Seismic Issues

Nov 16, 2009

Mitsubishi Heavy Industries, LTD.

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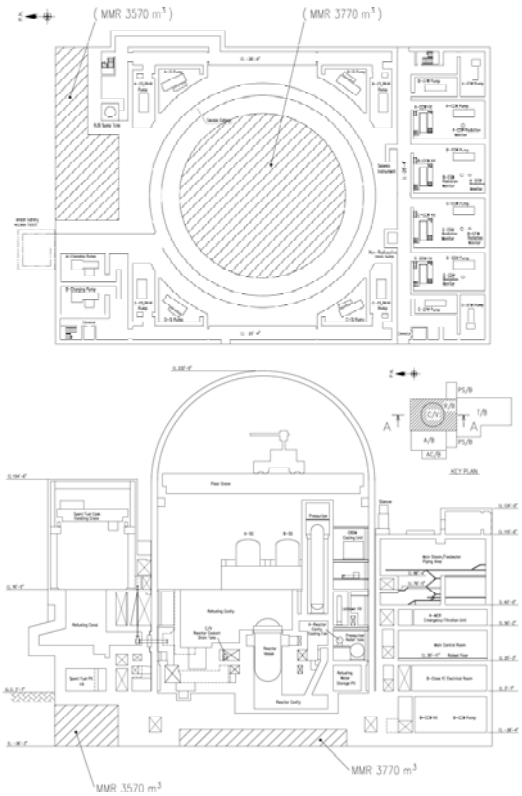
Modifications form Rev. 1 to Rev. 2

Basemat Simplification

- Basemat of R/B and PCCV is changed to accommodate broader customer specifications and higher seismic requirement for specific site.
- R/B
  - Rectangular basemat
- PCCV
  - Uniform thickness

Others

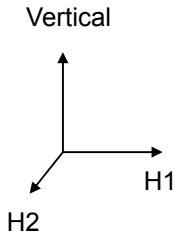
- CSDRS: No change
- Seismic Analysis Method: No chage

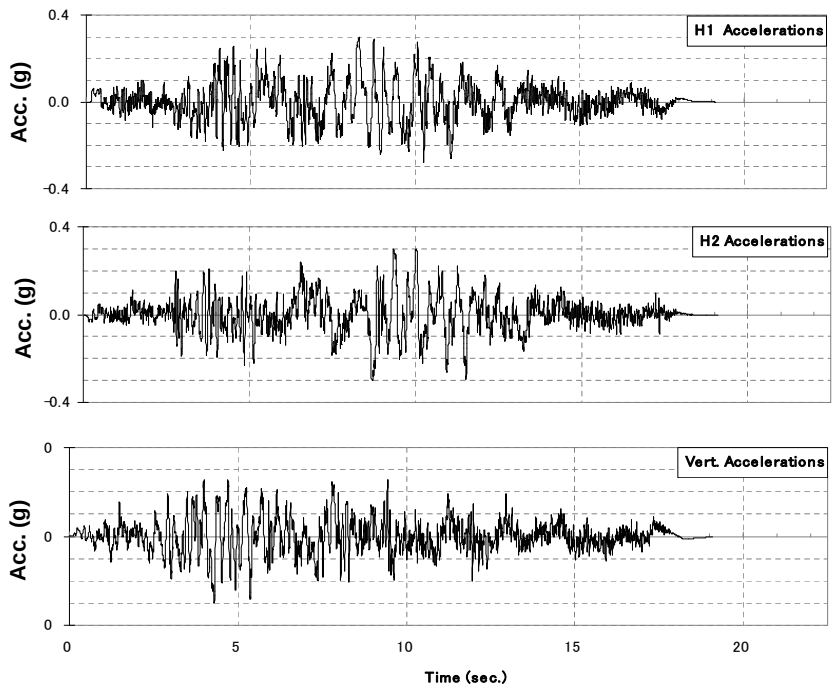


Ground Motion Time Histories (1/5)

