3/31/2011

NRC Public Meeting for US-APWR DCD Chapter 3
-Mitsubishi Presentation Materials and Presenters-

MATERIAL #	TOPIC	PRESENTER
A	Introduction	John Regan (MNES)
B	Seismic Design Basis Models	Luben Todorovski (URS)
C	Effect of Concrete Cracking	Tom Panayotidi (URS)
D	Soil Profiles	Luben Todorovski (URS)
E	Structure-Soil-Structure Interaction (SSSI)	Luben Todorovski (URS)
F	Water Table Effects	Luben Todorovski (URS)
G	Embedment Effects on Seismic Response	Wen Tseng (Rizzoassoc)
H	High Frequency Consideration in CSDRS	Joe Tapia (MNES)
I	Foundation Analysis	Radu Popescu (URS)
J	Sliding Stability	Wen Tseng (Rizzoassoc)
K	Gap between Structures	Michael McKenna (URS)
L	Steel Concrete (SC) Modules	Carl Baylor (URS)
M	Steel Liner Plate Strain Near PCCV Penetration	Bill Hovis (URS)
N	Conclusion	John Regan (MNES)

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Comparison Table between Key Seismic Technical Issues and Presentation Letters (03-31-11)

Key Seismic Technical Issues	Symbol of Presentation
(1) Seismic Analysis Approach	
• Development of design basis model	**B**
• High frequency ground motion input	**H**
(2) Seismic Design Basis Models	
• Validation of lumped mass stick model	**B**
• Effect of water table	**F**
• Effect of concrete cracking	**C**
• High frequency response	**B**
(3) Soil-structure Interaction (SSI) Analysis	
• Selection of soil profiles/ properties	**D**
• Cat II/Cat I structure	**E, K**
• Embedment effect	**G**
(4) Design reports of seismic Category I structures and their combined basemat: PCCV, containment internal structures, reactor building complex, power source buildings, and essential service water pipe tunnel	
• Structural member sizes and connection detail	**N/A**
• Steel liner plate strain near PCCV penetrations subjected to combined membrane and bending stresses	**M**
• Effects of concrete cracking on seismic response	**C**
• Effects of high water table on seismic response	**F**
• Adequacy of 4-in gap between building considering lateral displacement due to seismic motions, concrete cracking, and differential settlement	**K**
• Containment Internal Structures	**L**
○ Applicability of the 1/10th scale cyclic test report	**L**
○ Sufficiency design considerations	**L**
▪ Applicability of design methods	**L**
▪ Adequacy of fire rating for the PCCV and containment internal structures	**L**
• Critical sections	**N/A**
○ Clarify the criteria used to determine the critical sections in the structures	**N/A**
(5) Design reports of seismic Category II structures and their basemats, T/B and A/B	
• Structural member sizes and connection detail	**N/A**
• Effects of high water table on seismic response	**F**
• Adequacy of 4-in gap between buildings	**K**
(6) Soil foundation adequacy	
• Acting dynamic soil pressure vs. allowable dynamic soil bearing strength	**I**
• Short-term (elastic) structure settlement vs. design predictions during construction	**I**
• Long-term settlement vs. allowable structure settlement or/and uneven settlement	**I**
○ Potential for pounding between adjacent structures due to differential settlement and tilt of the foundation and lateral seismic movement	**I, K**
Sliding Stability	**J**
Structure-soil-structure Interaction	**E**

US-APWR

Introduction

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

Introduction

- A Seismic Task Force has been formed to address US-APWR Standard Plant issues, specifically related to NRC Staff questions and RAIs related to DCD Chapters 3.7 and 3.8
- Task Force Membership
  - ✓ MNES and MHI
  - ✓ URS
  - ✓ Dominion (with technical support from Bechtel)
  - ✓ Luminant (with technical support from Enercon)
- Presentation is a US-APWR Standard Plant Seismic Presentation as informed by the Seismic Task Force efforts

Introduction

- **Objective**
  - ✓ NRC Staff key issues have been divided into twelve major topics
    - Provide cross reference comparison table/matrix of topics to NRC's key seismic technical issues
  - ✓ Regarding the twelve issues, present the US-APWR Standard Plant:
    - Current design basis
    - Proposed resolutions (some of which necessitate a change to current US-APWR strategy)
  - ✓ Identify associated deliverables

Introduction

- Identification of the twelve topics (B through M)

Morning Session

A – Introduction
B – Seismic Design Basis Models
C – Effect of Concrete Cracking
D – Soil Profiles
E – Structure-Soil-Structure Interaction (SSSI)
F – Water Table Effects
G – Embedment Effects on Seismic Response
H – High Frequency Consideration in CSDRS

Afternoon Session

I – Foundation Analysis
J – Sliding Stability
K – Gap Between Structures
L – Steel Concrete (SC) Modules
M – Steel Liner Plate Strains Near PCCV Penetrations
N – Conclusion

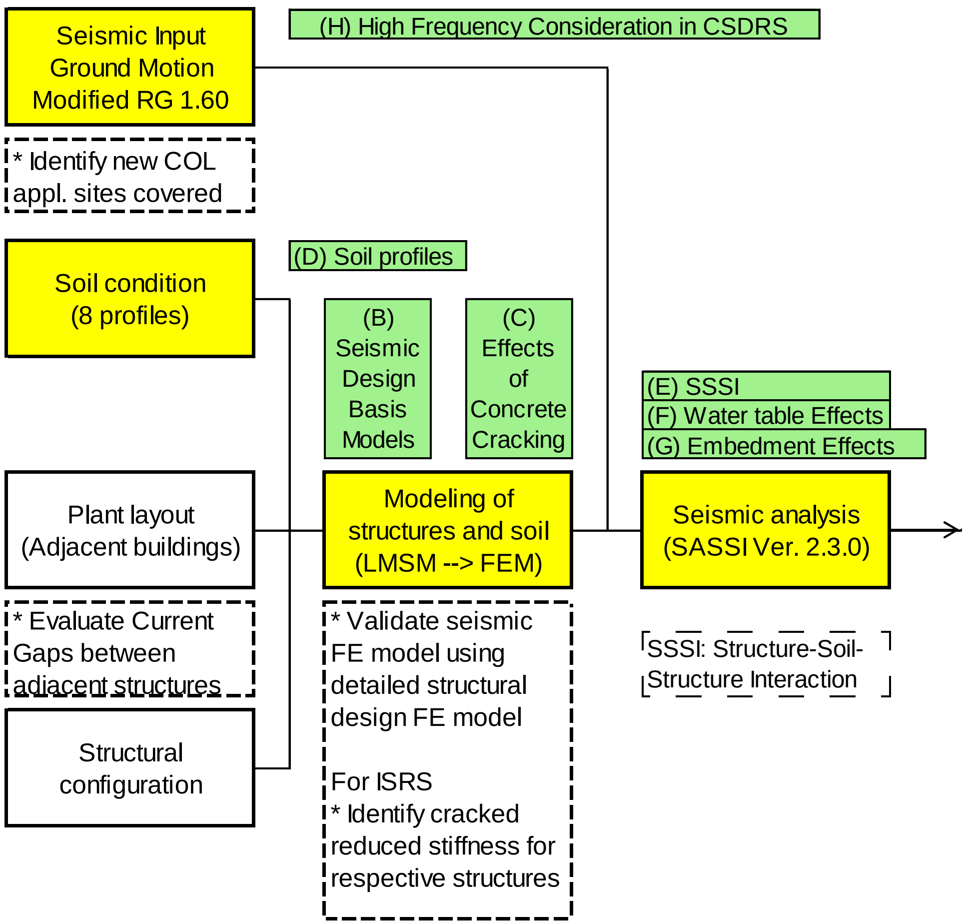
Introduction

➢ Flow of slides for each of the twelve topics

1. Issue Statement	**Describes concern(s) for each of the twelve topics**
2. Current Status	**Provides current status based on documentation the NRC has available to date**
3. Resolution Proposal	**Identifies closure plan, whether current path remains or an alternate path to resolution has been selected**
4. Deliverables	**Identifies deliverables associated with each resolution proposal**
5. Summary	**Overall review of each topic and an opportunity to present questions or comments**

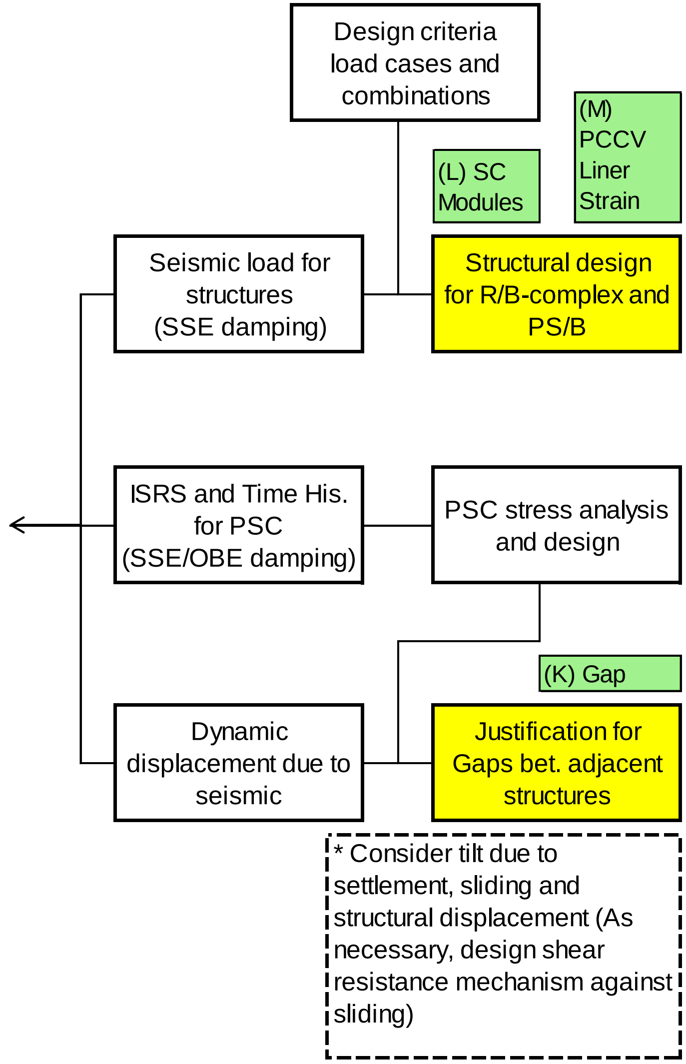
Introduction

- Overview of design flow, seismic analysis and modeling



Introduction

- Overview of design flow, downstream of seismic analysis



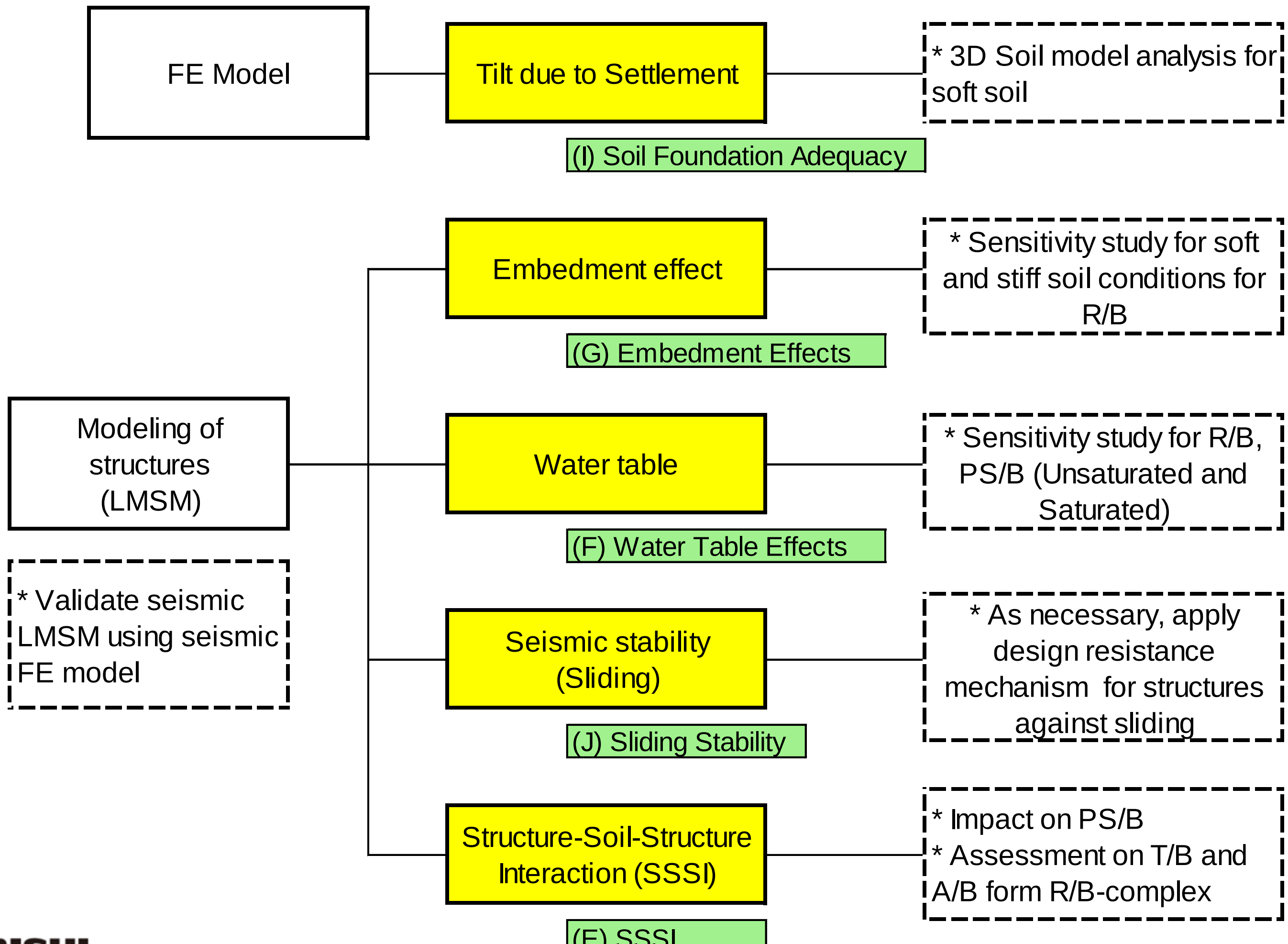
Introduction

- Identification of Change in Analysis Model
- Topic (B) Seismic Design Basis Models

		Previous/Current		Resolution Plan	
		Seismic analysis	Structural design	Seismic analysis	Structural design
Seismic Category I	R/B-Complex (R/B, PCCV, CIS and Common basemat)	LMS model	FE model (Detailed)	FE model	FE model (Detailed)
	PS/B	FE model	FE model (Detailed)	FE model	FE model (Detailed)
Seismic Category II	A/B	FE model	FE model (Detailed)	FE model	FE model (Detailed)
	T/B	FE model	FE model (Detailed)	FE model	FE model (Detailed)

Introduction

- Design flow considering LMSM application for stability evaluation and selected assessments



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Seismic Design Basis Models

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

- Lumped Mass Stick Models of R/B and CIS may not adequately capture local seismic responses in all directions
- Lumped Mass Stick Models of R/B and CIS have a limited ability to capture high frequency responses
- Refinement of basemat meshes and cut-off frequency of analyses are not adequate to capture responses at high frequencies for all soil cases

