs, 7 DDOFs

6th Pre-application Review Meeting

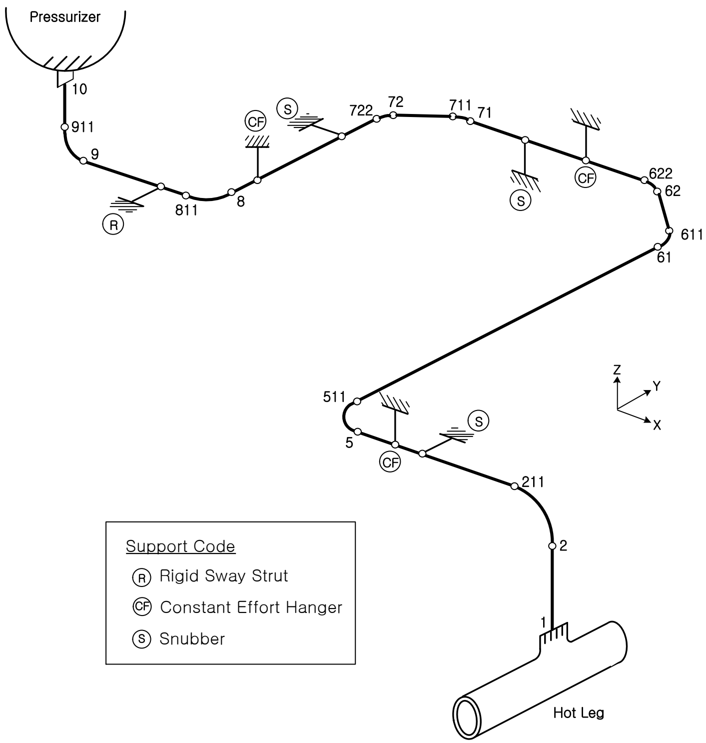
2) Analytical Modeling of RCS (cont'd)

- **Surge Line Seismic Model**

Surge Line



Surge Line Model

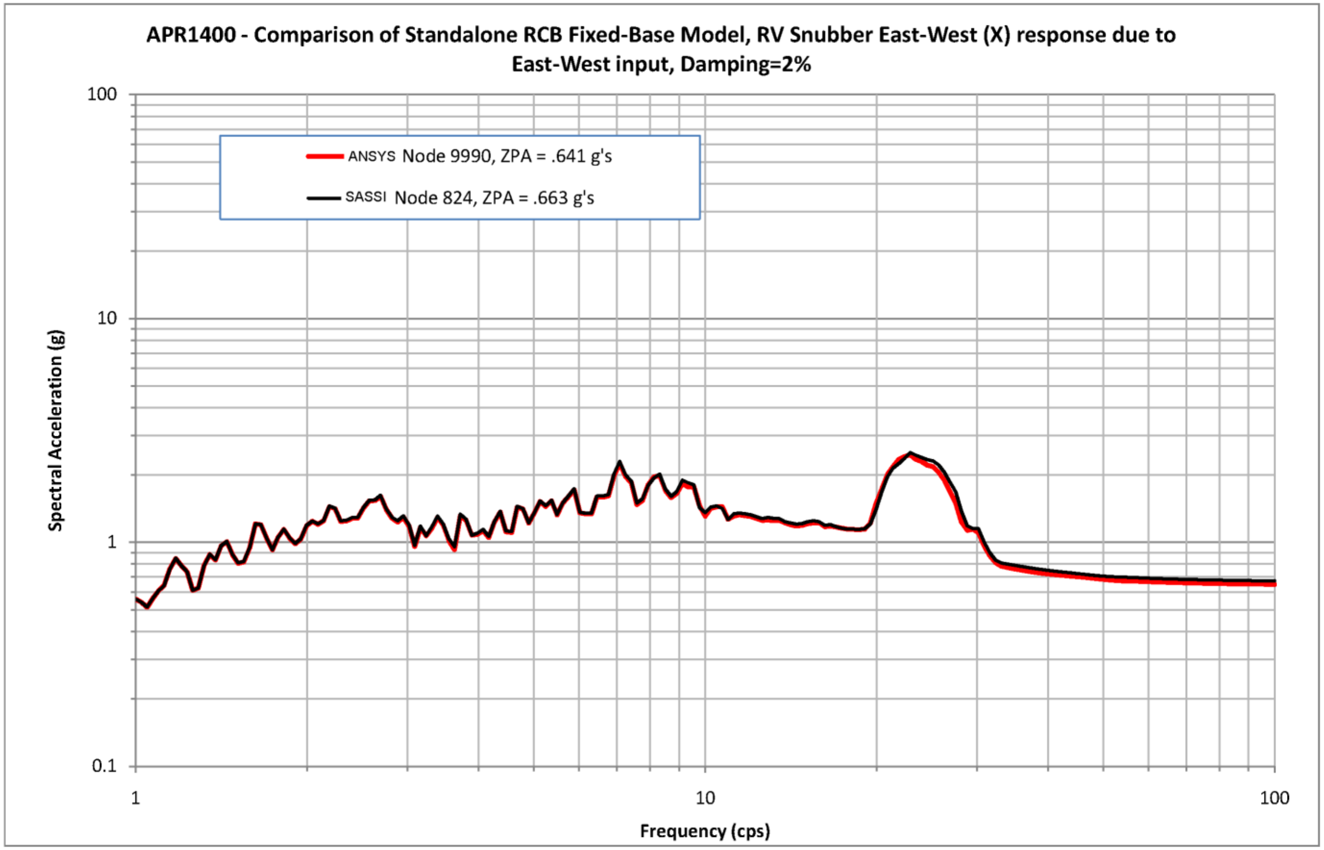


2) Analytical Modeling of RCS (cont'd)

- **Coupled NI-RCS Seismic Model**
  - NI seismic model
    - 3D finite element model
    - RCB
      - Containment Shell, Primary and Secondary Shield Wall
    - Auxiliary Building
  - RCS supports are connected to the internal structure of building model using rigid links to maintain boundary conditions at support locations
  - ANSYS model converted into ACS-SASSI model
    - ANSYS ver. 14.0
    - ACS-SASSI Fast Solver NQA Ver. 2.3.0