- Artificial ground motion time histories used as input for seismic response analyses.
  - ✓ DCD Rev. 1:
    - Synthesized using Gaussian white noise
  - ✓ DCD Rev. 2 Technical Report:
    - Generated using seed ground motion recordings
- Conformance with SRP 3.7.1
  - ✓ Seed earthquake:
    - Station 3 Recording of M 6.8 Nahanni earthquake December 23, 1985.
  - ✓ Requirement:
    - Option 1, Approach 2 in Section II.B of SRP 3.7.1

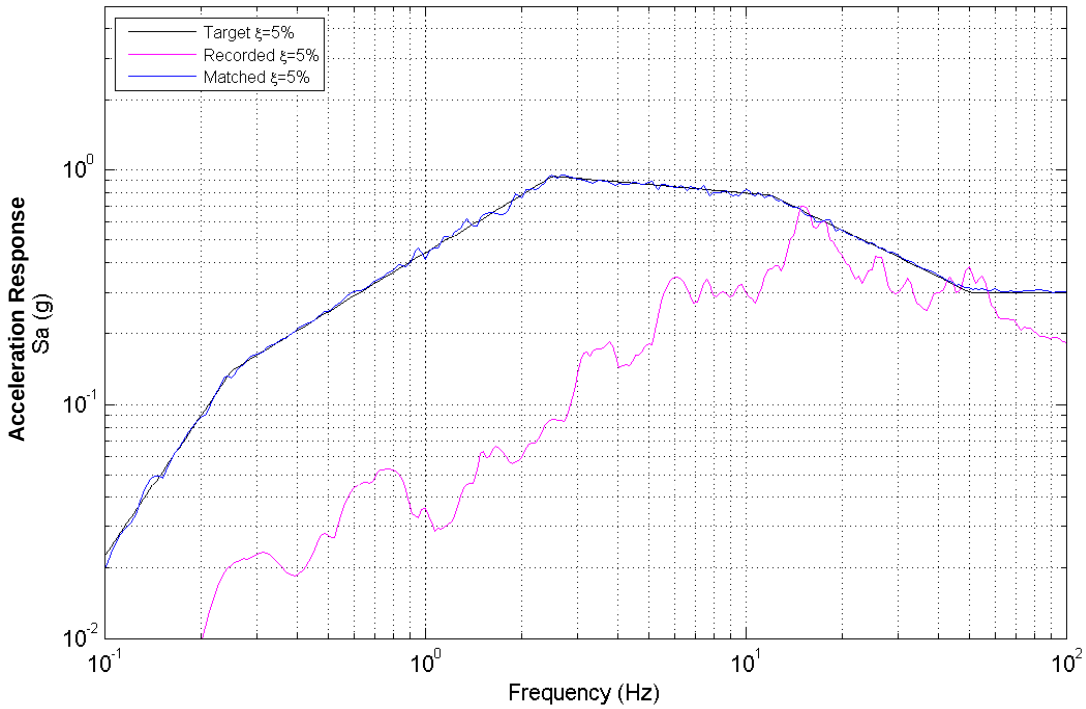
Ground Motion Time Histories (2/5)