2. Current Status (1/6)

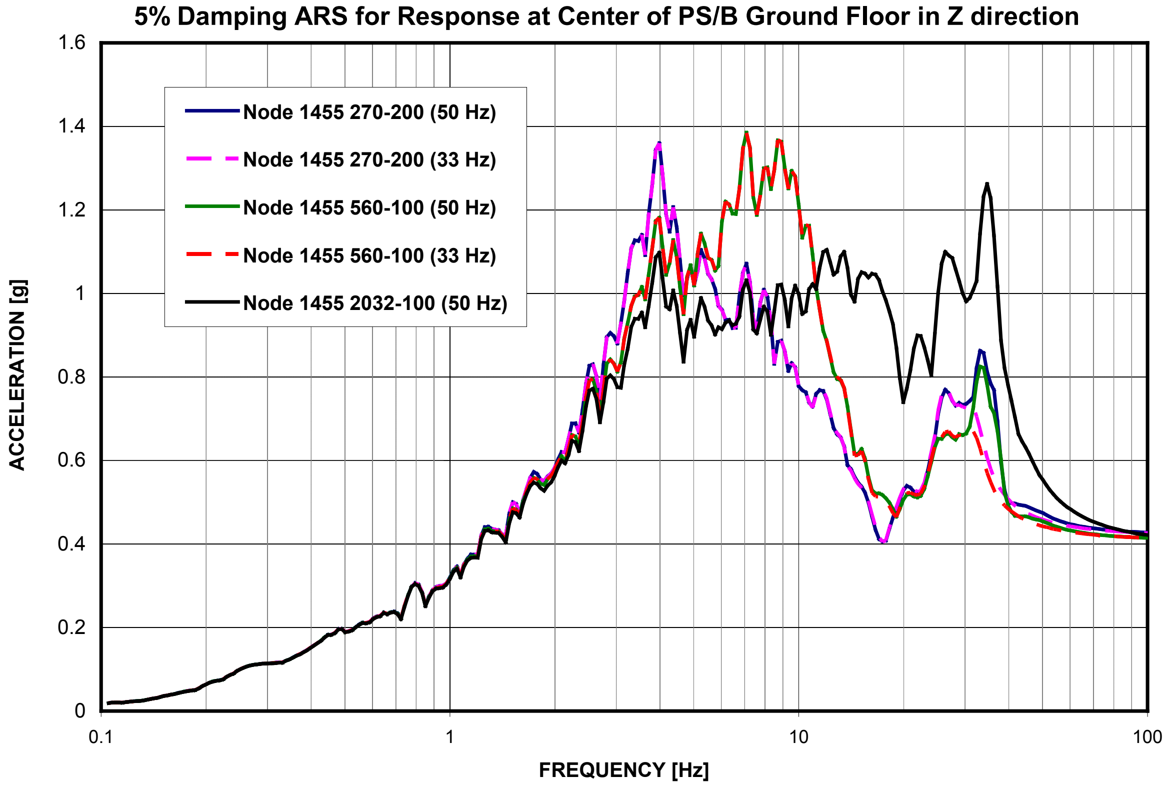
- Seismic response site-independent soil-structure interaction (SSI) analyses of seismic Category I and II structures are presented in:
  - ✓ MUAP-10001 (R2) documents design basis for SSI analyses (CSDRS input ground motion, generic site profiles, R/B Complex and PS/B dynamic models)
  - ✓ MUAP-10006 (R1) documents SSI analyses results of R/B Complex and PS/B
  - ✓ MUAP-11001 (R0) documents dynamic model and SSI analyses results of A/B
  - ✓ MUAP-11002 (R0) documents dynamic model and results of SSI analyses of T/B

2. Current Status (2/6)

- Methodology used for SSI analyses
  - ✓ SASSI frequency domain time history seismic response analyses provide resulting seismic responses that include effects of SSI frequency dependence and foundation flexibility
  - ✓ Seismic Category I and II basemats are considered resting on subgrade surface and effects of backfill are neglected as secondary
  - ✓ Seismic design of structures and components based on envelope of responses obtained from SSI analyses of 8 generic layered soil profiles
  - ✓ A set of three statistically independent acceleration time histories compatible to CSDRS used as input ground motion at foundation level
  - ✓ Response due to three directions of earthquake are combined using SRSS method

2. Current Status (3/6)

- Response to RAI 660-5134 Question 3.7.2-57 demonstrated that for analyses of softer soil profiles, use of less refined FE models and lower values of cut-off frequencies does not affect design basis ISRS

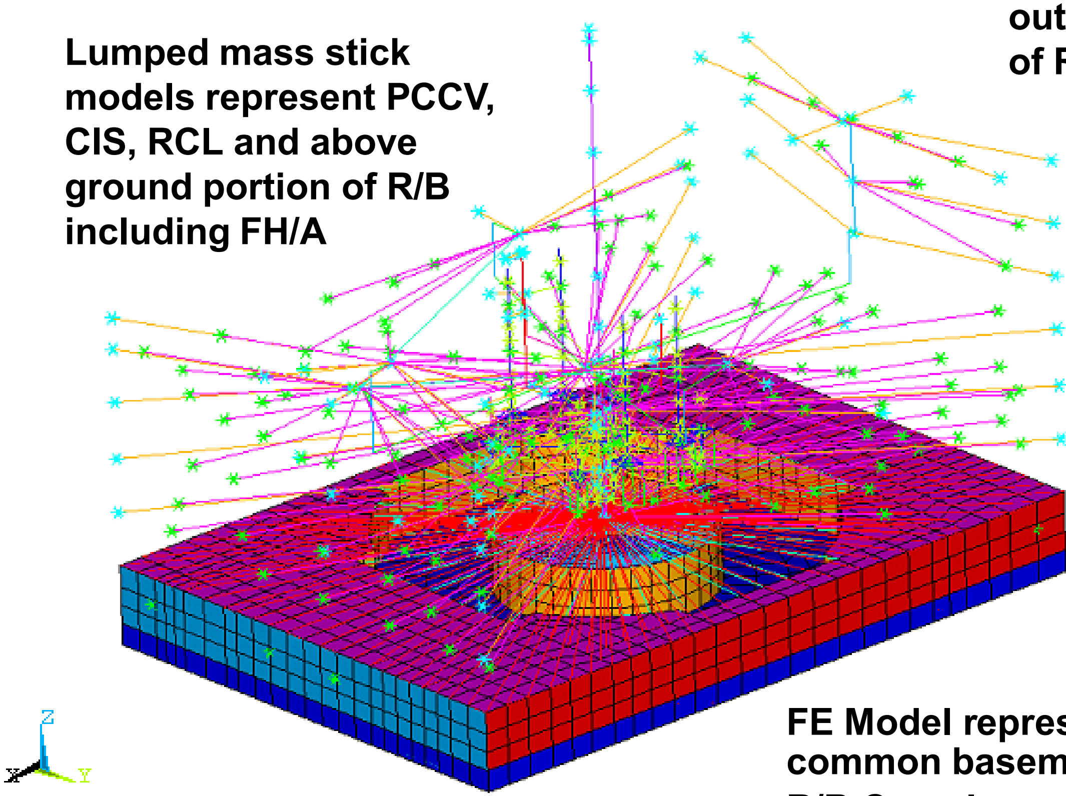


2. Current Status (4/6)

- Lumped Mass Stick Model (LMSM) of R/B Complex Structures

Lumped mass stick models represent PCCV, CIS, RCL and above ground portion of R/B including FH/A

SDOF oscillators represent out-of-plane local response of R/B slabs and walls



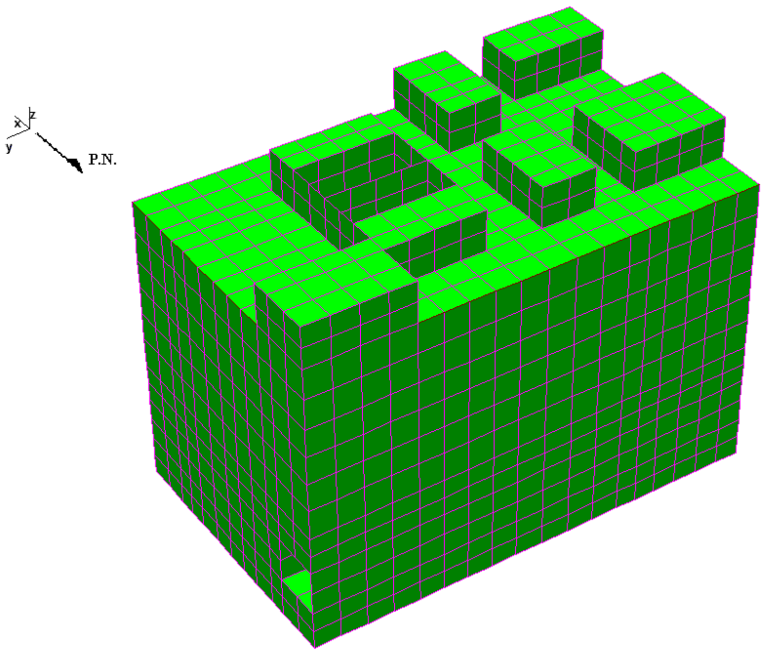
PCCV, CIS and R/B lumped mass stick models are uncoupled

CIS model coupled with RCL lumped mass stick model

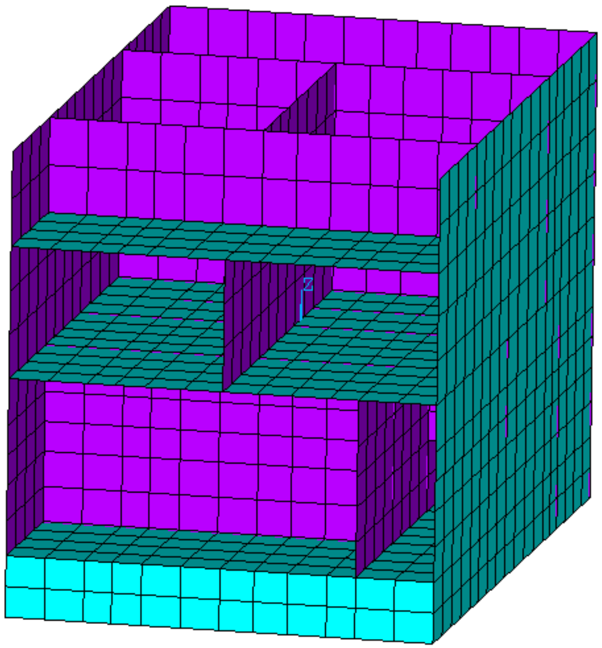
FE Model represents common basemat for R/B Complex

2. Current Status (5/6)

- PS/B Seismic Design Basis Model

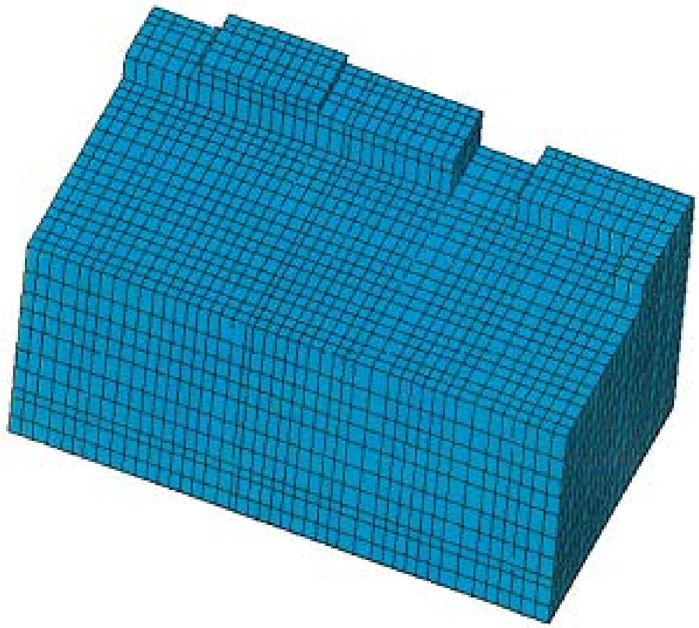


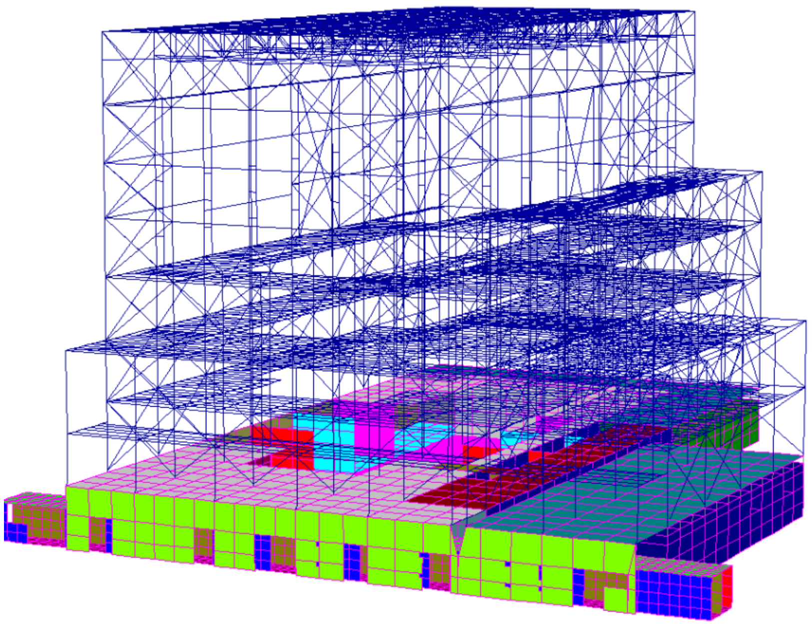
FE Model represents the dynamic properties of East and West PS/B's



2. Current Status (6/6)

- A/B Seismic Design Basis Model





- T/B Seismic Design Basis Model

3. Resolution Proposal (1/18)

- R/B Complex dynamic FE model will be adopted to address modeling concerns of lumped mass stick models
  - ✓ R/B Complex lumped mass stick model will be used for development of seismic driving forces for stability evaluations, SSSI analyses and selected studies on R/B Complex global seismic behavior
- Seismic response analysis of all US-APWR seismic Category I and II structures will be based on dynamic FE models
- Dynamic FE model is developed and validated following similar methodology to one presented in MUAP-10001 for validation of PS/B dynamic FE model

3. Resolution Proposal (2/18)

- Using the methodology described in MUAP-10001 and MUAP-10006, the following SSI analyses will be performed for each of the 8 generic subgrade profiles on the:
  - ✓ R/B Complex dynamic FE model with full (uncracked concrete) stiffness of R/B and PCCV structures and best estimate stiffness of CIS
  - ✓ R/B Complex dynamic FE model with reduced (cracked concrete) stiffness of R/B and PCCV structures and best estimate stiffness of CIS
  - ✓ Evaluation of CIS SC modules stiffness and damping are ongoing

3. Resolution Proposal (3/18)

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- Results of SSI analyses of models with following material properties will be used to develop seismic design basis:

Structure	Stiffness	Damping	ISRS	SSE Loads
CIS*	Best estimate	5%	**X**	**X**
PCCV	Full (uncracked)	3%	**X**	**X**
	Reduced (cracked)	5%	**X**	**X**
R/B	Full (uncracked)	4%	**X**	**X**
	Reduced (cracked)	7%	**X**	**X**
PS/B	Full (uncracked)	4%	**X**	**X**
	Reduced (cracked)	7%	**X**	**X**

* To be Confirmed

3. Resolution Proposal (4/18)

- Frequencies of Analyses

Soil Case	Soil Vs fps	R/B Complex		PS/B		f_{cutoff} Hz
		d_{FE} ft	$f_{FE\ max}$ Hz	d_{FE} ft	$f_{FE\ max}$ Hz	
270-500	1242	9	27.6	6.3	39.4	40
270-200	1302		28.9		41.3	40
560-500	1698		37.7		53.9	50
560-200	1552		34.5		49.3	50
560-100	1588		35.3		50.4	50
900-200	3237		71.9		102.7	70
900-100	3403		75.6		108	70
2032-100	7333		163		233	70

d_{FE} – Nominal basemat finite element mesh size

f_{FE_max} – Maximum passing frequency

f_{cutoff} – Cut-off frequency of Analysis

3. Resolution Proposal (5/18)

- Use of Updated Design Basis
  - ✓ SSE design loads for seismic design of R/B Complex structures will be developed from maximum acceleration results from SSI analyses of dynamic FE model following methodology used in MUAP-10006 to develop SSE loads for design of PS/B
  - ✓ SSE loads from dynamic FE model will be compared to SSE loads in MUAP-10006 to validate/reconcile current design of R/B complex structures
  - ✓ Dynamic FE model will serve as the new design basis model for development of ISRS used for seismic design of R/B Complex subsystems, components and equipment
  - ✓ Design ISRS for different damping values and locations within R/B Complex will be developed using ACS SASSI by grouping and enveloping responses calculated for different node locations within dynamic FE model