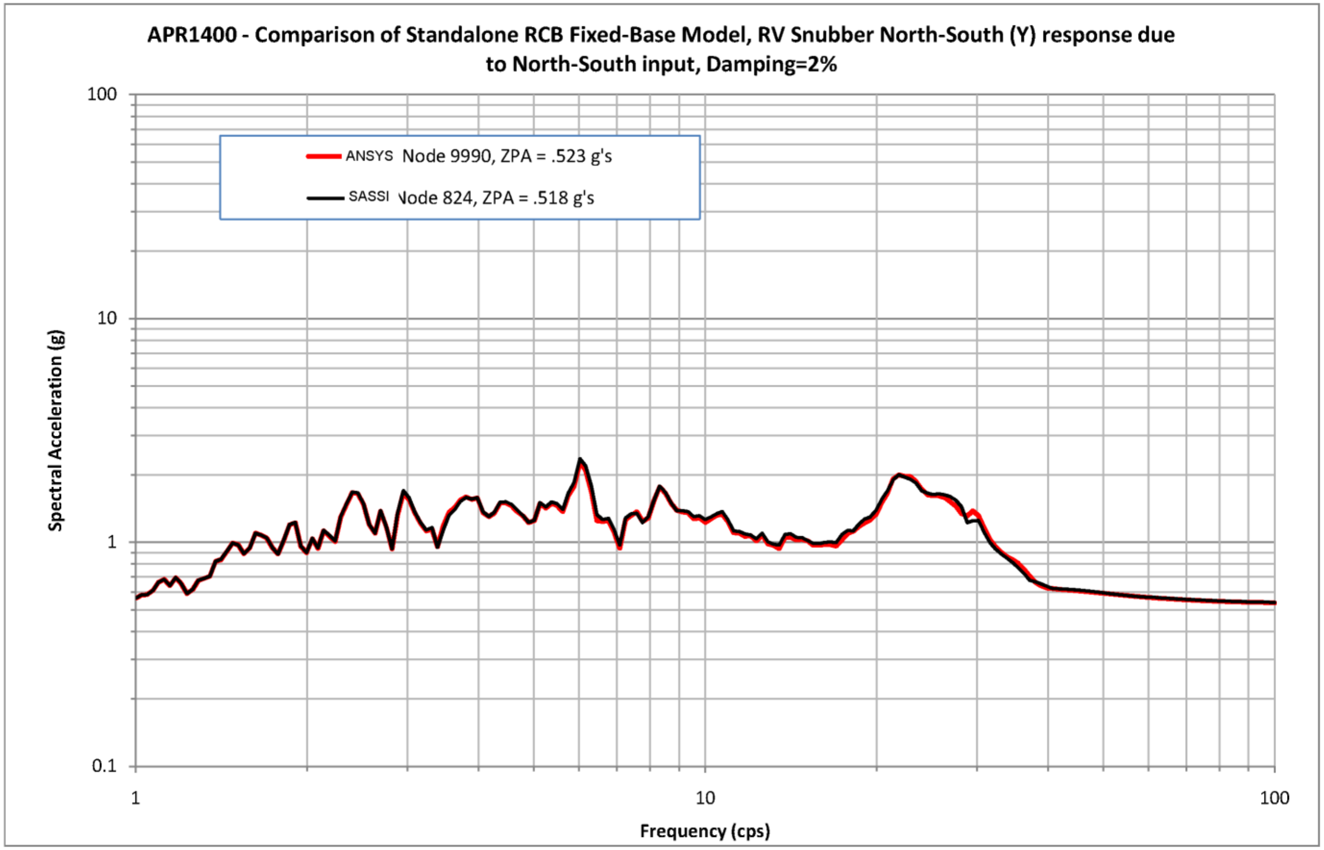
2) Analytical Modeling of RCS (cont'd)

- **Comparison of ANSYS and SASSI result**
  - RV Snubber (East-West) – 2% damping



2) Analytical Modeling of RCS (cont'd)

- **Comparison of ANSYS and SASSI result**
  - RV Snubber (North-South) – 2% damping



3) Methods of RCS Seismic Analysis

- Model
  - Coupled NI-RCS seismic model
- Excitation
  - SSE motion at the free-field ground surface for SSI analysis
  - Time step : 0.005 sec
  - Duration : 20.48 sec
- Analysis Code: ACS-SASSI
- Complex frequency response method

4) Damping for RCS Seismic Analysis

- Damping values of the RCS components consistent with RG 1.61
- Two cases of damping values for the building structure of NI model
  - OBE damping values for un-cracked building structure case in accordance with RG 1.61, C.1.2
  - SSE damping values for cracked building structure case
  - Enveloped seismic responses from the two analyses are to be used for seismic design
- SSE damping values for RCS components