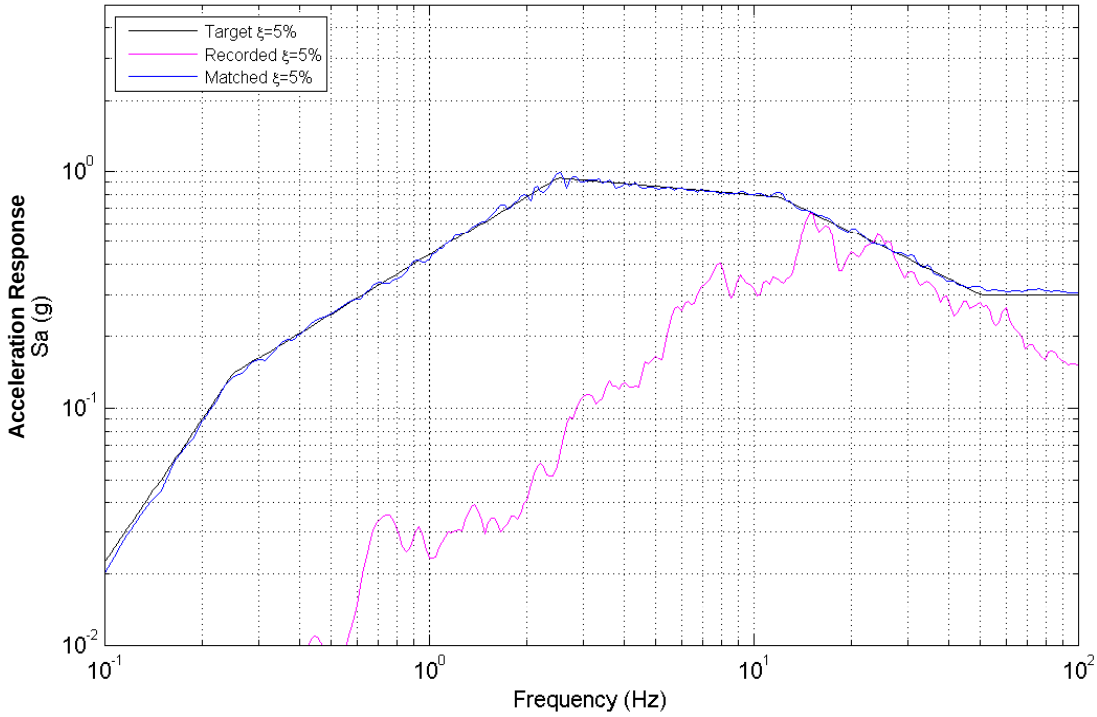
Acceleration Time Histories

Ground Motion Time Histories (3/5)



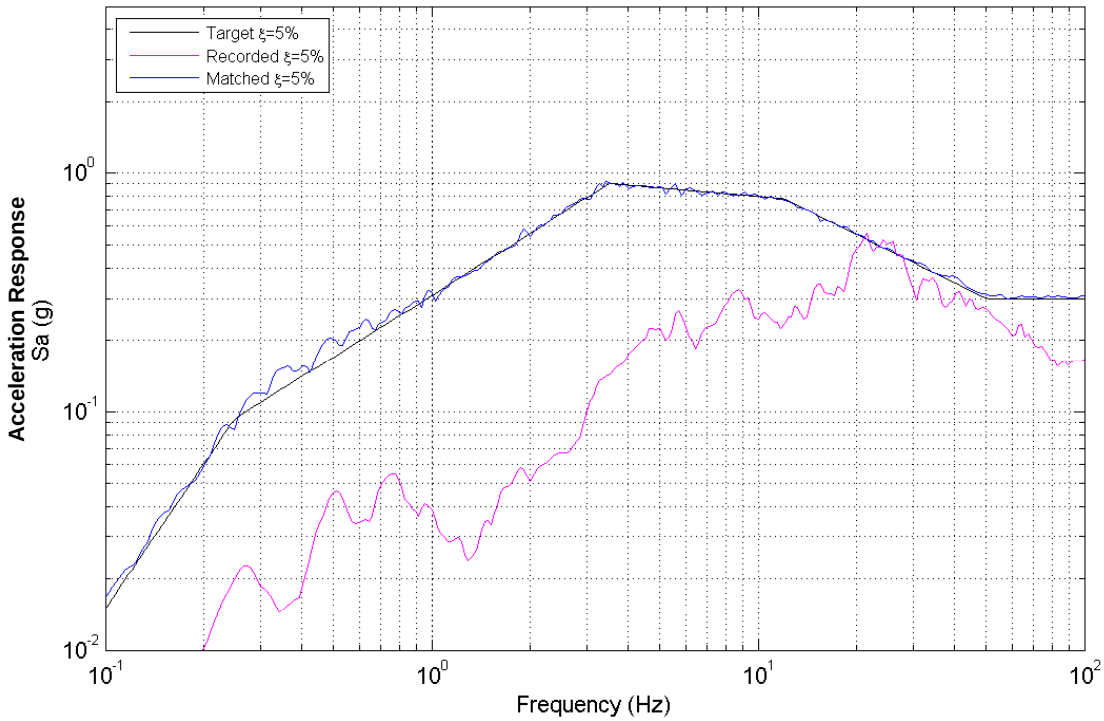
5% Damping Acceleration Response Spectra
H1 Earthquake