3. Resolution Proposal (6/18)

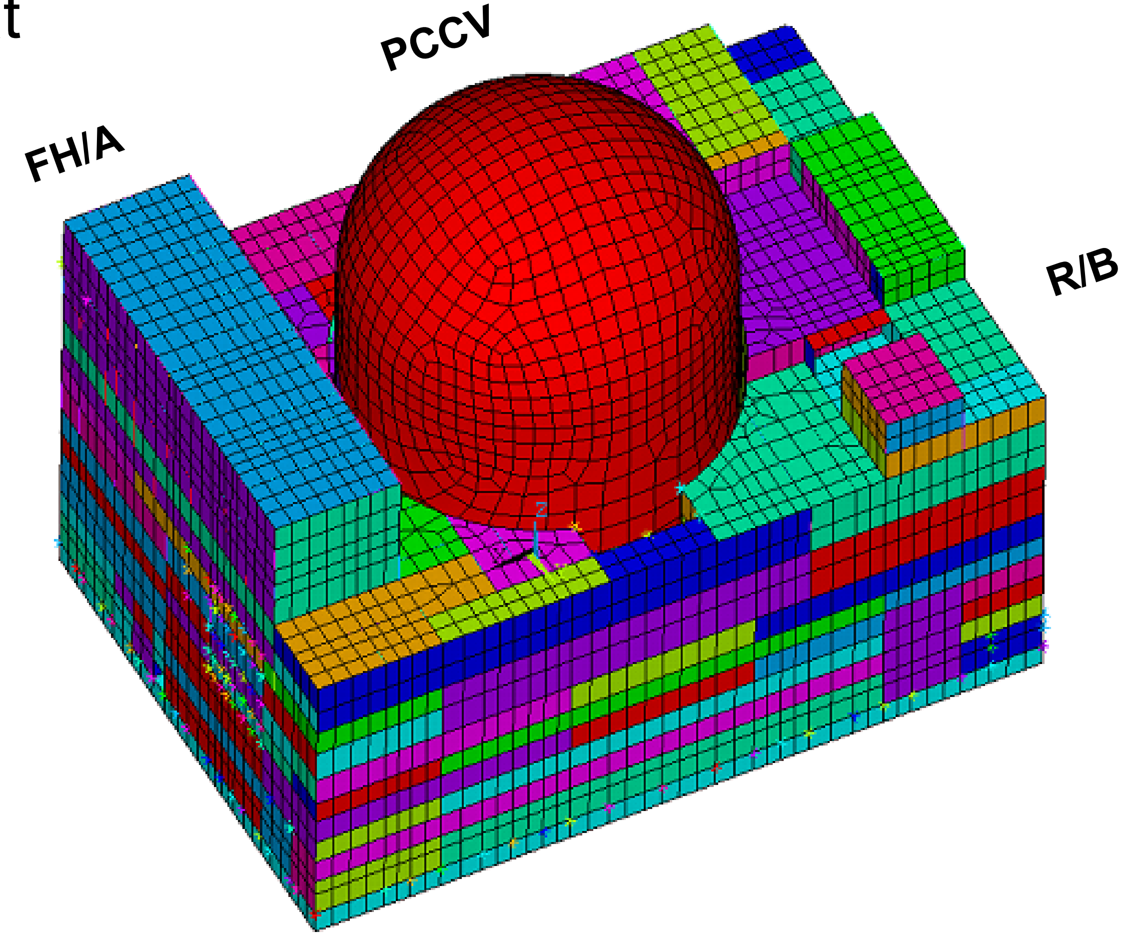
- Future use of R/B Complex Lumped Mass Stick Models
  - ✓ Existing lumped mass stick models will be validated to ensure they adequately capture overall dynamic response in first few significant structural modes of vibrations
  - ✓ SSI analyses performed on R/B Complex lumped mass model will provide seismic base reactions for stability evaluations
    - Seismic base reactions are a function of mainly the global response in first significant modes of vibration
    - Comparison of results for envelope maximum base reactions from lumped mass stick and FE models will be used to validate results

3. Resolution Proposal (7/18)

- Future use of R/B Complex Lumped Mass Stick Models (continued)
  - ✓ SSI analyses performed on R/B Complex lumped mass model will provide analyses of other effects important for global response of structure and/or are manifested in low frequency range (such as water table effects, embedment effects, etc.)
  - ✓ Lumped mass stick models will be used for SSSI evaluations to represent dynamic properties of nearby heavy structures (ex. R/B Complex and A/B) affecting response of FE models of lighter buildings (ex. PS/B)

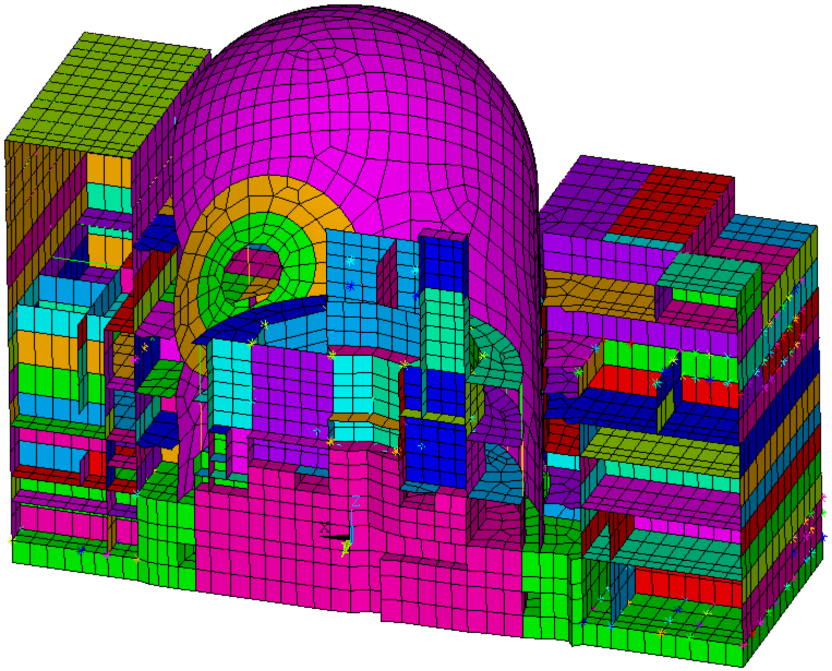
3. Resolution Proposal (8/18)

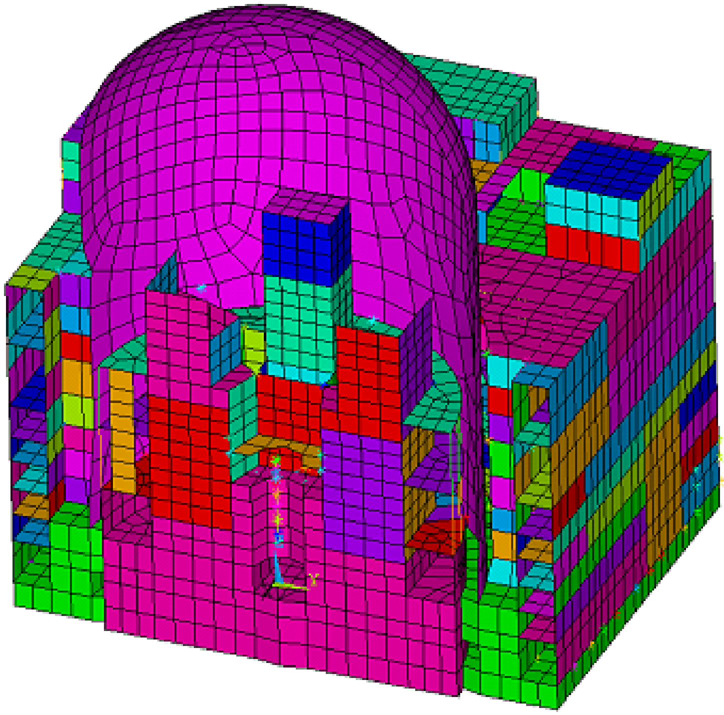
- Shell and Solid dynamic FEs are used to model the PCCV, CIS, R/B and FH/A resting on the common basemat



3. Resolution Proposal (9/18)

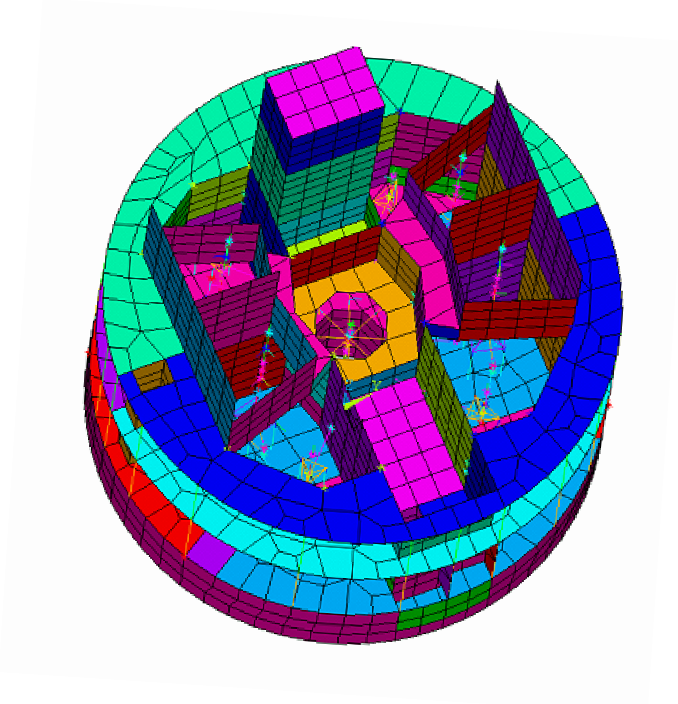
➢ Cross-section views of R/B Complex





3. Resolution Proposal (10/18)

- The CIS FE model is coupled with the RCL LMSM representing dynamic properties of NSSS equipment and piping
- Dynamic properties of RCL model are identical to those of the model used for piping stress analysis



3. Resolution Proposal (11/18)

- RCL model consists of Reactor Vessel (RV), Steam Generator (SG), Reactor Coolant Pump (RCP), Main Coolant Piping (MCP) and those components supports
- Damping values for RCL model are SSE damping values (3%) (Regulatory Guide 1.61)

3. Resolution Proposal (12/18)

- Validation of R/B Complex Dynamic FE Model
  - ✓ Validation of R/B Complex dynamic FE model is being performed in accordance with provisions of SRP 3.7.2 Section II and ISG-01 Section 3.1
  - ✓ Approach used for validation of R/B Complex dynamic FE model is similar to one used for validation of PS/B dynamic FE model (described in MUAP-10001 Section 5.4.2)
  - ✓ Detailed FE models used for calculation of stress demands for design of PCCV, CIS, R/B and R/B Complex common basemat serve as basis for validation of less refined dynamic FE model
  - ✓ Verification of dynamic properties is based on results of fixed base analyses performed on detailed and dynamic FE models of R/B Complex structures

3. Resolution Proposal (13/18)

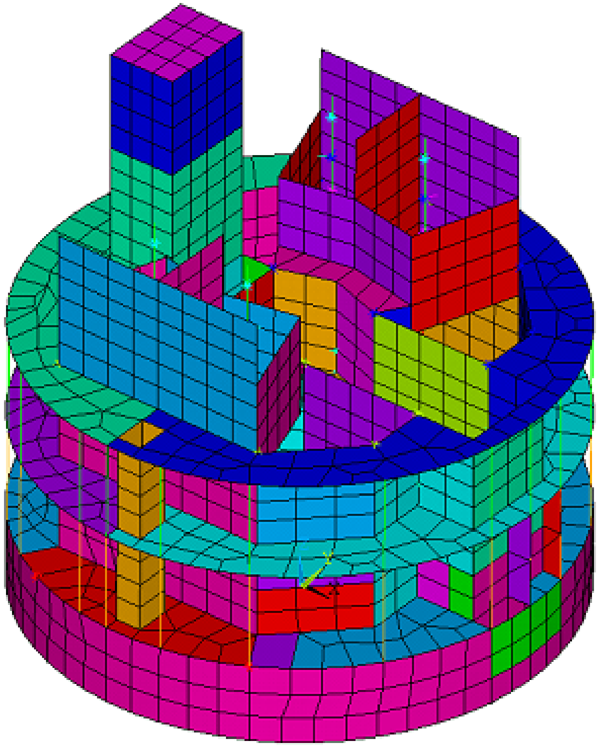
- Validation of R/B Complex Dynamic FE Model
  - ✓ Types of ANSYS validation fixed base analyses:
    - 1-g static analyses provide deflections used to validate mass inertia and stiffness properties
    - Modal analyses provide natural frequencies, mode shapes and mass participation factors used to compare overall dynamic properties
    - Local models of R/B slabs and walls are separated from detailed and dynamic model, and modal analyses are performed to demonstrate ability of dynamic model to capture local out-of-plane high frequency responses
    - Mode superposition time history analyses provide acceleration response spectra (ARS) used to compare response of models in representative locations

3. Resolution Proposal (14/18)

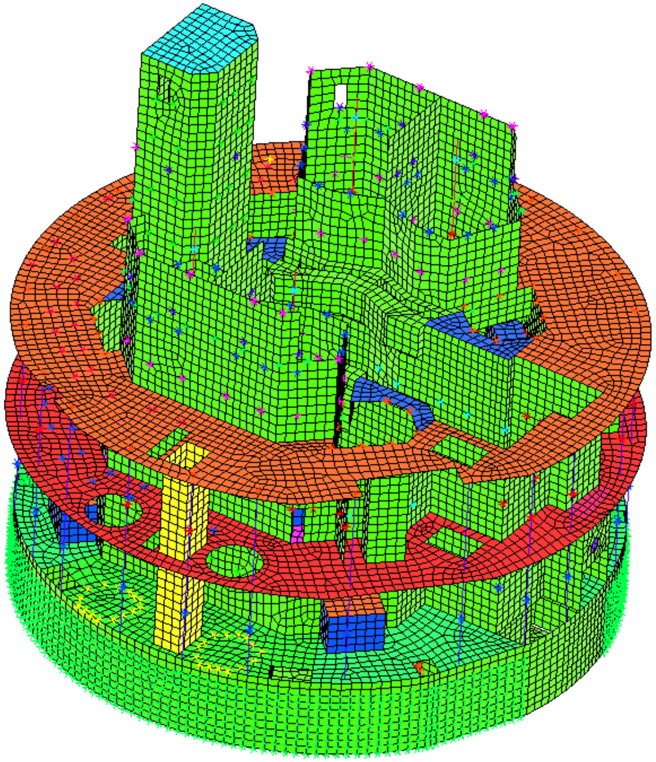
- Validation of R/B Complex Dynamic FE Model (continued)
  - ✓ SASSI analyses of FE model on surface of stiff half-space are performed. Translation of model into ACS SASSI will be verified by comparing:
    - Transfer Function results with results of ANSYS modal analyses
    - ARS results with results of ANSYS modal superposition time history analyses

3. Resolution Proposal (15/18)

- R/B Complex Dynamic FE Model Validation
  - ✓ Dynamic FE model of CIS is validated using detailed FE model used for stress evaluation of CIS structural components