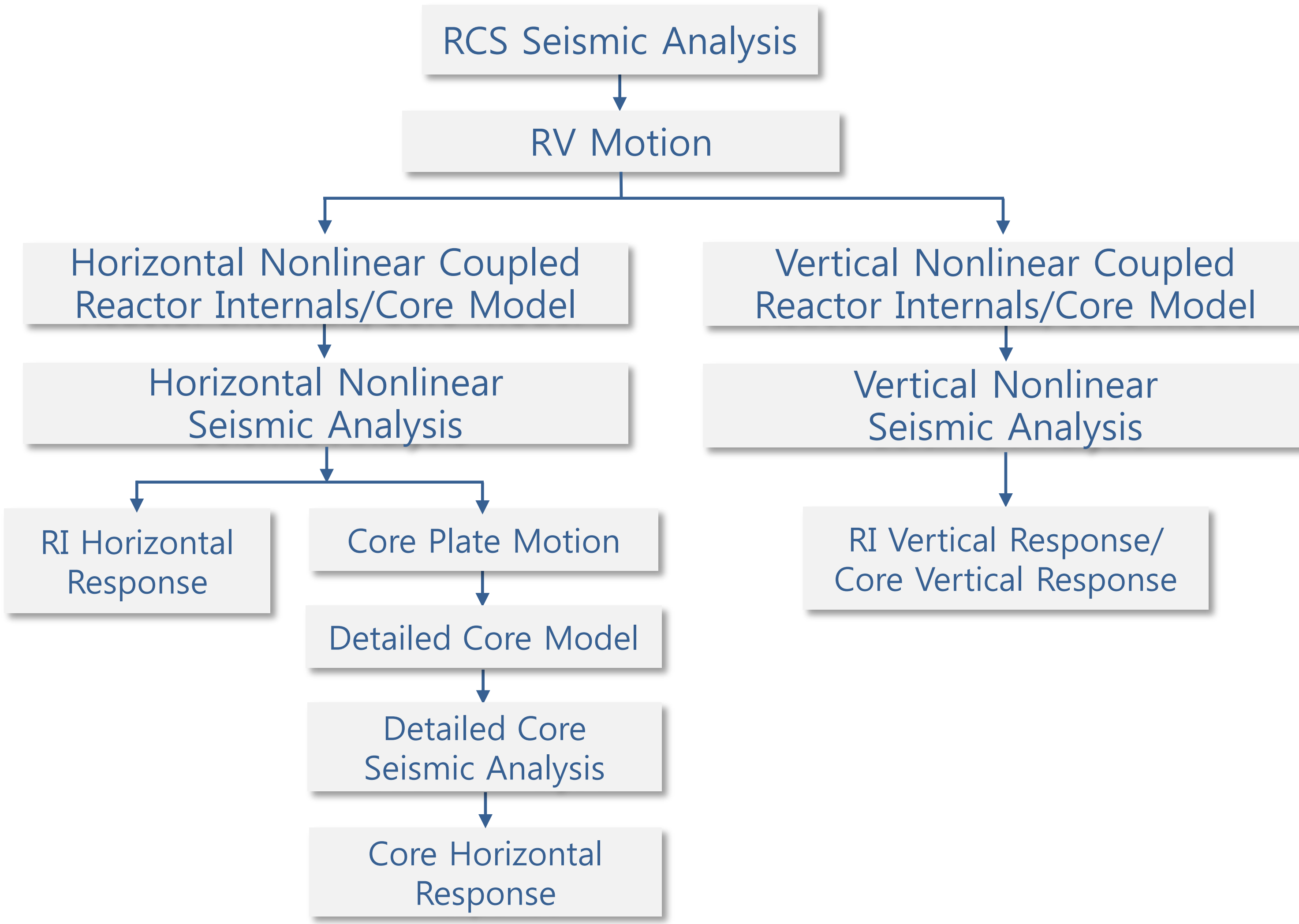
5) Outputs of RCS Seismic Analysis

- Forces and moments for RCS component and their supports
- Forces and moments for RCS piping & nozzle
- Max. displacements at branch nozzles
- Design response spectra for RCS components
- Response time histories and spectra for
  - RI analysis
  - CEDM, IHA & ICI analysis
  - Surge line analysis
  - Branch piping analysis

B-2. Seismic Analysis for RI

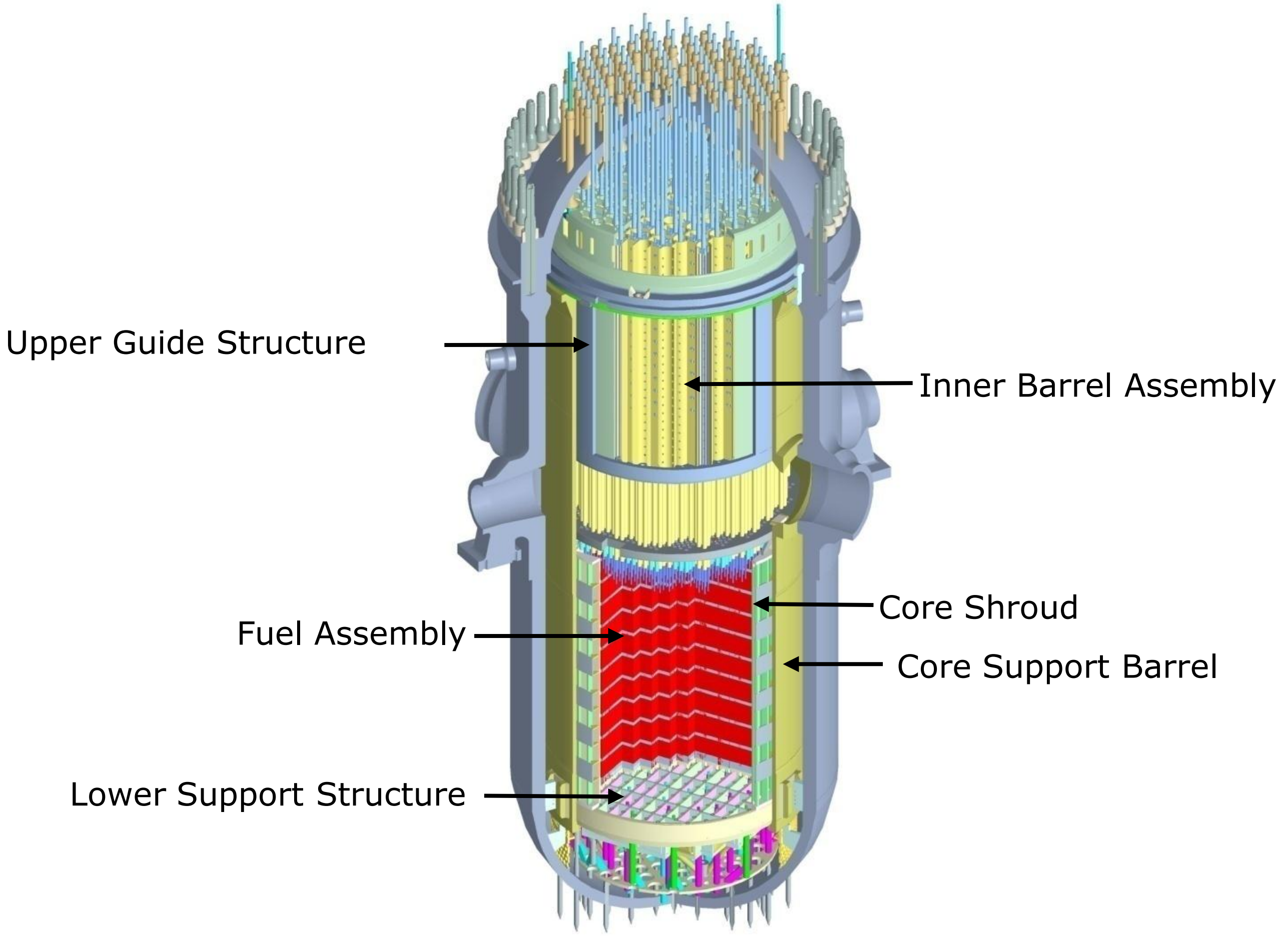
1) Procedure of RI Seismic Analysis
2) Analytical Modeling of RI
3) Methods of RI Seismic Analysis
4) Damping for RI Seismic Analysis
5) Outputs of RI Seismic Analysis