Ground Motion Time Histories (4/5)



5% Damping Acceleration Response Spectra
H2 Earthquake

Ground Motion Time Histories (5/5)



5% Damping Acceleration Response Spectra
Vertical Earthquake

Generic Site Profiles (1/8)

- Generic site profiles for SSI analyses selected to envelope conditions for a wide range of candidate sites within continental USA:
  - ✓ DCD Rev.1 approach:
    - 4 generic uniform sites representing soft to hard rock subgrade stiffness
    - Frequency independent lumped SSI parameters
    - Reduced horizontal SSI damping to account for layering

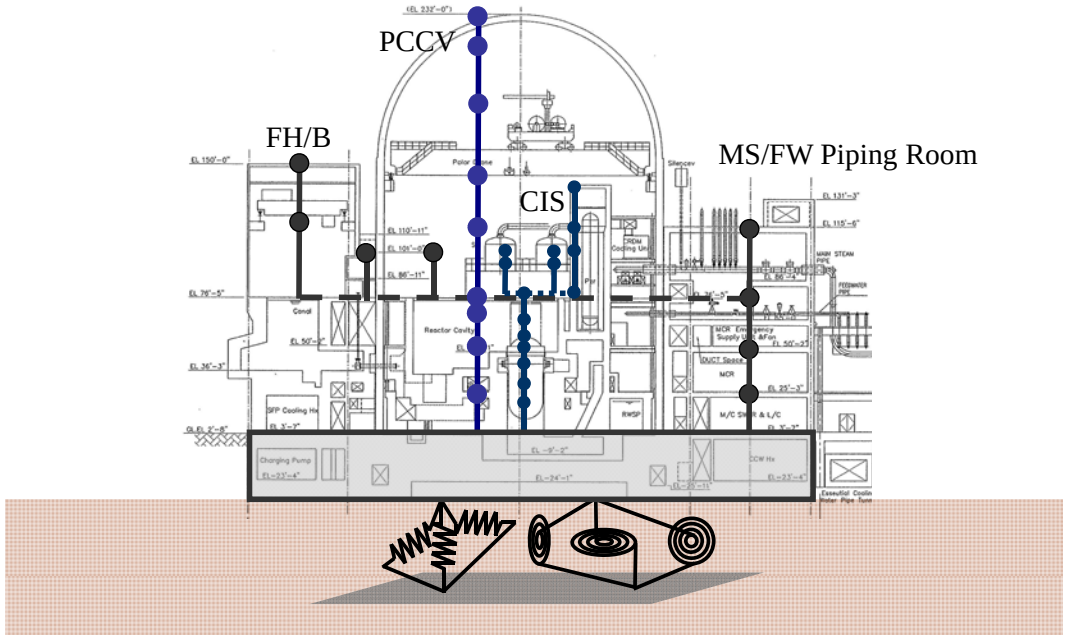
	Soft	Medium1	Medium2	Fixed (Hard Rock)
V_s (fps)	1,000	3,500	6,500	(8,000)
V_s (m/s)	300	1,100	1,980	(2,500)
Density (pcf)	110	130	140	(160)
Poisson's Ratio	0.40	0.35	0.35	(0.30)

V_s: Shear Velocity

Generic Site Profiles (2/8)

DCD Rev. 1 Approach:

- SSI effects modeled using soil springs and dashpots
- Responses obtained from direct integration time history analysis (THA).