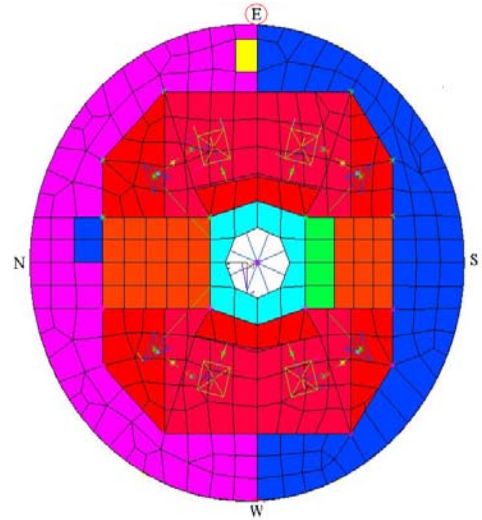
CIS Dynamic FE Model

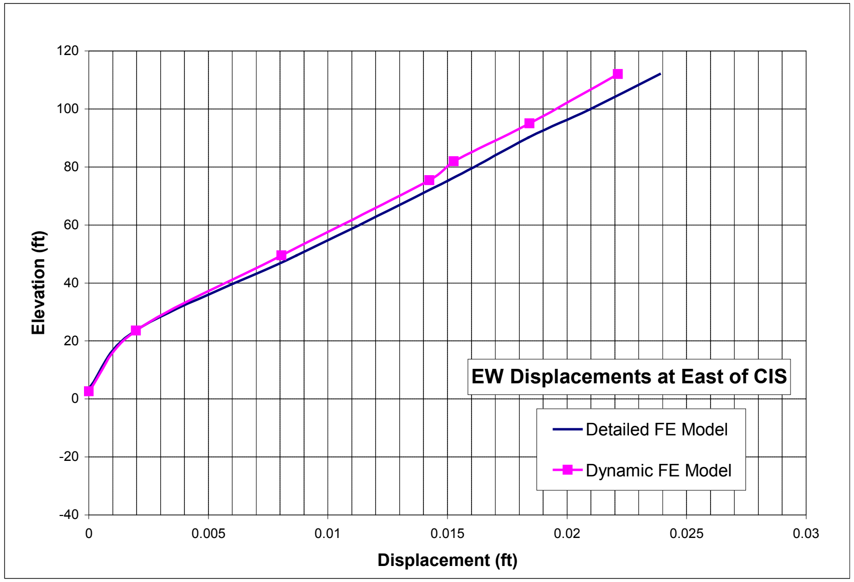


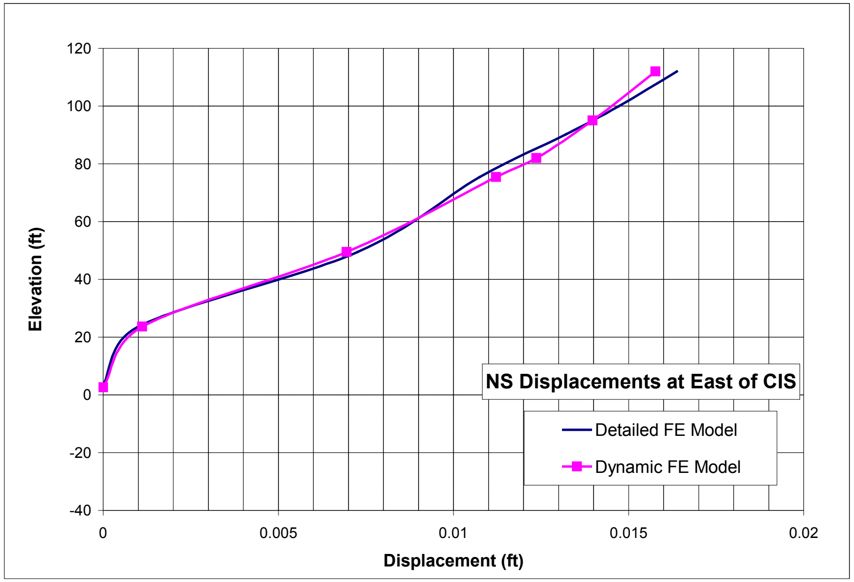
CIS Detailed FE Model

3. Resolution Proposal (16/18)

- R/B Complex Dynamic FE Model Validation
  - ✓ Preliminary Results of 1-g verification analysis

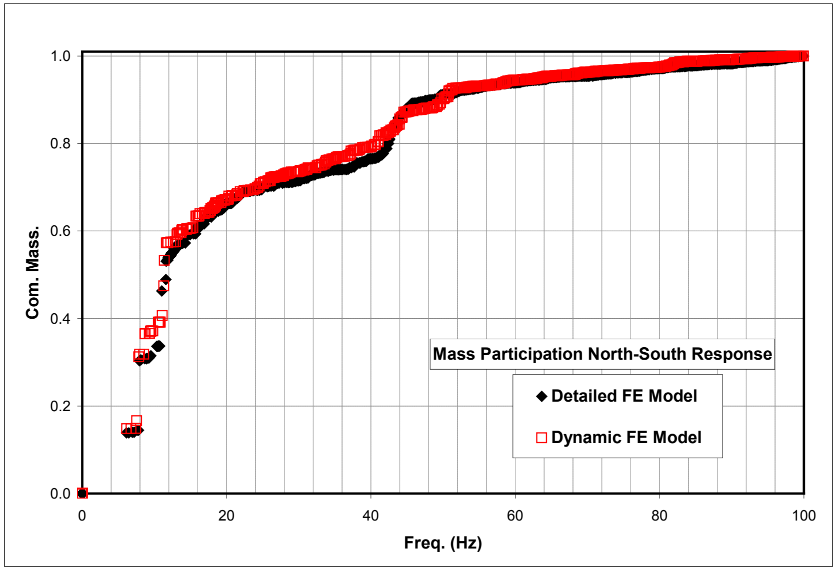






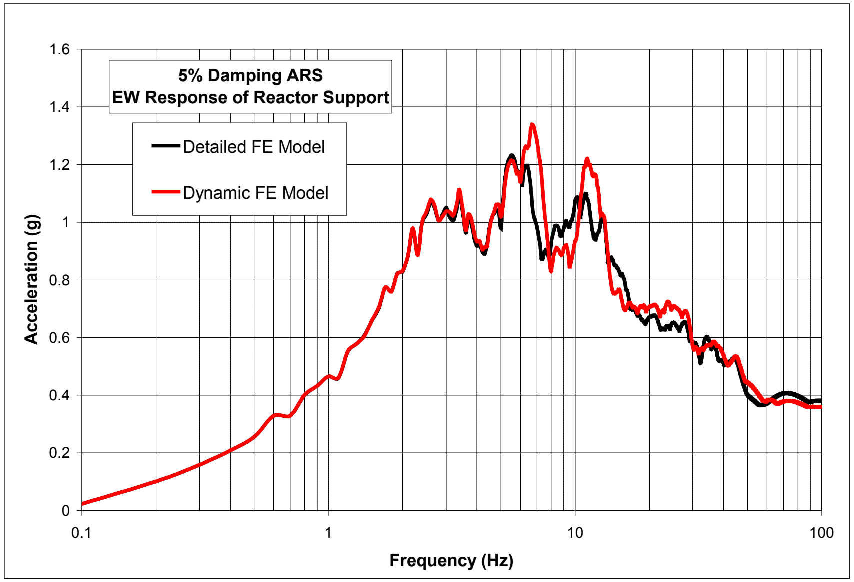
3. Resolution Proposal (17/18)

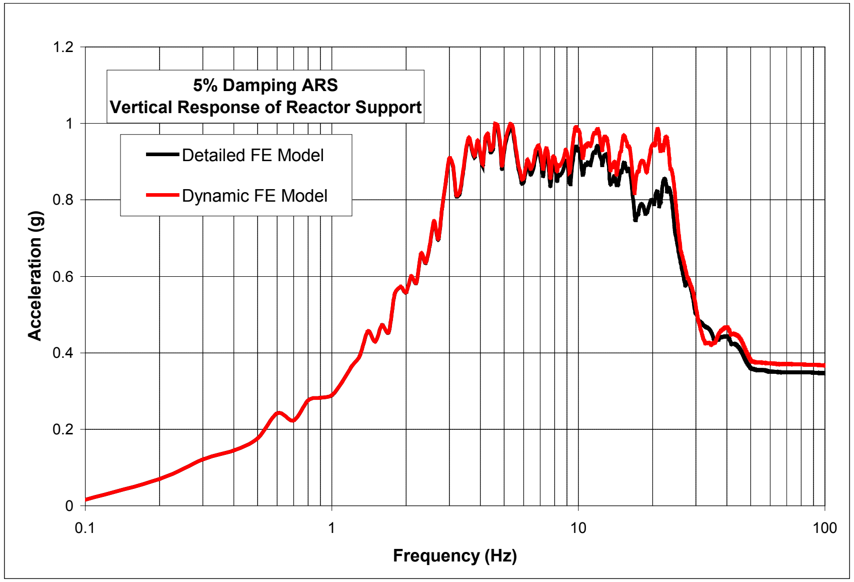
- R/B Complex Dynamic FE Model Validation
  - ✓ Preliminary Results of CIS Modal Verification Analyses



3. Resolution Proposal (18/18)

- R/B Complex Dynamic FE Model Validation
  - ✓ Preliminary Results of CIS Time History Verification Analyses





4. Deliverables

- Technical Reports
  - ✓ MUAP-10001 will be revised to document development and validation of R/B Complex dynamic FE model
  - ✓ MUAP-10006 will be revised to include results of site-independent SSI analyses of R/B Complex dynamic FE model and development of design basis SSE loads and ISRS
- Tracking report of Section 3.7.2 of DCD will reflect seismic response analyses of R/B Complex dynamic FE model

5. Summary

- MHI will adopt a R/B Complex dynamic FE model that fully complies with SRP 3.7.2 Section II and ISG-01 Section 3.1 requirements to develop design basis SSE loads for structural design and ISRS for evaluation of subsystems, components and equipment
- Lumped mass stick models will be validated as needed and will be used for specific case studies and calculations of base reactions where consideration only of global response is required

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Effect of Concrete Cracking

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

- Concrete cracking affects the dynamic characteristics of a building, altering its response to seismic excitation and thus affecting seismic design bases (ISRS and SSE loads) obtained from seismic response analyses
- Stiffness and damping assigned to structural models used for seismic response SSI analyses has to adequately reflect the effects of concrete cracking
- Concrete cracking considerations for R/B Complex, PS/B, and PCCV require clarity
- SC modules in CIS present unique challenges since there are no industry codes governing design and analysis

2. Current Status (1/3)

- DCD (R2) Seismic Response Analyses in MUAP-10006 (R1) considered the effects of concrete cracking by using best estimate stiffness for PS/B Dynamic FE model and R/B Complex lumped mass stick models
- Reduction of stiffness of R/B and PS/B shear wall structures were evaluated in MUAP-10001(R2) based on stress results of DCD (R1) design analyses:
  - ✓ 50% reduction of out-of-plane stiffness of all flexible walls and slabs
  - ✓ 50% reduction of in-plane stiffness of FH/A walls
- Overall stiffness of CIS reduced by 25% to account for concrete cracking
- Effect of concrete cracking on PCCV stiffness was assumed to be negligible

2. Current Status (2/3)

- Evaluation of effect of cracking on R/B and PS/B shear wall reinforced concrete structures
  - ✓ When imposed stress levels exceed the cracking strength, per ASCE 43-05 Table 3-1:
    - In-plane stiffness is reduced by 50% when shear stresses exceed the concrete shear strength of the section
    - Out-of-plane stiffness is reduced by 50% when bending stresses exceed the cracking strength of the section
- Modeling of stiffness in reinforced concrete members is based on the stress level caused by the most critical seismic load combination

2. Current Status (3/3)

- Evaluation of effect of cracking on R/B and PS/B shear wall reinforced concrete structures
  - ✓ Nominal Shear Capacity of Low Aspect Ratio Wall (h_w/l_w <=2.0)

$$v_c := 8.3 \cdot \sqrt{fc'} - 3.4 \cdot \sqrt{fc'} \cdot \left(\frac{h_w}{l_w} - 0.5 \right)$$

  - ✓ Nominal Shear Capacity of High Aspect Ratio Wall (h_w/l_w >2.0)

$$v_c = 2 \cdot \left(f'_c \right)^{0.5}$$

  - ✓ Nominal Out-of-Plane Bending Capacity

Cracking moment $M_{cr} = \frac{f_r I_g}{y_t}$

Concrete Modulus of Rupture $f_r = 7.5\sqrt{f'_c}$

3. Resolution Proposal (1/5)

- Effect of concrete cracking will be addressed by using models with different material properties

Structure	Stiffness	Damping	ISRS	SSE Loads
CIS*	Best estimate	5%	X	X
PCCV	Full (uncracked)	3%	X	X
	Reduced (cracked)	5%	X	X
R/B	Full (uncracked)	4%	X	X
	Reduced (cracked)	7%	X	X
PS/B	Full (uncracked)	4%	X	X
	Reduced (cracked)	7%	X	X

* To be Confirmed

3. Resolution Proposal (2/5)

- New set of site-independent SSI analyses will consider 2 stiffness levels for PCCV, R/B and PS/B
  - ✓ Full stiffness representing uncracked concrete condition
  - ✓ Reduced stiffness representing cracked concrete condition
- Each model will be run for eight generic soil cases
- Design loads and ISRS will be enveloped by seismic responses with the two bounding stiffness levels

3. Resolution Proposal (3/5)

- PCCV - Seismic response analyses will consider two stiffness and damping levels in order to address variations in the extent of concrete cracking during normal and accidental conditions:
  - ✓ Full Stiffness (Uncracked Concrete):
    - Flexure: 1.0 $E_c I_g$
    - Shear: 1.0 $G_c A_w$
    - Axial: 1.0 $E_c A_g$
    - OBE damping of 3%
  - ✓ Reduced Stiffness (Cracked Concrete):
    - Flexure: 0.5 $E_c I_g$
    - Shear: 0.5 $G_c A_w$
    - Axial: 1.0 $E_c A_g$
    - SSE damping of 5%

3. Resolution Proposal (4/5)

- R/B and PS/B - Seismic response analyses will consider two stiffness and damping levels in order to address possible variations in the extent of concrete cracking in these shear wall type structures:
  - ✓ Full Stiffness (Uncracked Concrete):
    - Flexure: 1.0 $E_c I_g$
    - Shear: 1.0 $G_c A_w$
    - Axial: 1.0 $E_c A_g$
    - OBE damping of 4%
  - ✓ Reduced Stiffness (Cracked Concrete):
    - Flexure: 0.5 $E_c I_g$
    - Shear: 0.5 $G_c A_w$
    - Axial: 1.0 $E_c A_g$
    - SSE damping of 7%
- Stiffness and damping values are per ASCE 43-05

3. Resolution Proposal (5/5)

- Methodology for Calculating Effective Stiffness of SC Modules in Dynamic FE Model
  - ✓ Value of stiffness used in the dynamic FE models will be based on pertinent recommendations of the AISC N690 draft code provisions and subcommittee members. They will account for:
    - Effects of shrinkage and creep
    - Cracking due to in-plane and out-of-plane demands estimated based on the stress analyses of the detailed FE models
    - Thermal cracking under normal operating and accident conditions
- Request technical meeting with NRC to discuss methodology in detail

4. Deliverables

- MUAP-10006 will be revised
  - ✓ PCCV using reduced stiffness (cracked) and full stiffness (uncracked) analyses
  - ✓ R/B and PS/B using reduced stiffness (cracked) and full stiffness (uncracked) analyses
  - ✓ CIS using best estimate stiffness analysis

5. Summary

- Provided a description of approach for each structure
  - ✓ PCCV: Reduced stiffness (cracked) and full stiffness (uncracked) assessed
  - ✓ R/B and PS/B: Reduced stiffness (cracked) and full stiffness (uncracked) assessed
  - ✓ CIS: Best estimate stiffness based on stress evaluation