1) Procedure of RI Seismic Analysis



2) Analytical Modeling of RI

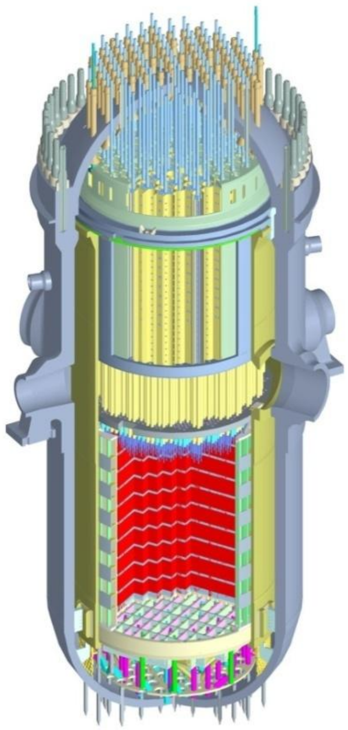
- **Reactor Internals**



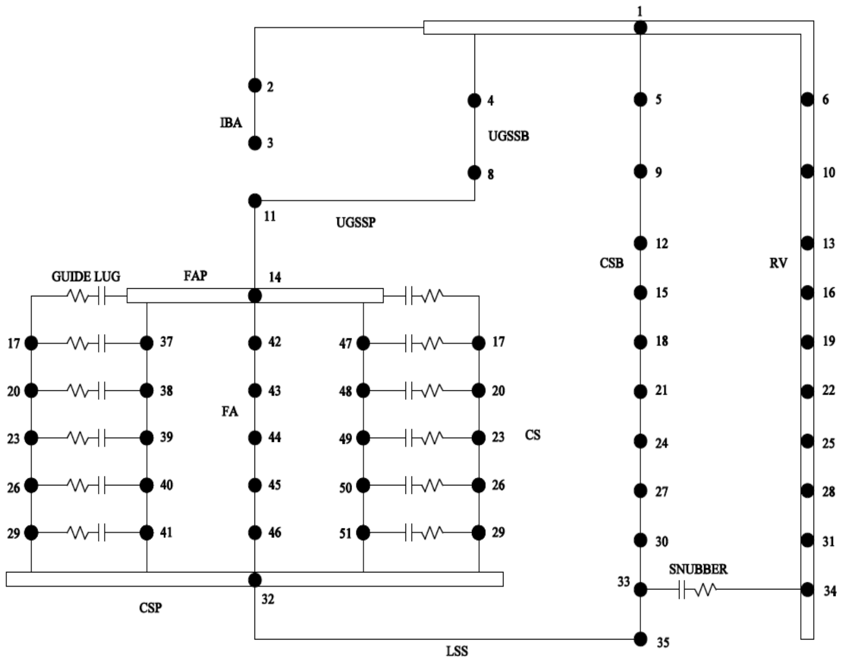
2) Analytical Modeling of RI (cont'd)

- **Horizontal Reactor Internals Model**

Reactor Internals



Horizontal Reactor Internals Model



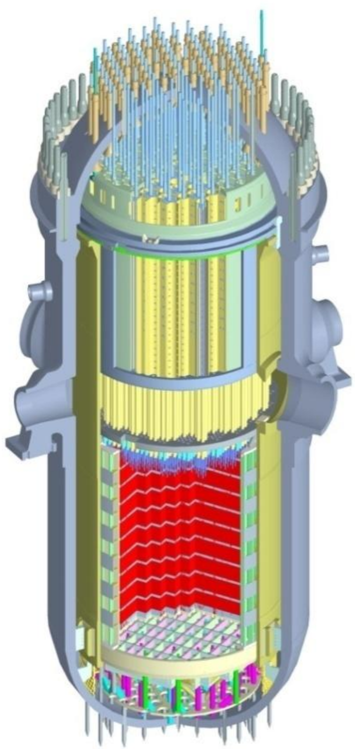
2) Analytical Modeling of RI (cont'd)

- **Horizontal Reactor Internals Model**
  - Lumped masses and linear elastic-beam elements
  - Criterion for mass concentration
    - To provide for accurate representation of the significant modes of vibration
  - Beam element properties between the lumped masses
  - Nonlinear spring elements for the gaps
  - Three(3) fuel assembly groupings
  - Hydrodynamic added mass and coupling to consider fluid structure interaction effect