Generic Site Profiles (3/8)

DCD Rev. 1 Approach

DCD Requirements for COL Validation of Standard Seismic Design	
GMRS	DCD Certified seismic design response spectra (CSDRS) (modified RG 1.60 spectra with PGA 0.3 g) must envelope COL site specific GMRS and FIRS at all frequencies
ISRS	DCD ISRS must envelope ISRS obtained from COL site specific SSI analysis. DCD standard design SSI analysis: • CSDRS defined ground motion • Rigid foundation on uniform half-space • Frequency independent SSI COL site-specific SSI analysis: • Site specific ground motion • Flexible foundation on layered subgrade • Effects of embedment and water table considered • Frequency dependent SSI impedance

Generic Site Profiles (4/8)

- MHI believes that validation requirements of DCD Rev. 1 standard seismic design ensure adequate applicability on site-specific COL basis. If this does not meet NRC expectation, following is proposed.
- Generic site profiles for SSI analyses are selected that envelope conditions found at a wide range of candidate sites within continental USA:
  - ✓ DCD Rev. 2 Technical Report approach:
    - Selection made by MHI technical advisory group consisting of nationally recognized seismology, geotechnical and soil structure interaction experts.
    - Selection based on uniform hazard and site response spectra from a large database of nuclear facilities sites
    - Properties varied with depth to envelope effects of site layering
    - SSI analyses based on frequency dependent SSI impedances

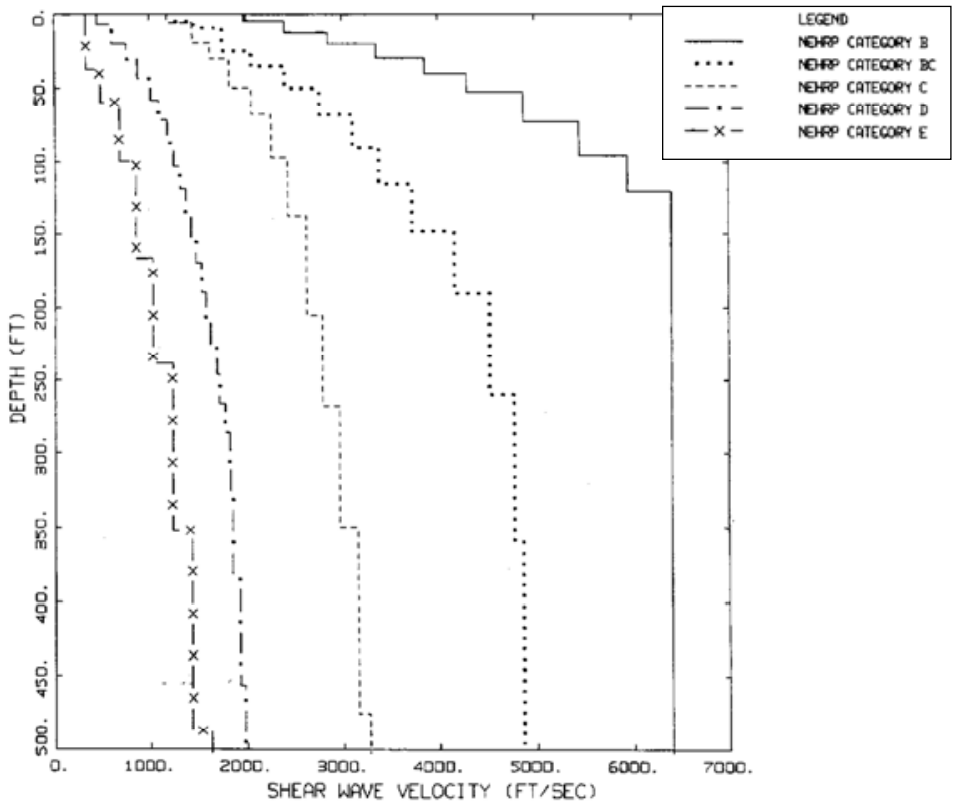
Generic Site Profiles (5/8)