US-APWR

Soil Profiles

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

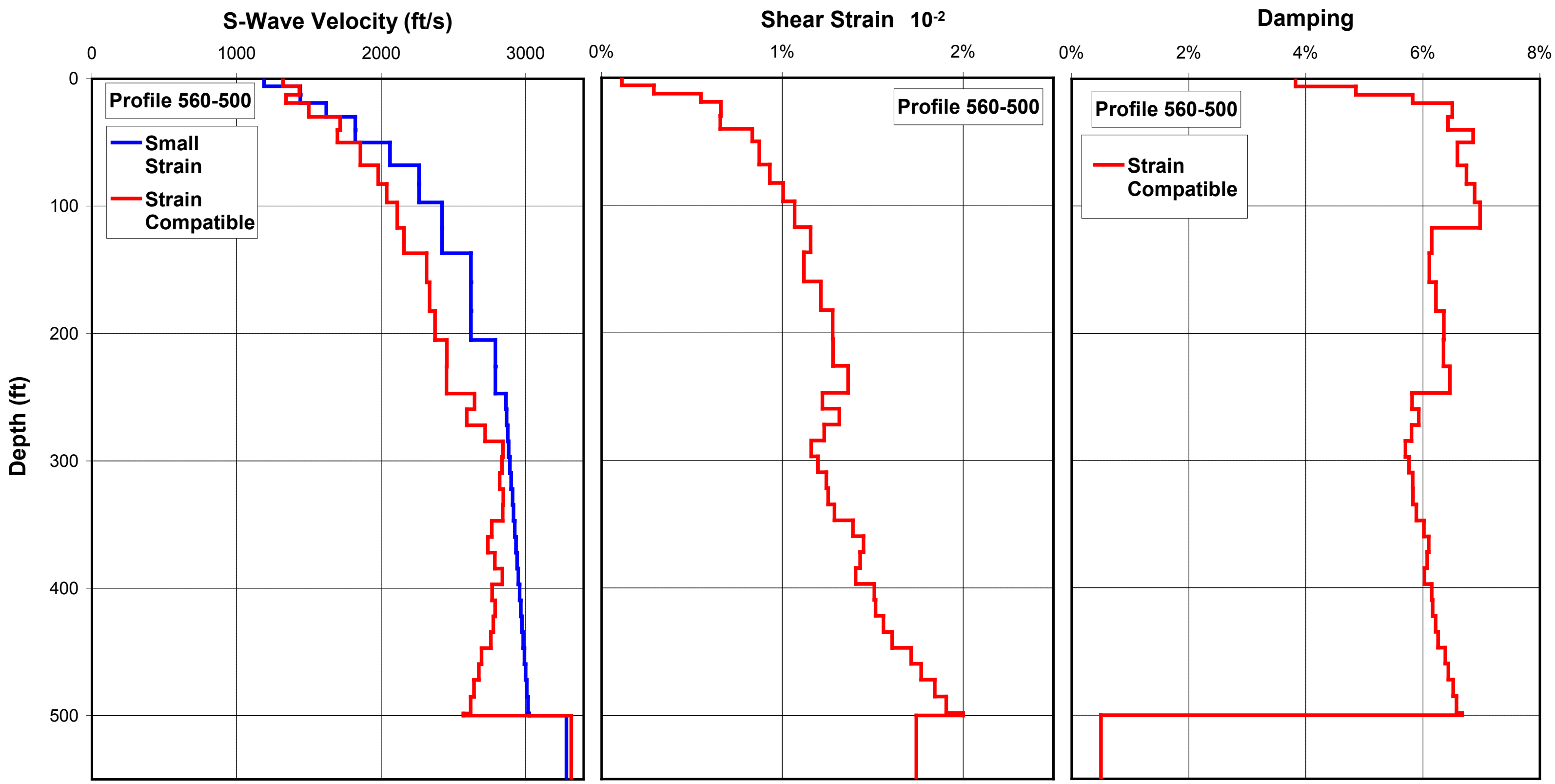
- Degradation curves used for site response analyses in MUAP-10001 (R2) to account for strain dependent behavior of rock materials have not been available for NRC review
- Generic soil profile properties in MUAP-10001 (R2) Tables 5.2-4 and 5.2-5 show unrealistic variation of S-wave velocity with depth
- Parametric studies for selection of depth of site models used for SSI analyses are not provided as required by SRP 3.7.2

2. Current Status (1/2)

- Degradation curves used in site response analyses for rock materials have not yet been published or provided for NRC review
- S-wave velocity profiles presented in MUAP-10001 (R2) Tables 5.2-4 and 5.2-5 are strain compatible and consistent with the anticipated seismic response of actual sites
- Parametric studies of effects of site model depth on SSI responses have not been performed to date

2. Current Status (2/2)

- Decrease in velocity with depth in generic profile 560-500 from about 400 ft to the soft rock profile base at 500 ft is due to strain degradation of soft rock material



3. Resolution Proposal

- Provide for NRC review the unpublished degradation curves for rock materials
- Demonstrate that generic soil profiles in MUAP-10001 (R2) show variations of strain-compatible S-wave velocity with depth that are consistent with variation of strains generated by the seismic response of the sites
- Perform a parametric study of effects of site model lower boundary on SSI responses as required by SRP 3.7.2

4. Deliverables

- Supplemental response to RAI 659-5133, Question 3.7.1-17 will be provided
  - ✓ Include previously unpublished degradation curves for rock materials
  - ✓ Demonstrate that generic soil profiles in MUAP-10001 are consistent with variation of strains generated by the seismic response of the sites
- MUAP-10006 will be revised to include results of sensitivity study on effects of SSI model lower boundary

5. Summary

- Provide supplemental response to RAI 659-5133 Question 3.7.1-17 to include previously unpublished degradation curves for rock material, and to provide explanation for decrease of strain compatible S-wave velocity with depth
- Perform sensitivity study of lower boundary effect as required by SRP 3.7.2

US-APWR

Structure-Soil-Structure Interaction

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

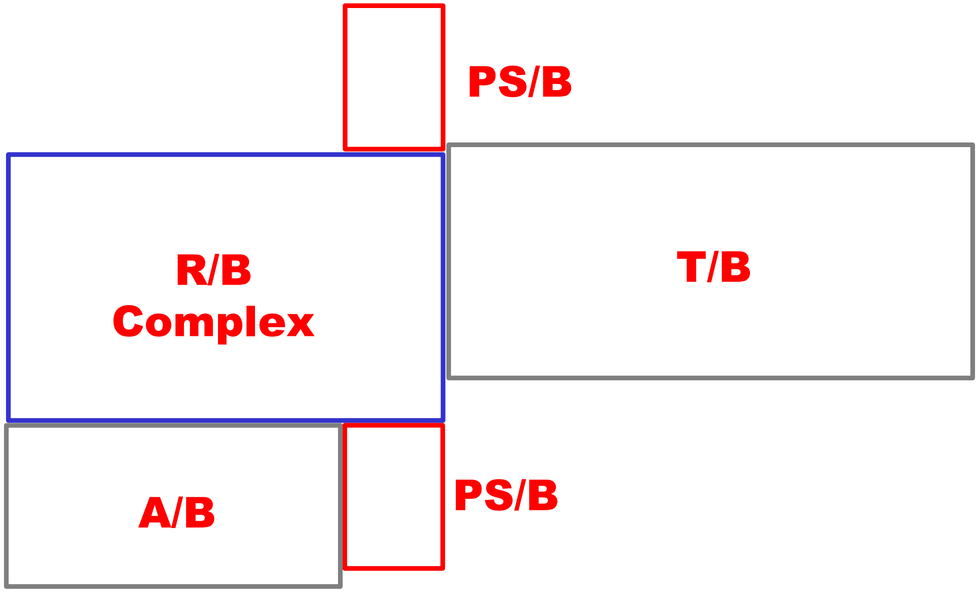
- US-APWR plant buildings are located close to each other, and may influence each other's seismic response due to Structure-Soil-Structure Interaction (SSSI) effects

2. Current Status (1/2)

- DCD (R2) does not address effects of SSSI on seismic response of US-APWR standard design
- DCD COL 3.7(10) requires further consideration of SSSI in COLA based on site specific conditions

2. Current Status (2/2)

- Standard plant structures are separated from each other and other site-specific buildings and foundations by a gap
- Bottom elevations of US-APWR standard plant building's foundations are almost identical
- PS/B design ISRS will be most affected by SSSI effects



3. Resolution Proposal (1/3)

- Approach for addressing SSSI effects
  - ✓ SSSI primarily has impact on design ISRS (in particular those of lighter buildings that are in vicinity of heavy buildings) and only secondary effect on structural design
  - ✓ Two aspects of SSSI will be investigated:
    - Kinematic interaction manifested by effect of stand-alone heavy buildings on ground motion in proximity of the buildings
    - Dynamic interaction, where SSI analysis will be performed with the combined model that includes multiple structures, and the SSSI effects will be explicitly evaluated
  - ✓ Study of kinematic effects will provide first-hand assessment of importance of SSSI effects on standard design for different generic subgrade conditions
  - ✓ SASSI analyses of combined model of PS/B, R/B Complex and A/B will provide effects of SSSI on PS/B design basis ISRS and SSE loads

3. Resolution Proposal (2/3)

- Steps to study SSSI effects on standard plant structures and include them in seismic standard design:

  1. Evaluate SSSI kinematic effects of R/B Complex on other US-APWR standard buildings for different soil conditions
  2. Perform SASSI analyses of combined PS/B, R/B Complex and A/B resting on surface of selected critical soil cases
  3. Evaluate dynamic SSSI effects by comparing ISRS and maximum accelerations results from SASSI analyses of stand alone and coupled models
  4. Reconcile design basis to include possible exceedances due to SSSI effects

3. Resolution Proposal (3/3)

- SASSI analyses of combined PS/B dynamic FE model with R/B Complex and A/B lumped mass stick models
  - ✓ Lumped mass stick models that can capture overall dynamic properties of R/B Complex and A/B structures are appropriate for capturing SSSI effects on PS/B response
  - ✓ Investigation of dynamic SSSI effects will be mainly focused on effects of heavy R/B Complex and A/B on response on lighter PS/B
  - ✓ Assess effect of SSSI by comparing PS/B ISRS results from SASSI analyses of PS/B stand alone model and combined R/B Complex-A/B-PS/B model
- If effects of SSSI on PS/B ISRS are significant, then SSSI effects on other buildings will be further investigated

4. Deliverables

- Technical Report MUAP-11011 will be issued to present SSSI sensitivity study
- Technical Report MUAP-10006 will be revised to document design ISRS that include possible SSSI effects, if necessary
- Tracking report of DCD will include description addressing SSSI effects

5. Summary

- MHI will perform sensitivity study of SSSI effects on standard plant design that is based on SASSI analyses of combined model of R/B Complex, A/B and PS/B
- SSSI study will be documented in Technical Report MUAP-11011
- Design basis in next revision of MUAP-10006 will be reconciled to include possible SSSI effects, if needed

US-APWR

Water Table Effects

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

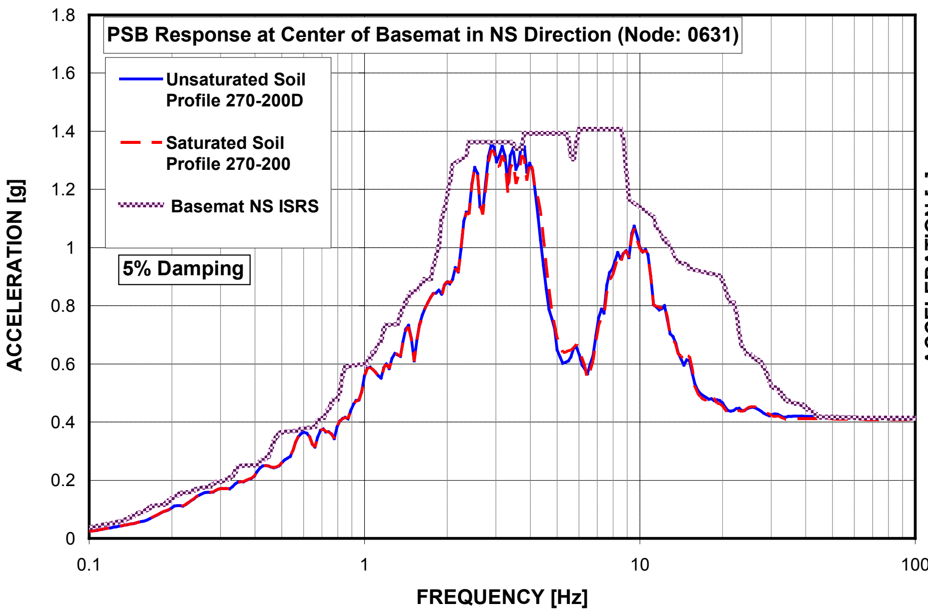
- Selection of two soil profiles considered in the sensitivity study needs to be explained
- Justification for assuming same unit weight for saturated and unsaturated soil needs to be provided
- Response of R/B Complex structures was not addressed in the sensitivity study

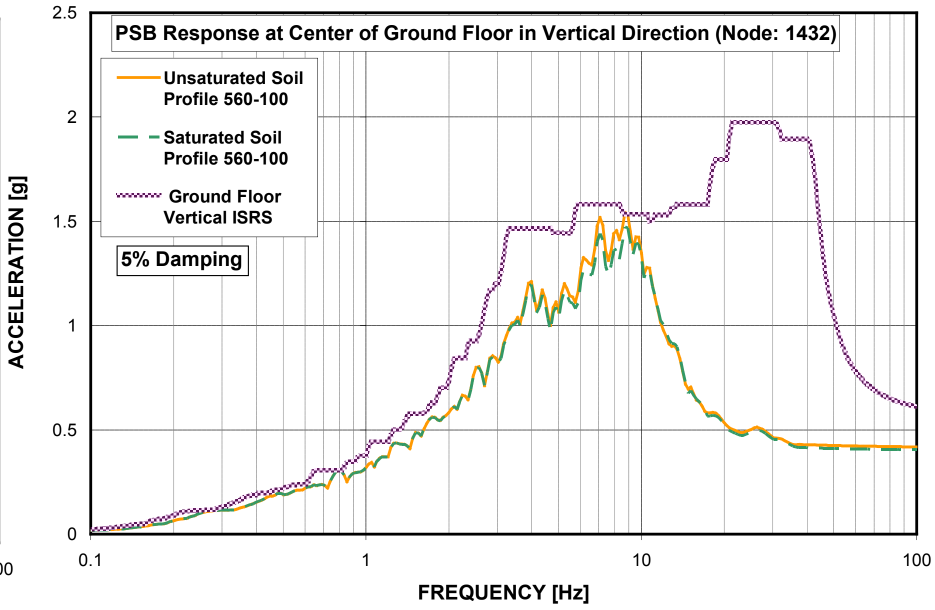
2. Current Status (1/3)

- Generic profiles for site-independent analyses in MUAP-10001 (R2) consider fully saturated subgrade with P-wave velocity Vp of saturated soil greater than or equal to 5,000 ft/s = Vp of water
- Response to RAI 660-5134 Question 3.7.2-60 included a sensitivity study
  - ✓ Investigation of generic subgrade profiles revealed that water table fluctuations affect only P-wave velocities of generic soil profiles with soil layer Vs = 270 m/s up to depth of about 200 ft and soil layer Vs = 560 m/s up to depth of 100 ft
  - ✓ Two profiles were developed (270-200D and 560-100D) by adjusting Poisson ratio to represent unsaturated soil properties. Difference in unsaturated and saturated unit weight was not considered
  - ✓ SASSI analyses of PS/B FE model resting on surface of unsaturated soil profiles 270-200D and 560-100D provided ISRS that were compared to current design basis ISRS