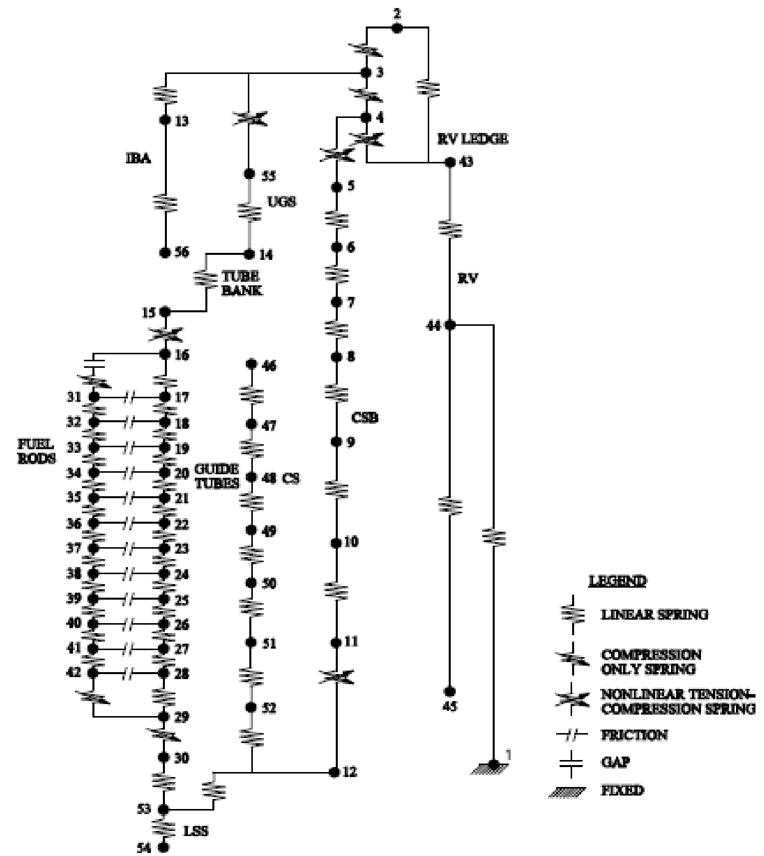
2) Analytical Modeling of RI (cont'd)

- **Vertical Reactor Internals Model**

Reactor Internals



Vertical Reactor Internals Model



2) Analytical Modeling of RI (cont'd)

- **Vertical Reactor Internals Model**
  - Various nonlinear elements around the fuel assemblies to simulate the vertical behavior of the fuel assemblies.
    - Compression only spring
    - Nonlinear tension-compression spring
    - Friction coupling
    - Gap
  - Compression only spring for the RV ledge region to simulate the vertical behavior of the holddown ring

3) Methods of RI Seismic Analysis

- Models
  - Horizontal reactor internals model
  - Vertical reactor internals model
- Excitation
  - Horizontal acceleration time histories at RV Flange and Core Stabilizing Lug
  - Vertical acceleration time history at RV Flange
- Analysis Code : CESHOCK ver.6 mod.5
  - A nonlinear dynamic analysis code for spring-lumped mass systems
- Non-linear time history analysis
  - Direct integration method

4) Damping for RI Seismic Analysis

- Reactor internal components for SSE : 4%
- Fuel assembly for SSE : based upon the results of full scale forced vibration tests for fuel assembly
- Composite mass damping and stiffness damping

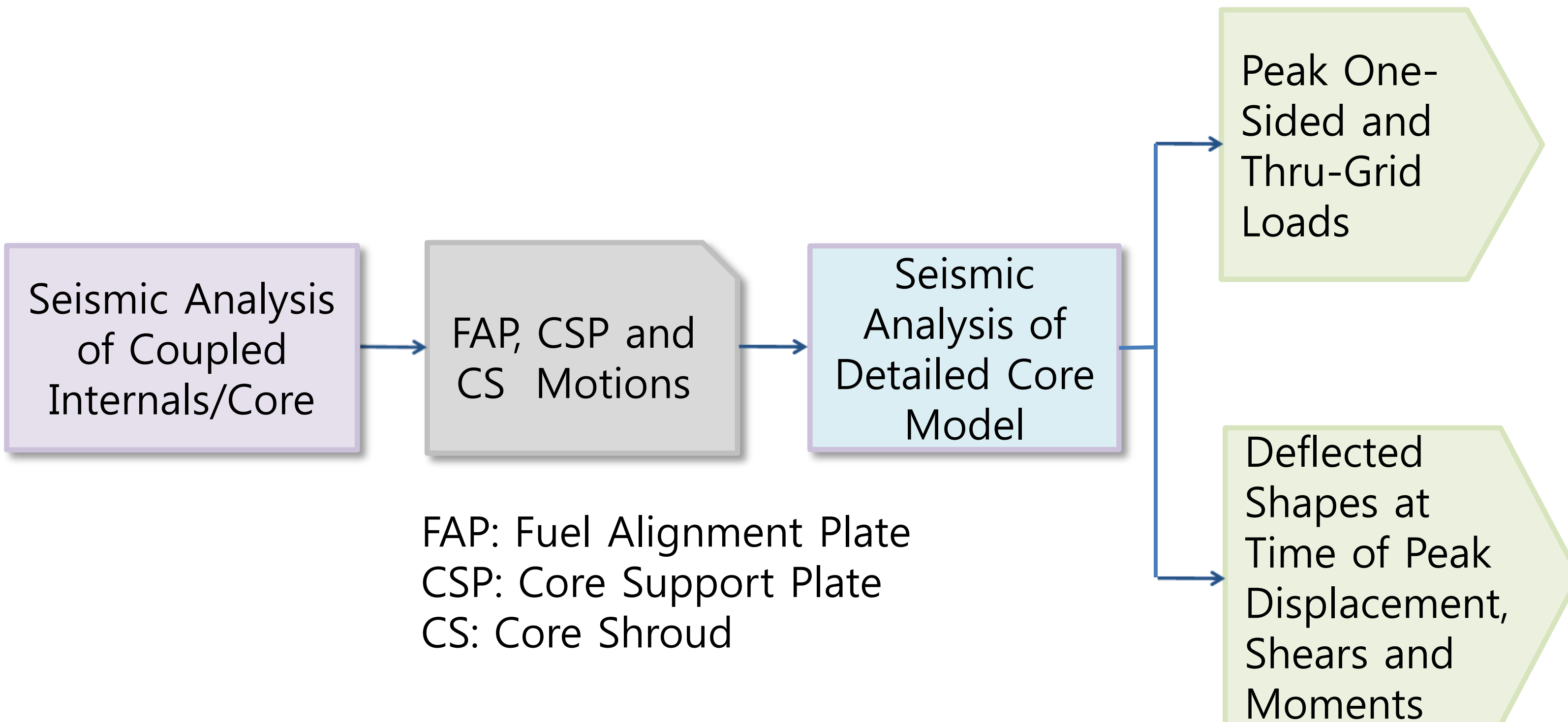
5) Outputs of RI Seismic Analysis

- Forces and Moments for Reactor Internal components
- Response Spectra for Subcomponent analyses
- Core Plate motions for Detailed Core Seismic Analysis