- Development of generic layered profiles considers:
  - Database of several hundred profiles from nuclear power plant (NPP) sites (including EPRI 28 NPP), DOE sites (Savannah River, ORNL, Paducah) and other project sites.
  - Site geologies characteristic for different regions within continental USA
  - Profile samples of soft to firm soil overlying hard and soft rock.
  - Different depths of reference rock with Vs ≈ 9,300 fps and soil depths ranging from 200 ft to 10,000 ft.
  - Damping characteristics of sites sampled using kappa coefficients.
  - Several sets of soil degradation curves to account for nonlinear dynamic material properties
  - Poisson ratio profiles for P-wave profiles and empirical H/V ratios for vertical ground response spectra

Generic Site Profiles (6/8)

- **Site amplification functions and ground response spectra for each profile developed from fully probabilistic site response analyses:**
  - with multiple modulus reduction and damping curves**.**
  - with control motion from single-verses double-corner source models
  - results are weighted to accommodate uncertainty in nonlinear soil properties, shape and magnitude of source spectra
- **Generic profile categories selected based on:**
  - average V_s of top 30m soil
  - different depths to hard rock crustal model
  - UHS is enveloped by US-APWR CSDRS
- **Generic profile categories are verified through comparison with responses of site specific profiles**

Generic Site Profiles (7/8)



Generic Site Profiles (8/8)

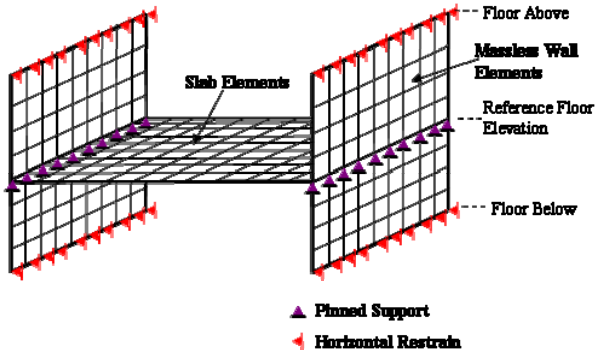
Candidate Generic Layered Site Profiles for SSI Analyses

Strain compatible V_S * (fps)	Depth of very hard rock (ft)	
	200	500
810	X	X
1500	X	X
2700	X	
6000	X	

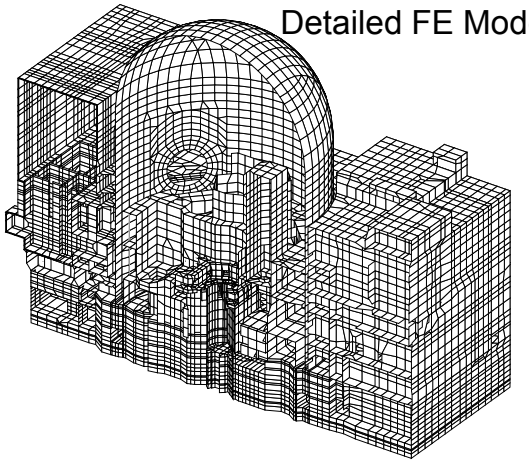
* Average of top 90 ft of soil

Structural Modeling (1/5)

- Selection of Reactor Building (R/B) flexible floors and walls
- Modeling of flexible floors and walls as single-degree-of-freedom (SDOF) systems (lollipops)
  - Models extracted from Detailed R/B Complex Finite Element (FE) Model
  - Out-of-plane stiffness reduced to account for concrete cracking effects
  - Boundary conditions

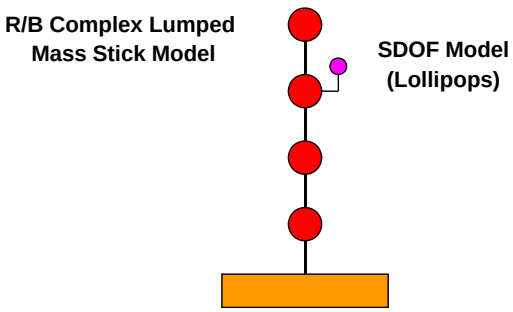


Detailed FE Model



Structural Modeling (2/5)