2. Current Status (2/3)

- Effect of Water Table Fluctuation on Seismic Response
  - ✓ Comparison of preliminary results for 5% damping ISRS obtained from analyses of PS/B FE model for unsaturated soil cases to corresponding saturated soil cases indicate that effects of water table fluctuations on SSI response and seismic standard design are insignificant





2. Current Status (3/3)

- Basis for selection of two unsaturated soil profiles 270-200D and 560-100D for the sensitivity study is:
  - ✓ Given strain compatible S-wave velocities, presence of water only affects P-wave velocities (Vp) of softer soil materials with Vp < 5,000 ft/s
  - ✓ Only porous and softer soil materials can be affected by difference in unit weight for saturated and unsaturated conditions
  - ✓ Among generic soil profiles, only P-wave velocities of the softer profiles (nominal Vs = 270 m/s and Vs = 560 m/s) are affected by water table fluctuations
  - ✓ Profiles representing shallow layers of soil resting on rock results in bounding SSI responses due to reduced geometric damping of subgrade. Therefore, sensitivity study considered two shallow soil profiles that result in higher structural responses than deeper soil profiles

3. Resolution Proposal

US-APWR

- Additional sensitivity studies will be performed to address the following:
  - ✓ In order to better represent the saturated and unsaturated conditions, unit weights of unsaturated soil will be reduced from 125 pcf to 120 pcf for 270-200D and from 131 pcf to 125 pcf for 560-100D
  - ✓ SSI analyses will be re-performed on PS/B FE model and R/B Complex lumped mass stick model resting on surface of adjusted profiles 270-200D and 560-100D
    - R/B Complex lumped mass stick model is appropriate for this sensitivity study since SSI effects from softer soil profiles affect responses in lower frequency range for which this model is adequate
  - ✓ ISRS obtained from SASSI analyses of unsaturated soil profiles will be compared to saturated soil and current design basis ISRS to demonstrate that effect of water table fluctuation on standard seismic design is insignificant

4. Deliverables

- Supplemental response to RAI 660-5134, Question 3.7.2-60 will be provided
- Technical Report MUAP-10006 will be revised to include appendix documenting the sensitivity study on effect of water table fluctuations on seismic response

5. Summary

- Use of 2 soil profiles is adequate for sensitivity study on effects of water table fluctuations on seismic response
- MHI will perform a sensitivity study to further address NRC concerns regarding unit weight of unsaturated soil and effects of water table fluctuations on seismic response of R/B Complex and PS/B

US-APWR

Embedment Effects on Seismic Response

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

- Seismic response analyses of standard plant structures need to consider effects of embedment

2. Current Status (1/7)

- Seismic standard design is based on results of soil-structure interaction (SSI) analyses of surface mounted foundations
  - ✓ COL Item 3.7(25) requires standard design to be verified by site-specific SSI analysis including effect of embedment
  - ✓ Standard design accounts for dynamic earth pressure on basement walls using hand calculated pressure distribution based on Wood's solution
  - ✓ Standard design is based on enveloped responses obtained from multiple generic sites
  - ✓ R/B Complex, PS/Bs, A/B and T/B are not in contact with soil on every side

2. Current Status (2/7)

- Response to RAI 660-5134, Question 3.7.2-53 presents results of sensitivity study on effects of embedment on standard design
- Study is based on results of SSI analyses of R/B Complex lumped mass stick model with embedded foundation for two generic soil cases using SASSI Direct (Flexible-Volume) Method
- Ground motion consistent with CSDRS is used as input for SSI analyses of embedded foundation that was derived from results of site response analyses in accordance with NRC ISG-17 guidelines and Brookhaven National Laboratory (BNL) procedure

2. Current Status (3/7)

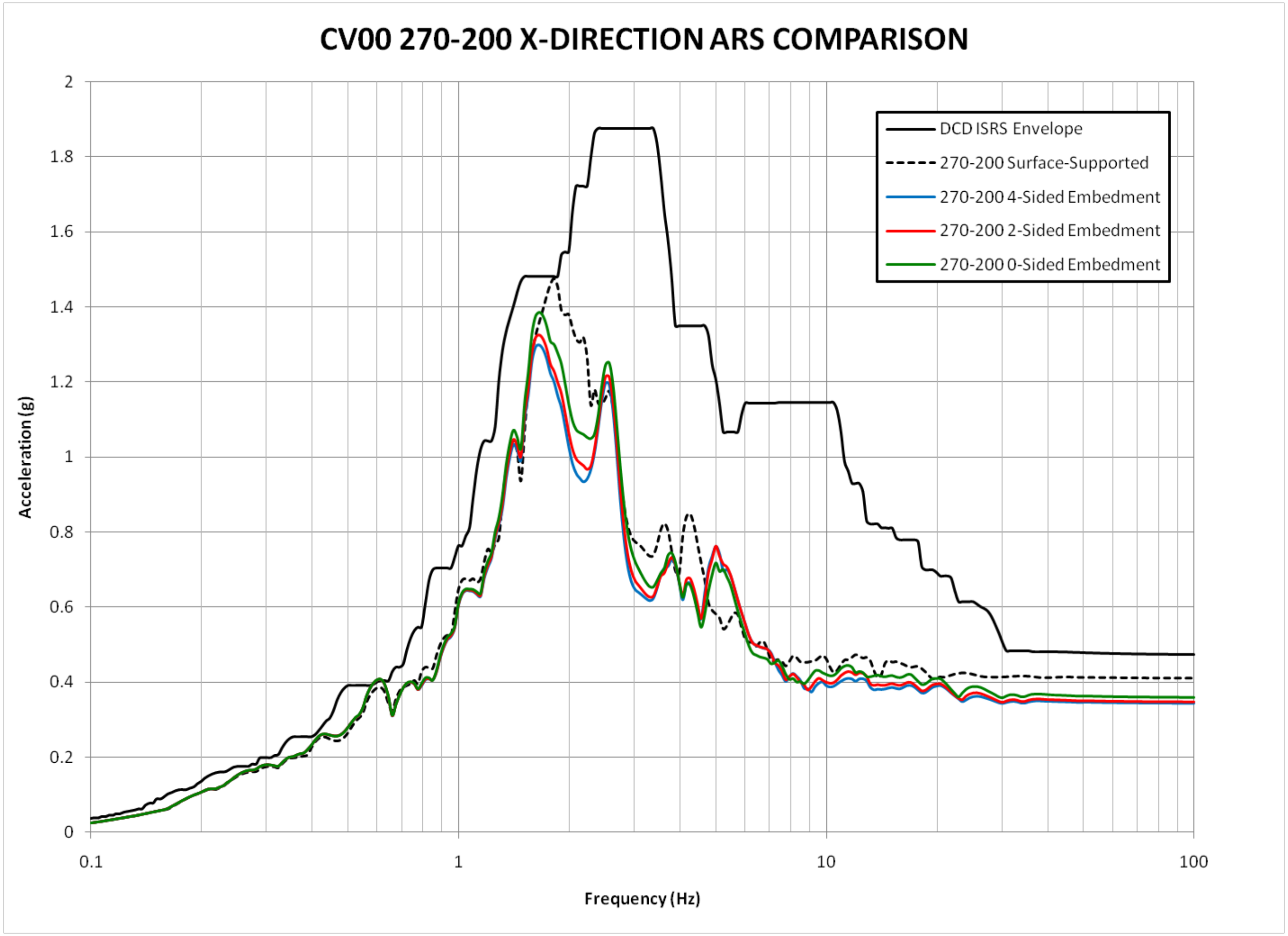
- Four cases of foundation embedment were studied:
  - ✓ Surface supported
  - ✓ Embedded with 4-sides in contact with side soil (4-sided embedment)
  - ✓ Actual condition, embedded with 2-sides (N & E) in contact with side soil (2-sided embedment)
  - ✓ Embedded without direct contact with side soil (0-sided embedment)
- Embedment effects were studied by comparing ISRS results at selected locations from SSI analyses of four embedment cases and corresponding design ISRS presented in MUAP-10006 (R1)

2. Current Status (4/7)

- Sensitivity study is based on 270-200 and 560-100 full column soil profiles presented in MUAP-10001 (R2)
- Soil properties of full column profiles below 40 ft depth are identical to those of truncated soil profiles used for design basis SSI analyses presented in MUAP-10006 (R1)
- Rational for selection for the study of the two softer soil profiles:
  - ✓ SSI effects are more prominent for softer sites and therefore embedment effect on SSI response will also be more prominent for softer sites
  - ✓ Design basis SSI analysis results indicate that shallow soil profiles control ISRS at lower frequency range because of reduced SSI geometric damping

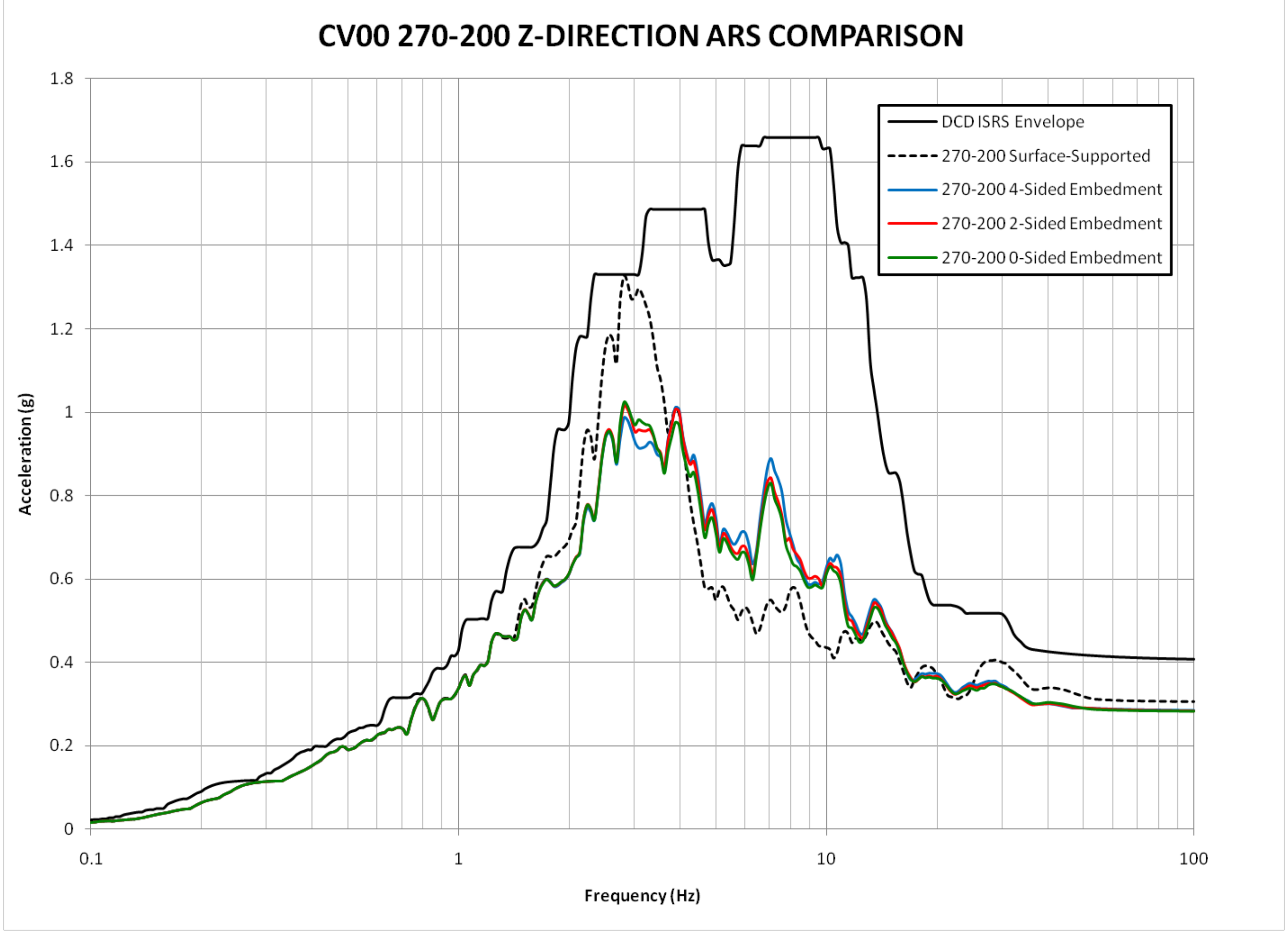
2. Current Status (5/7)

- Comparison of preliminary ISRS results for north-south (NS) response at top of PCCV foundation



2. Current Status (6/7)

- Comparison of preliminary ISRS results for vertical response at top of PCCV foundation



2. Current Status (7/7)

- Conclusions from preliminary sensitivity study
  - ✓ Within their controlling frequencies for the two site profiles studied, embedment effect is noticeable but not significant
  - ✓ Seismic SSI response of R/B Complex is relatively not sensitive to 4-, 2-, and 0-sided embedment conditions
  - ✓ Embedment effect produces slightly higher fundamental SSI frequencies but lower associated ISRS amplitudes
  - ✓ ISRS variations due to embedment effect are covered within the ISRS envelopes in MUAP-10006 (R1) assuming surface-supported structure condition

3. Resolution Proposal

US-APWR

- Additional sensitivity studies will be performed to provide:
  - ✓ Effects of embedment for two (2) stiffer soil cases that control design ISRS at high frequency range
  - ✓ Soil pressures on external basement walls to validate design basis seismic earth pressures in MUAP-10006
  - ✓ Responses for embedded foundation conditions from free-field input motion derived using NEI approach, which is an acceptable alternative procedure permitted by NRC ISG-17

4. Deliverables

- MUAP-10006 will be revised to include an appendix documenting the sensitivity study performed to assess embedment effects

5. Summary

- Results of preliminary sensitivity study presented in response to RAI 660-5134, Question 3.7.2-53 indicate that consideration of different embedment conditions produce noticeable but not significant seismic response variations that in general are covered by design ISRS documented in MUAP-10006
- Additional sensitivity studies will be performed to investigate embedment effects for stiff soil and validate dynamic earth pressures used in standard design

US-APWR

High Frequency Consideration in CSDRS

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

- US-APWR certified seismic design response spectra (CSDRS) does not envelope some hard rock, high frequency sites in Central and Eastern United States (CEUS)

2. Current Status (1/2)

- Standard plant CSDRS are derived from RG 1.60, enhanced by broadening spectra in high frequency (HF) range
- COL Item 3.7(6) requires Applicant to compare site-specific ground motion response spectra (GMRS) to CSDRS, and modify standard plant seismic design if applicable
- US-APWR CSDRS bounds over 60% (11/18) of new COL applicant sites
- US-APWR CSDRS, when considered in conjunction with North Anna Unit 3 GMRS, bounds HF spectra at all but one of new COL applicant sites