B-3. Seismic Analysis for Core

1) Procedure of Core Seismic Analysis
2) Analytical Modeling of Detailed Core
3) Methods of Detailed Core Seismic Analysis
4) Damping for Detailed Core Seismic Analysis
5) Outputs of Detailed Core Seismic Analysis

1) Procedure of Core Seismic Analysis

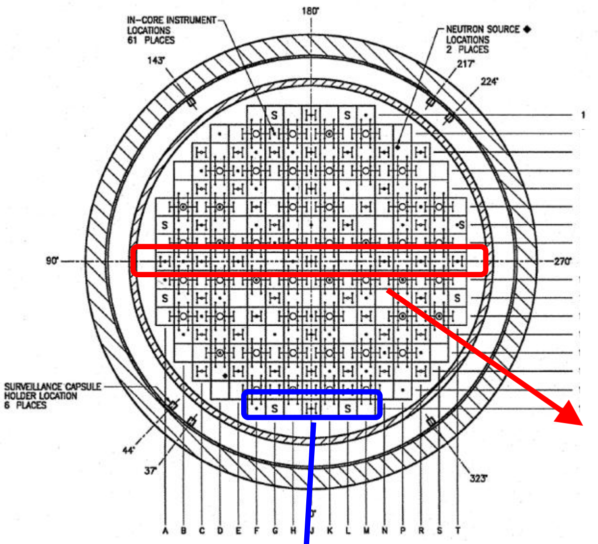


FAP: Fuel Alignment Plate
CSP: Core Support Plate
CS: Core Shroud

2) Analytical Modeling of Detailed Core

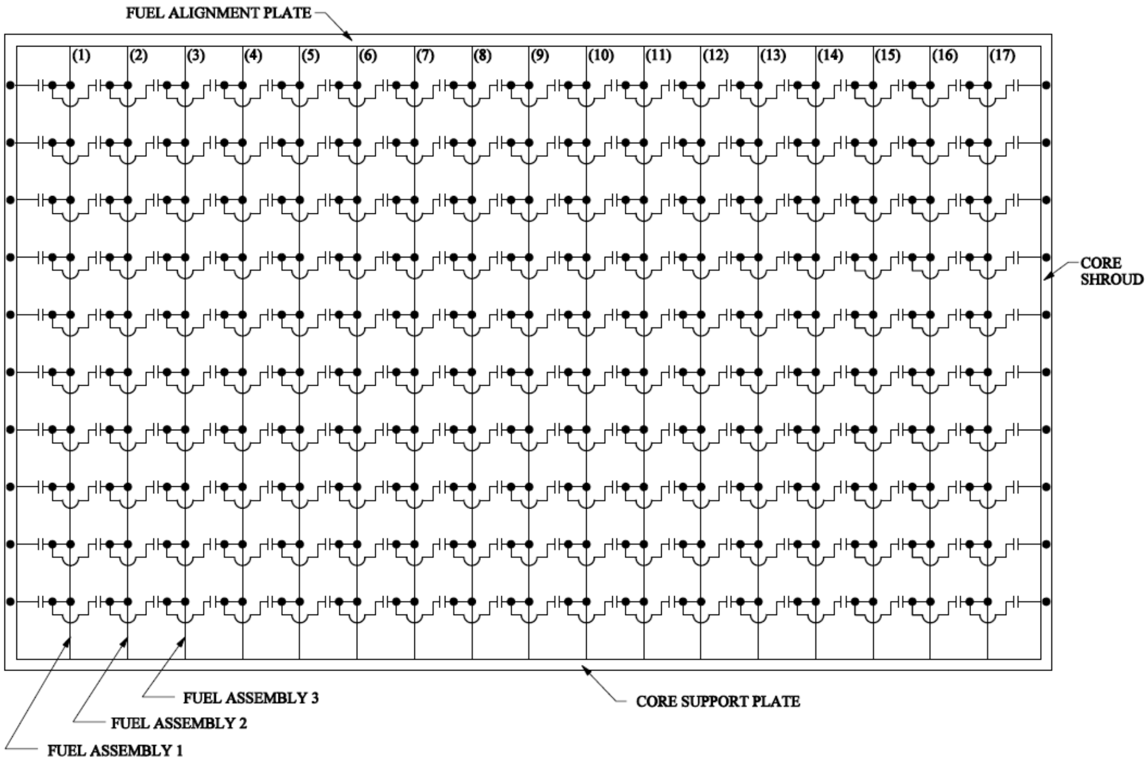
- **Detailed Core Modeling**
  - Nonlinear core models for 7 and 17 fuel assemblies per row across the core
  - Nonlinear spring coupling for the gap in the core
  - Energy dissipation during grid impact
    - Incorporated by the coefficient of restitution
  - All fuel assembly properties are based upon test data

2) Analytical Modeling of Detailed Core (cont'd)