- **Seismic response analysis of flexible walls and floors**
  - ✓ **Coupling approach**
    - **SDOF models (lollipops) of floors and walls are coupled with global R/B Complex lumped mass stick model of entire structure**
  - ✓ **In-structure response Spectra (ISRS) for out-of-plane response of flexible walls and floors**
    - **ISRS for out-of-plane response developed directly from SDOF acceleration response spectra (ARS) results .**

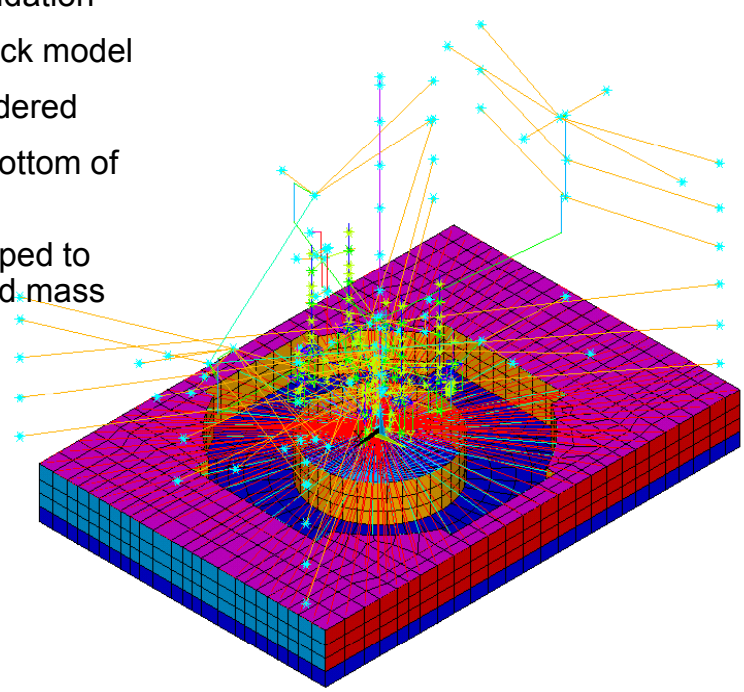


Structural Modeling (3/5)

- **Soil Structure Interaction (SSI) analyses to obtain seismic response of Category I structures:**
  - ✓ **DCD Rev.1 ANSYS direct integration THA:**
    - **Rigid foundation resting on uniform half-space**
    - **Frequency independent lumped SSI parameters (springs and dashpots)**
    - **Power Source Building (PS/B) embedment neglected**
  - ✓ **DCD Rev. 2 Technical Report ACS-SASSI analyses:**
    - **Flexible foundation resting on layered site**
    - **Frequency dependant SSI impedances**
    - **Effects of PS/B embedment considered**

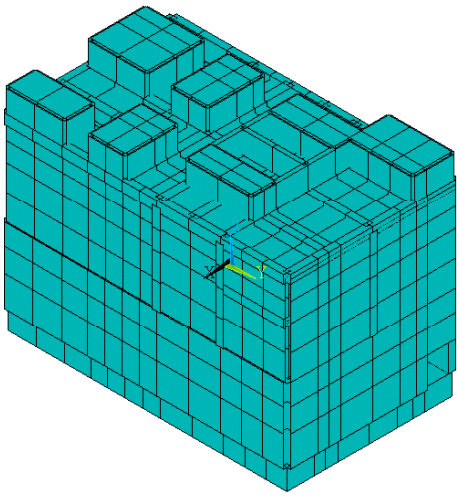
Structural Modeling (4/5)