2. Current Status (2/2)

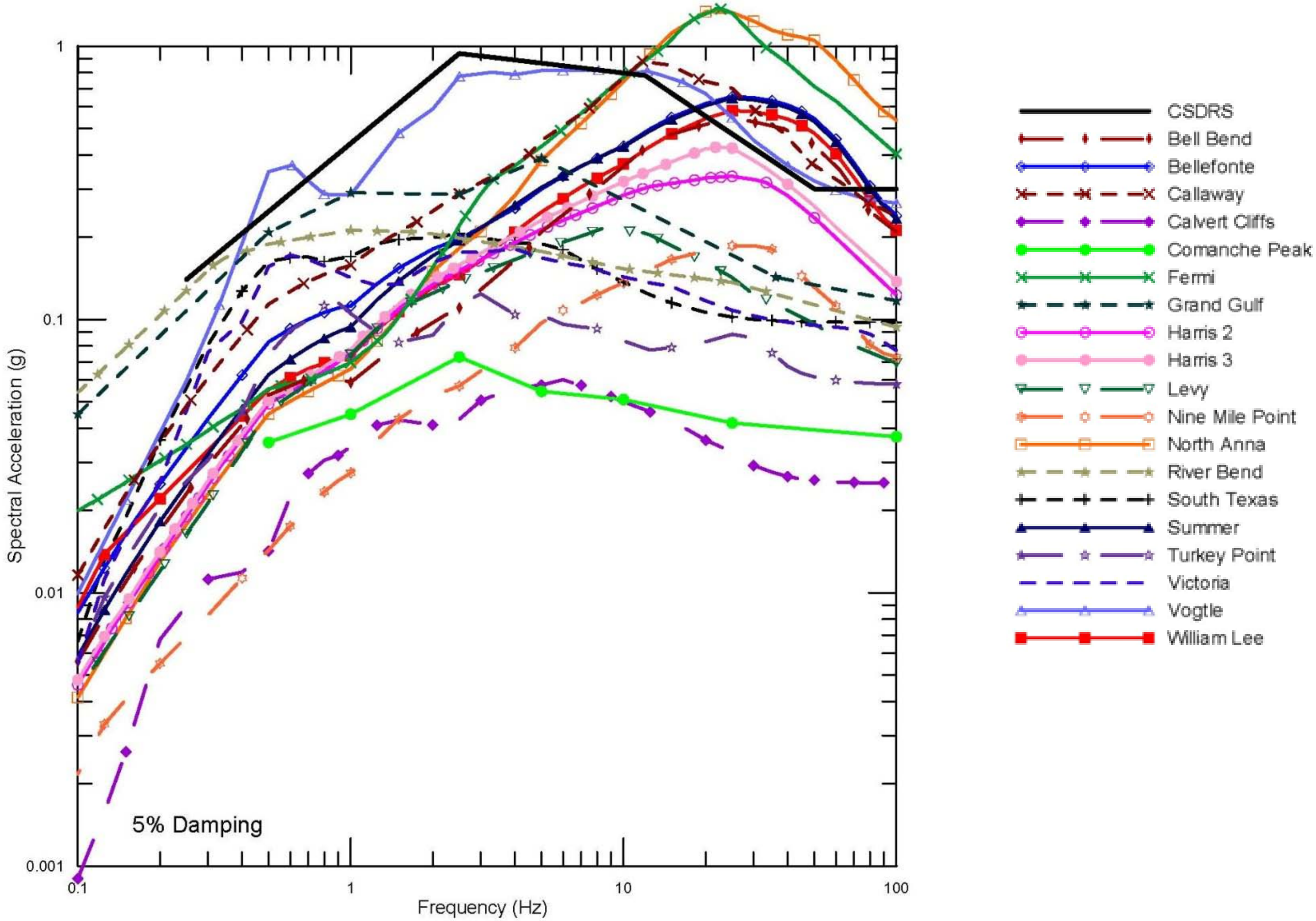


Figure 1. Comparison of US-APWR CSDRS and GMRS from 18 New Reactor COL Applications

3. Resolution Proposal

- US-APWR CSDRS complies with enhanced RG 1.60 spectra
- US-APWR satisfies 10 CFR 52 definition of *Standard Design* as usable at a multiple number of sites without NRC staff reopening or repeating the review

4. Deliverables

- No deliverables are applicable for this issue

5. Summary

- US-APWR satisfies 10 CFR 52 definition of *Standard Design*
- COL Applicant compares site-specific GMRS to standard plant CSDRS
- US-APWR CSDRS and North Anna Unit 3 GMRS bound HF spectra at all but one COL applicant site

US-APWR

Foundation Analysis

March 31, 2011

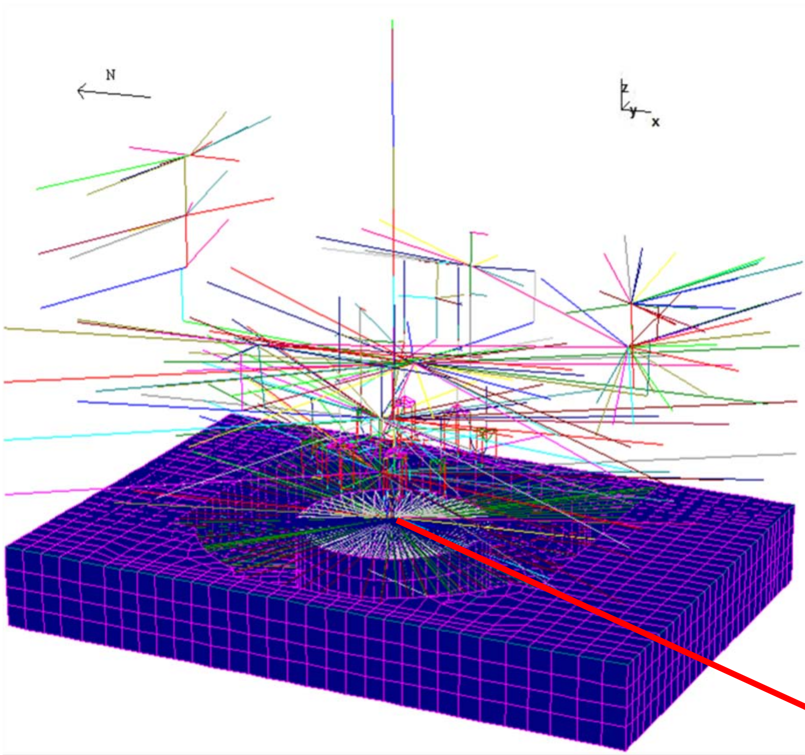
Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

- Potential for dynamic bearing pressure demand to exceed the allowable dynamic soil bearing strength
- Differential settlements between structures need to be accounted for
  - ✓ Short-term settlement must be addressed
  - ✓ Long-term settlements especially for soft soil at clay sites must be accounted for
- Differential settlement and associated tilt of structures may compromise the gap between structures

2. Current Status (1/7)

- **The Dynamic Bearing Pressure Demand** was calculated separately for soil and for rock sites. The calculations were done for the R/B Complex, in 3 steps:



STEP 1:

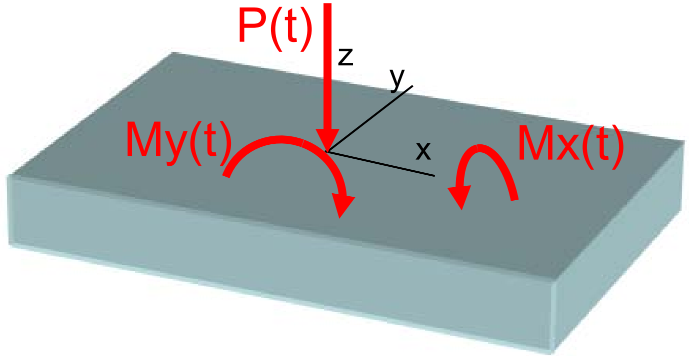
- ACS SASSI analyses of R/B Complex are done for all 8 soil/rock profiles (MUAP 10006)
- Structures are represented as lumped mass stick models; mat is discretized in finite elements
- Mat and subgrade flexibility are accounted for
- Results: time histories of forces and moments at top of mat

P(t)
Mx(t) → **STEP 2**
My(t)

2. Current Status (2/7)

STEP 2

- ✓ Analyze mat stability under P(t), Mx(t) and My(t) at each time instant, **t**. The mat is assumed rigid in this step.
- ✓ Select the most critical time instant for each of the eight profiles based on maximum bearing pressures
- ✓ Further select one soil profile and one rock profile that are the most critically loaded



SOIL: Profile 270-200
at **t** = 8.655sec

ROCK: Profile 900-200
at **t** = 8.645sec

STEP 3

P_{cr}, Mx_{cr}, My_{cr}

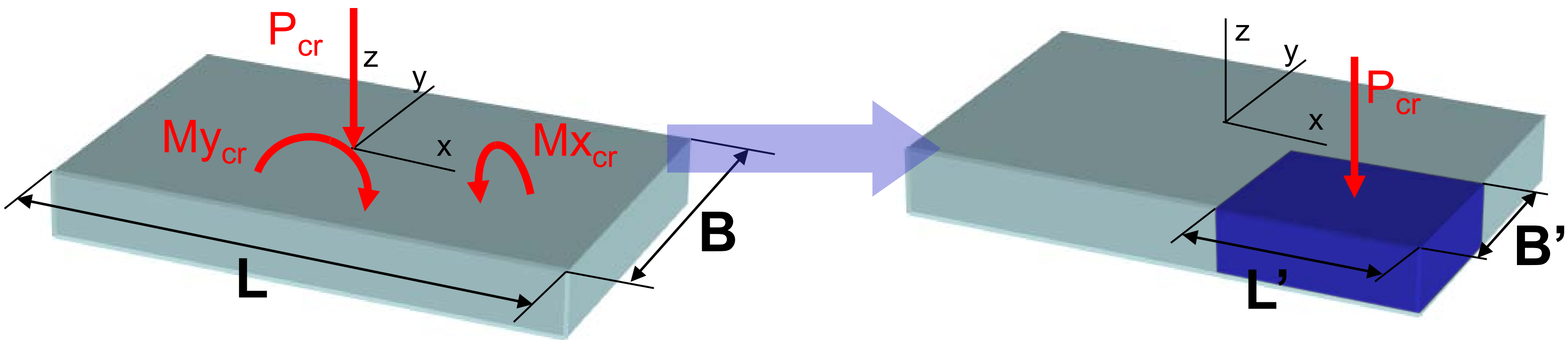
2. Current Status (3/7)

US-APWR

STEP 3

- ✓ Calculate the maximum uniform vertical bearing pressures from static and dynamic loads for effective footing dimensions:

$$q_{max} = \frac{P_{cr}}{B' \times L'} \quad \text{with:} \quad B' = B - 2e_y \quad L' = L = 2e_x \quad e_x = \frac{My_{cr}}{P_{cr}} \quad e_y = \frac{Mx_{cr}}{P_{cr}}$$



- ✓ Establish conservative **Bearing Pressure Demands from static and dynamic loads** $\mathbf{q_d \geq q_{max}}$
- ✓ Preliminary values: $\mathbf{q_d^{SOIL} = 25\ ksf}$, $\mathbf{q_d^{ROCK} = 40\ ksf}$

2. Current Status (4/7)

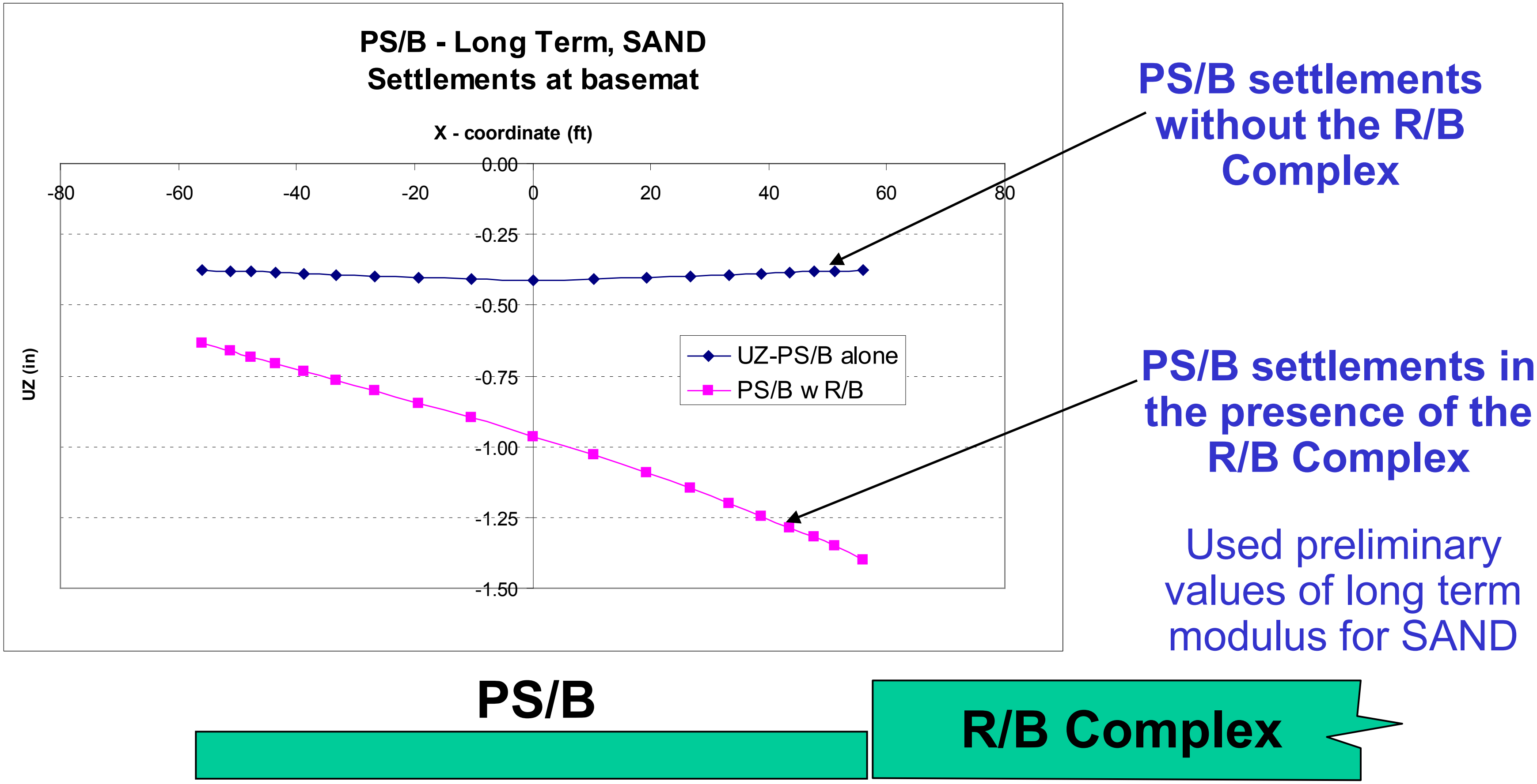
- Calculated short-term settlement using ANSYS with 2 soil profiles (270-500, 900-200) for the R/B complex

2. Current Status (5/7)

- Long-term settlement estimated by considering effect of neighboring structures by 2D Finite Element Analysis of pairs of structures (e.g. Effect of R/B Complex on PS/B)
  - ✓ Approach yields overly conservative tilt and non conservative dishing effect values

2. Current Status (6/7)

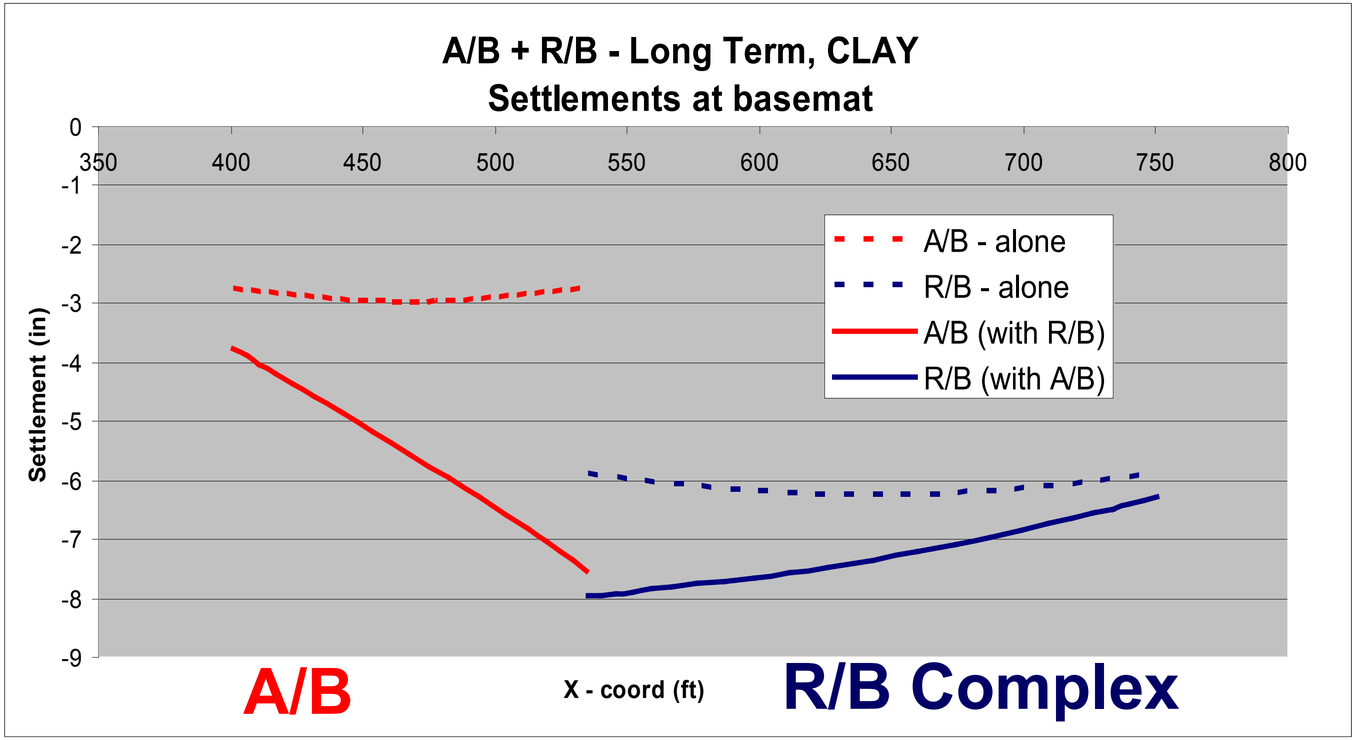
➤ Example Considering Long Term Loading for SAND sites: Effect of R/B Complex on PS/B Settlements