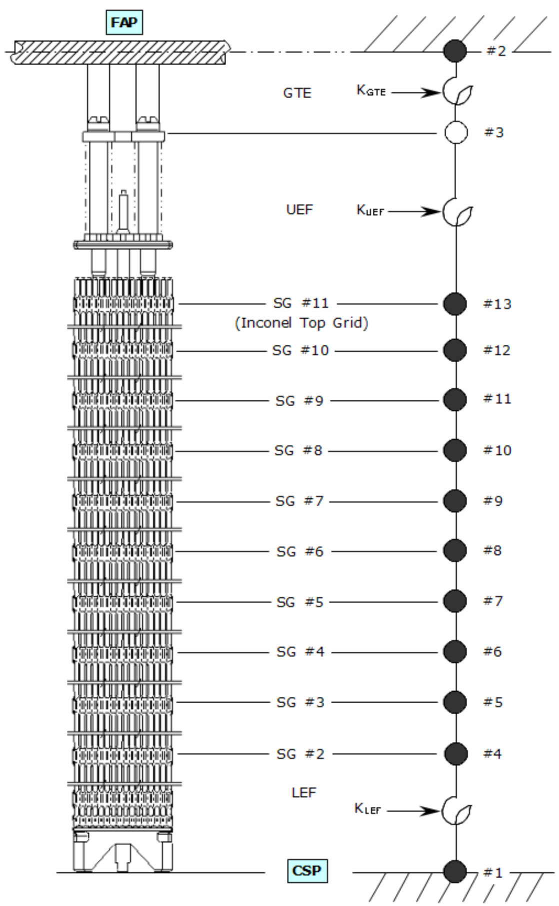
7 fuel assemblies

Detailed core model (17 fuel assemblies)



2) Analytical Modeling of Detailed Core (cont'd)

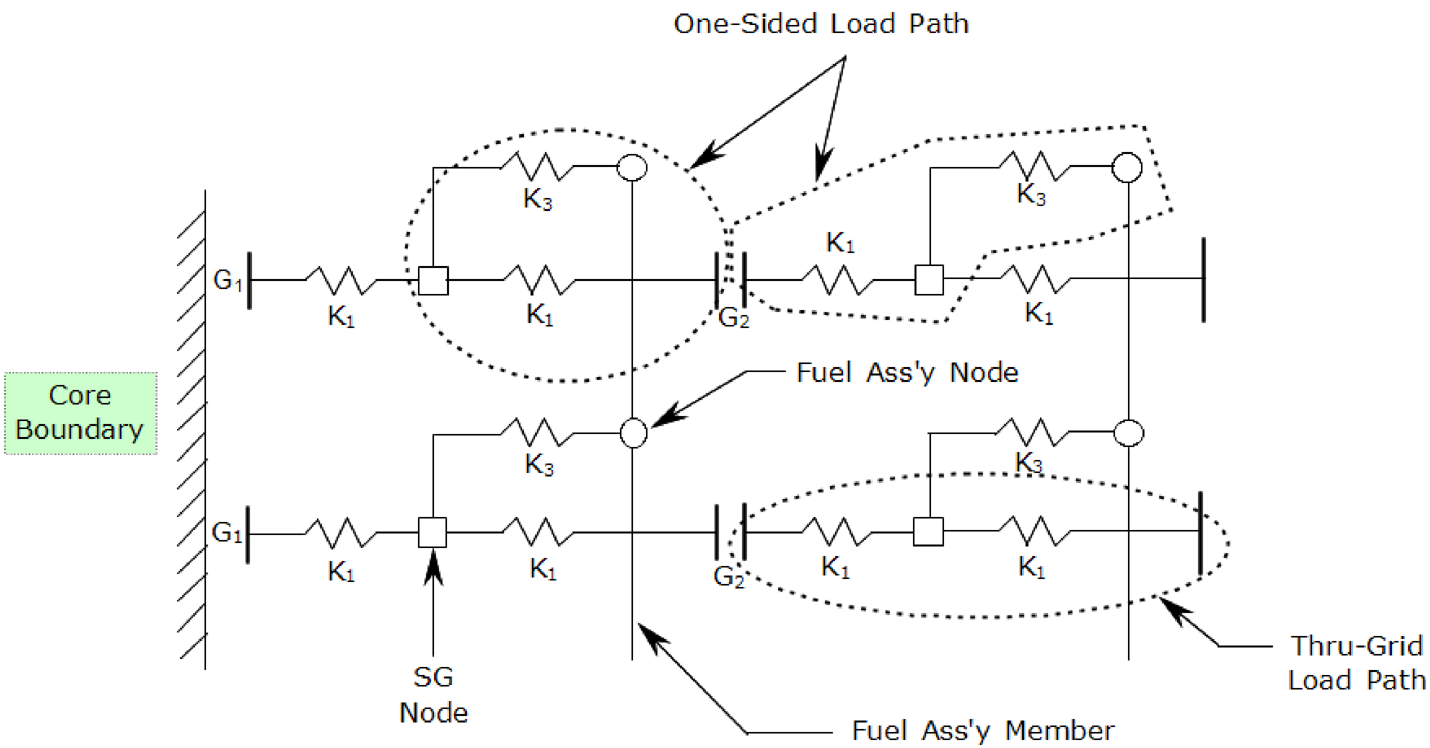
- **Fuel Assembly Model**



- Uniform beam with rotational springs at top and bottom ends
- Lumped mass at every spacer grid location
  - To represent the significant modes of the fuel
  - To account for possible grid impacting
- Flexural rigidity and rotational spring rates are derived from the test
- Connecting parts of the reactor internals are modeled as the rotational spring

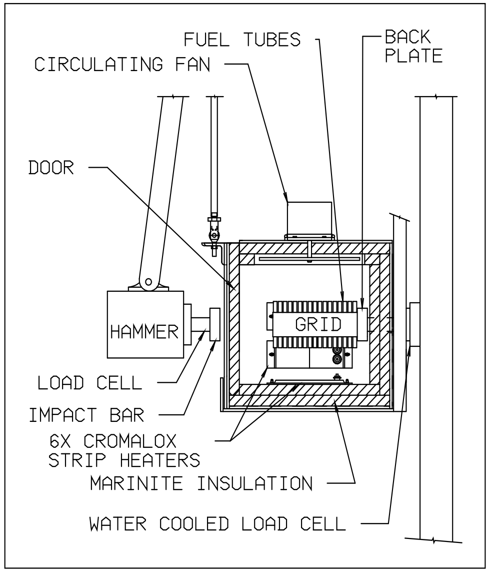
2) Analytical Modeling of Detailed Core (cont'd)