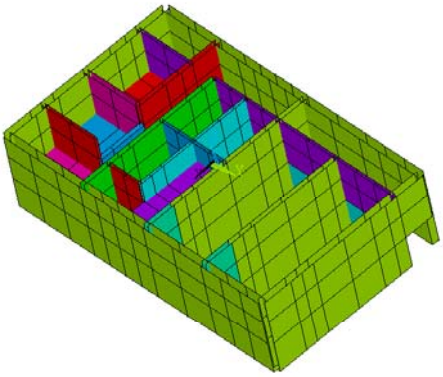
- **ACS-SASSI Analyses of R/B Complex**
  - FE model of building foundation
  - Coupled lumped mass stick model
  - Surface foundation considered
  - CSDRS input motion at bottom of basemat foundation
  - Selected sites are enveloped to determine ISRS at lumped mass locations



Structural Modeling (5/5)

- **ACS-SASSI Analyses of PS/B**
  - FE model of building
  - Surface and embedded foundation considered
  - CSDRS input motion at bottom of basemat foundation
  - Envelope ISRS at selected locations





SC Module Damping (1/2)

Damping in Final Safety Evaluation

	AP600	AP1000
Issued	September 1998	September 2004
Description	Specifically, for concrete-filled steel plate structures, the modified table specified a damping value of 5 percent. The use of **5 percent damping** for steel modules is consistent with test results and meets the guideline of RG 1.61. Consequently, Open Item 3.8.3.4-7 is closed.	The use of **5 percent damping** for the structural modules is in accordance with test data reported in DCD Reference 27. On this basis, the damping values specified in DCD Tier 2, Section 3.8.3.4.1.4, for reinforced concrete and structural modules of the CIS are acceptable. 27. H. Akiyama, H. Sekimoto, M. Tanaka, K. Inoue, M. Fukihara, Y. Okuda, "1/10th Scale Model Test of Inner Concrete Structure Composed of Concrete Filled Steel Bearing Wall," 10th International Conference on Structural Mechanics in Reactor Technology, 1989.

SC Module Damping (2/2)

US-APWR is equivalent to AP1000 in SC Configuration

		AP1000	US-APWR
Material	Concrete	Normal Concrete Compression Strength f'c=4,000psi	Normal Concrete Compression Strength f'c=4,000psi
	Steel	ASTM A36 Yield Strength Fy= 36ksi Tensional Strength Fu= 58 to 80ksi	ASTM A572 Grade 50 Yield Strength Fy= 50ksi Tensional Strength Fu= 65ksi
Thickness	Wall Thickness	30" and 48"	Primary Shield: 119" Secondary Shield: 48"
	Face Plate Thickness	0.5"	Primary Shield: 0.625" Secondary Shield: 0.5"
Stud		ASTM A108 Φ = 3/4", 嵊= 6" Pitch (H×V) @10"×about10"	ASTM A108 Φ= 3/4", 嵊=6" Pitch (H×V) @8"×8"

Conclusions (1/2)

Item	Issue Summary	Conclusions
Ground Motion Time Histories	Artificial time histories that are not based on seed recorded time histories should not be used.	MHI will re-analyse using the new artificial time histories that are based on seed recorded time histories.
Generic Site Profiles	(1) SSI when soil site is not uniform (2) High water table of 1 ft below grade (3) Soil spring constants of FE model were calculated by distributing soil springs of 3D lumped mass stick model.	In case NRC disagrees with DCD Rev. 1 approach, generic site profiles are proposed based on a large database of nuclear facilities sites • Varying properties with depth • Frequency independent SSI impedances • Envelope effects of site layering

Conclusions (2/2)

Item	Issue Summary	Conclusions
Structure Modeling	• PS/Bs are represented by lumped sum stick model. • Concrete is assumed to be cracked under thermal load and not cracked for mechanical and seismic loads.	• PS/Bs are analyzed by FE modeling. • Out-of-plane stiffness reduced to account for concrete cracking effect.
Damping Ratio of SC Modules	Adequate justification for damping values of SC modules is not provided	5% damping has been approved for SC walls for AP600 and AP1000. Based on similarity between US-APWR and AP1000, 5% damping for SC modules of US-APWR CIS is proposed.