- **Detailed Core Model (Dual Load Path)**



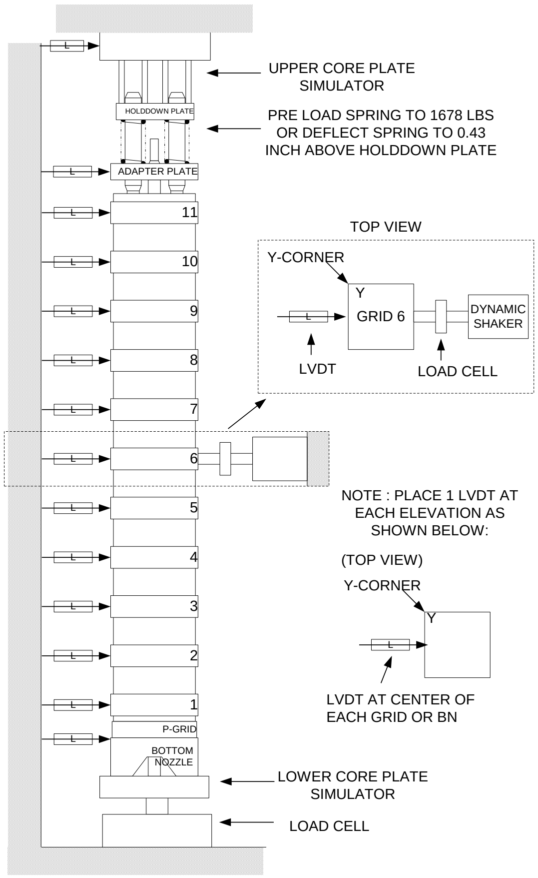
2) Analytical Modeling of Detailed Core (cont'd)

- **Mid Grid Buckling Test**

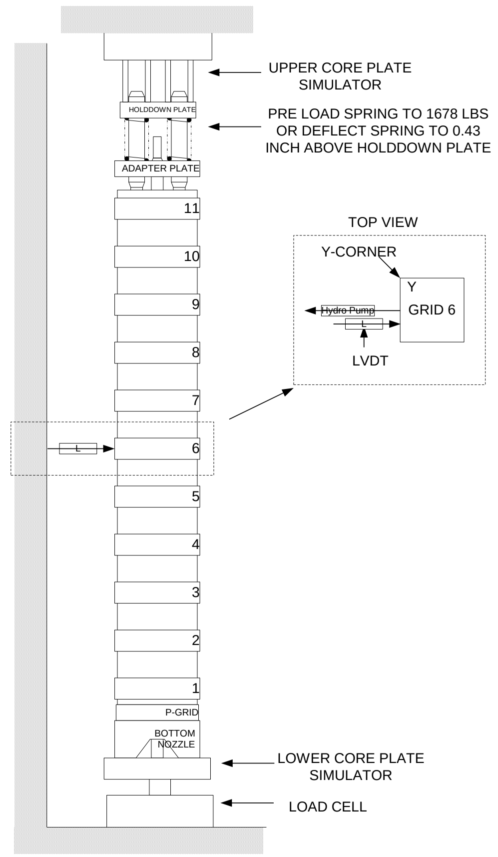


2) Analytical Modeling of Detailed Core (cont'd)

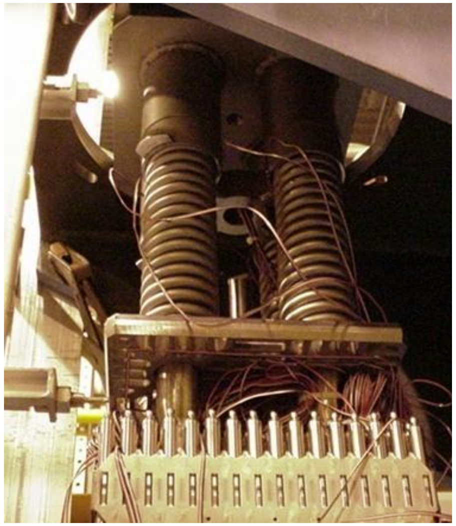
- **Horizontal Vibration Test**

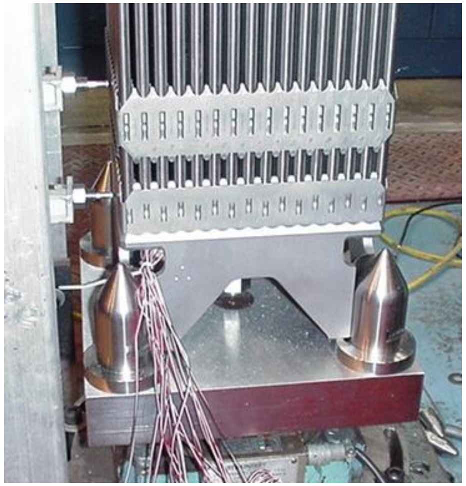


Forced Vibration Test



Pluck Vibration Test





3) Methods of Detailed Core Seismic Analysis

- Model
  - Detailed core model
- Excitation
  - Horizontal displacement time histories at fuel alignment plate, core support plate and core shroud
- Analysis Code : CESHOCK ver.6 mod.5
- Non-linear time history analysis
  - Direct integration method

4) Damping for Detailed Core Seismic Analysis

- Fuel assembly for SSE : based upon the results of full scale forced vibration tests for fuel assembly
- Mass and stiffness damping

5) Outputs of Detailed Core Seismic Analysis

- Peak spacer grid impact loads
- Deflected shapes of fuel assembly at the time of peak displacement, shear force and moment

Seismic Analysis of APR1400

C. Summary of System Part

Summary of System Part

- APR1400 RCS, RI, and Core seismic analyses are performed in accordance with the latest Regulations and Guides
- As RCS model is coupled with building, interaction effect between building structure and RCS is inherently reflected
- The mass degrees of freedom of RCS, RI, and Core models are distributed to properly account for the dynamic characteristics of corresponding components
- The seismic analyses can properly predict seismic responses of RCS, RI, and Core subjected to seismic loads