Used preliminary values of long term modulus for SAND

2. Current Status (7/7)

- Example Considering Long Term Loading for CLAY sites:
  Effect of R/B Complex on A/B Settlements (and A/B on R/B)



Used preliminary values of long term modulus for CLAY

3. Resolution Proposal (1/4)

- **Dynamic Soil Pressure Capacity**

1. **Estimate shear strength properties** of soil (softest profile 270-500) and rock (softest profile 900-200) based on lower bound of Shear Wave Velocities in MUAP-10001

2. **Calculate the ultimate bearing capacities (q_{ult})** for soil and rock accounting for load eccentricity
   - Use the General Bearing Capacity Equation
   - For soil assume both sand sites and clay sites

3. Verify that **Allowable Bearing Soil Strength (q_{all}** for SOIL and ROCK **)** exceeds the **Bearing Pressure Demand (q_d** for SOIL and ROCK, respectively**)** for all cases:

$$q_{all} = \frac{q_{ult}}{F_d} \geq q_d$$

where **F_d = 2** is the factor of safety for bearing capacity for dynamic loads

3. Resolution Proposal (2/4)

➢ Short-Term Settlement

- ✓ Short-term settlement can be partially compensated for during construction phase

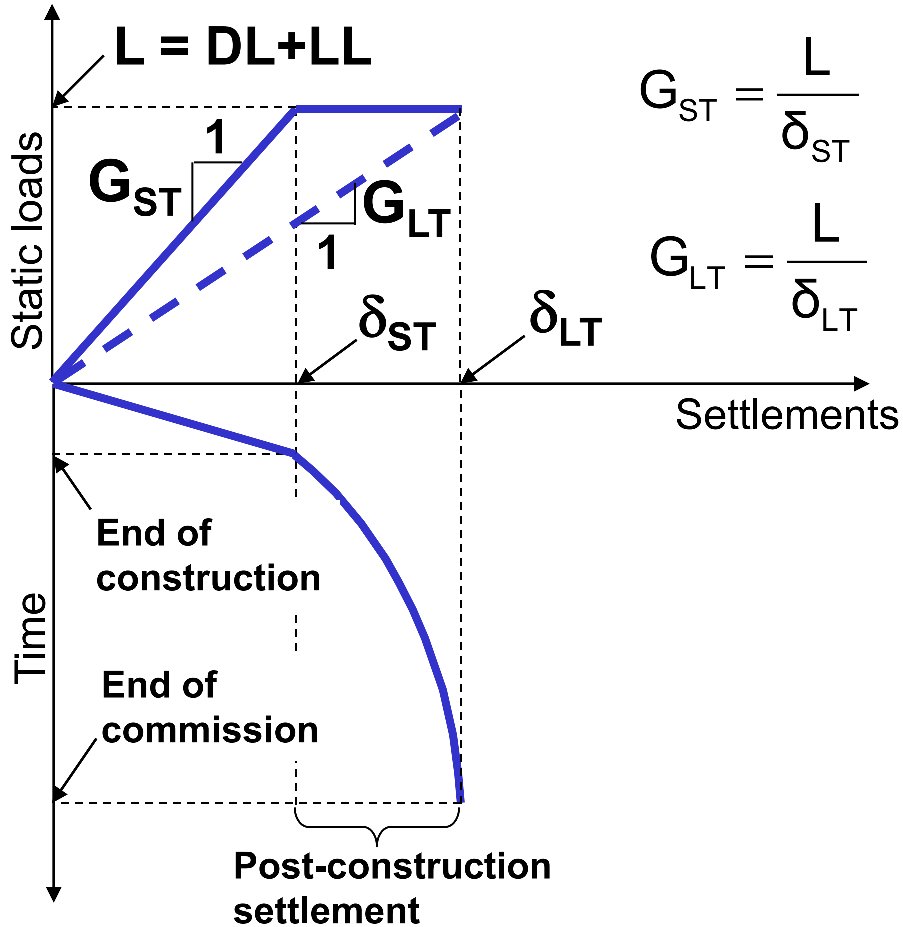
➢ Construction Sequence

- ✓ This is a site specific item that is expected to significantly reduce structure tilt
- ✓ Investigate construction schedule effects with 3D model: run 1 or 2 generic construction schedule scenarios for clay sites
  - A recommended construction sequence for soft soil sites would help meet settlement requirements

3. Resolution Proposal (3/4)

➢ Long-Term Settlement

✓ Re-evaluate long-term deformation moduli



$$G_{ST} = \frac{L}{\delta_{ST}}$$

$$G_{LT} = \frac{L}{\delta_{LT}}$$

Modulus Reduction Factor

$$F = \frac{G_{ST}}{G_{LT}} = \frac{\delta_{LT}}{\delta_{ST}}$$

δ_{ST} = Settlement during construction (mainly due to loading)

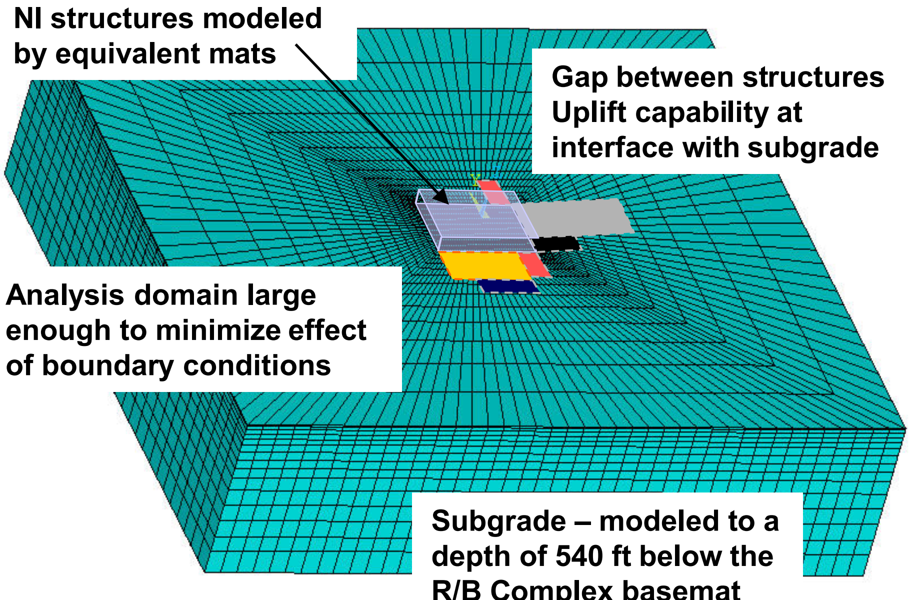
δ_{LT} = Total settlement at the end of commission

✓ Includes δ_{ST} and post-construction settlement

✓ Due to creep and primary consolidation

3. Resolution Proposal (4/4)

- **Long Term Settlement**
- ✓ 3D Finite Element model
  - Include all NI structures at one time
  - Include embedment effects
  - Possibility of gapping at soil-mat interface
  - Calculate tilt for gap closure
  - 2 sets of analyses (sand and clay)



- ✓ For clay sites, manually calculate primary consolidation settlements to validate linear elastic 3D Finite Element model that does not simulate this phenomenon
- ✓ All calculations – for Soil Profile 270/500 (softest)

4. Deliverables

- Calculation Report containing:
  - ✓ Demand and allowable bearing pressures
  - ✓ Long term deformation moduli for sand sites and clay sites
  - ✓ Long term displacements for Soil Profile 270-500 considering two types of subgrade – sand and clay
  - ✓ Settlements of all structures including dishing effects and effects of primary consolidation (clay)
  - ✓ Tilt of all structures from long term loads for gap
  - ✓ Differential settlements from long term loads (between adjacent structures and for each structure)
  - ✓ Revised Calculation Report will be available for audit

5. Summary (1/2)

- Will demonstrate, separately for soil profiles and rock profiles, that allowable dynamic bearing pressures exceed the dynamic pressure demands
- The COL Applicant must calculate the allowable bearing capacities for the specific site conditions and check the acceptance criterion
- Soil deformation moduli for long term loading to be re-assessed
- Long-term settlements for Standard Plant Buildings to be evaluated for tilt contribution to gap issue (K) using a 3D FE model

5. Summary (2/2)

- MHI's plan is to treat differential settlement due to construction sequence as being site-specific. General effects to be assessed
- Calculation Report to be available for NRC audit

US-APWR

Sliding Stability

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

UAP-HF-11075-J

1. Issue Statement

- Sliding stability safety factor (1.1) has not been demonstrated for all US-APWR standard plant buildings based on results of latest set of seismic response analyses
- Proper friction coefficient value to calculate sliding resistance at foundation-subgrade interface needs to be stated

2. Current Status (1/6)

- Sliding stability of R/B Complex and PS/B is being re-evaluated based on seismic response analyses results presented in MUAP-10006 (R1)
- Sliding stability of A/B is being evaluated based on seismic response analyses results presented in MUAP-11001 (R0)
- SRP requirement for sliding stability safety factor has been demonstrated for T/B based on seismic response analyses results presented in MUAP-11002 (R0)

2. Current Status (2/6)

- Results from SSI analyses of R/B Complex and A/B lumped mass stick models are used for calculation of seismic sliding driving forces:
  - ✓ Seismic base reactions are a function of mainly the global response characterized by the first few significant modes of vibration
  - ✓ Comparison of results for envelope maximum base reactions from lumped mass stick and FE models are used to validate results for controlling cases

2. Current Status (3/6)

- Seismic driving forces in three directions (NS, EW, Vertical) are calculated from time history results
  - ✓ Stick member forces for PCCV, CIS and above grade portion of R/B structure
  - ✓ Accelerations for below grade portion of R/B basement and basemat

- Seismic sliding driving force for each of the two horizontal directions (NS and EW) is calculated at each time step as:

$$F_H = P_{PCCV}+P_{CIS}+P_{RB}+m_{basement}\cdot a_{basement}+m_{mat}\cdot a_{mat}+ P_0$$

  The unbalanced at-rest earth pressure (P_0) from embedment soil is added to the seismic driving forces

- Horizontal driving force ($F_{sliding}$) due to two horizontal components of earthquake is combined at each time step using SRSS method

2. Current Status (4/6)

- Base sliding shear friction resistance is calculated at each time step as:

  $$F_R = \mu_s \cdot (P_{PCCV} + P_{CIS} + P_{RB} + m_{basement} \cdot a_{basement} + m_{mat} \cdot a_{ma} - BF)$$

  where:

  μ_s is static coefficient of friction

  BF is buoyancy force

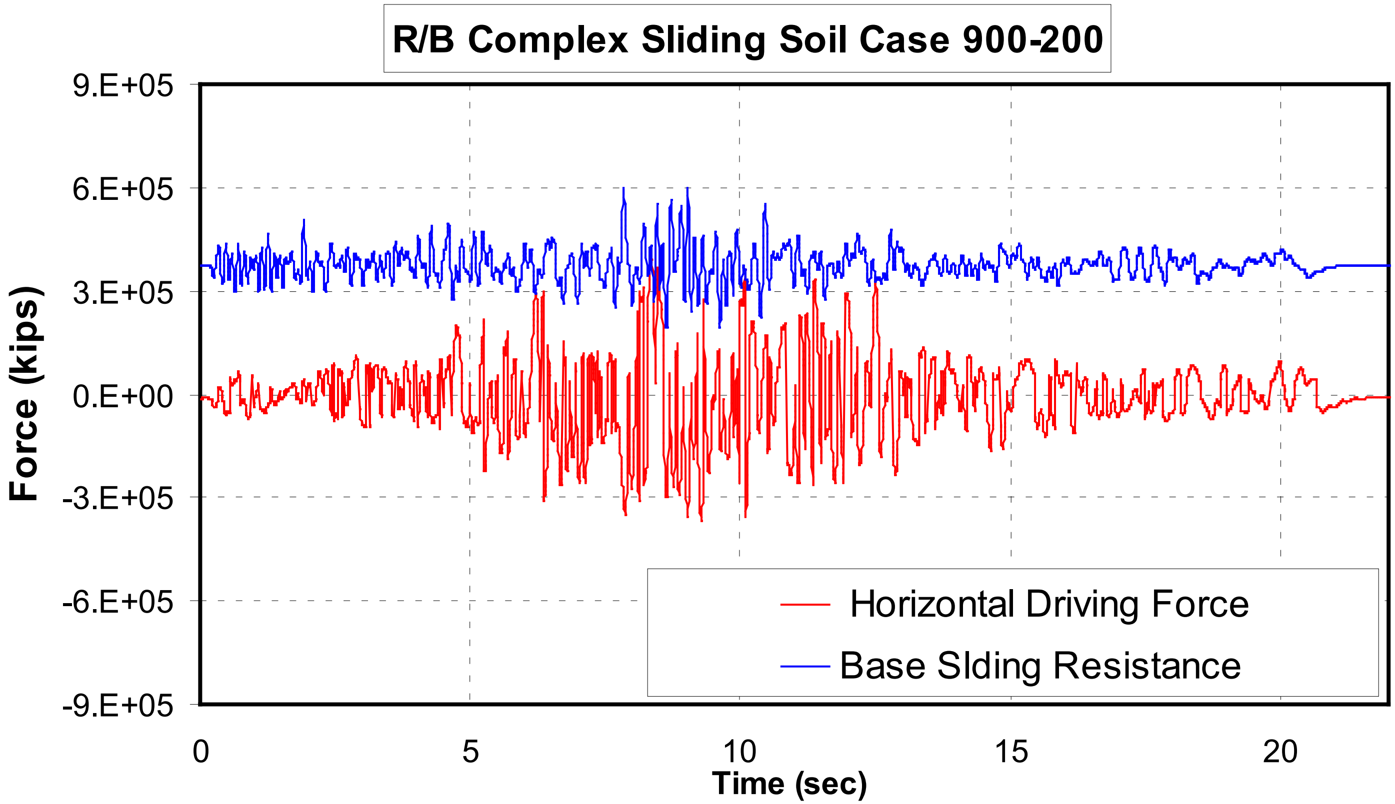
- Safety factor for sliding is calculated at each time step as:

  $$SF_{sliding} = F_R / F_{sliding}$$

- Minimum value of safety factor that is calculated for the whole duration of design earthquake is used to demonstrate sliding stability of the building

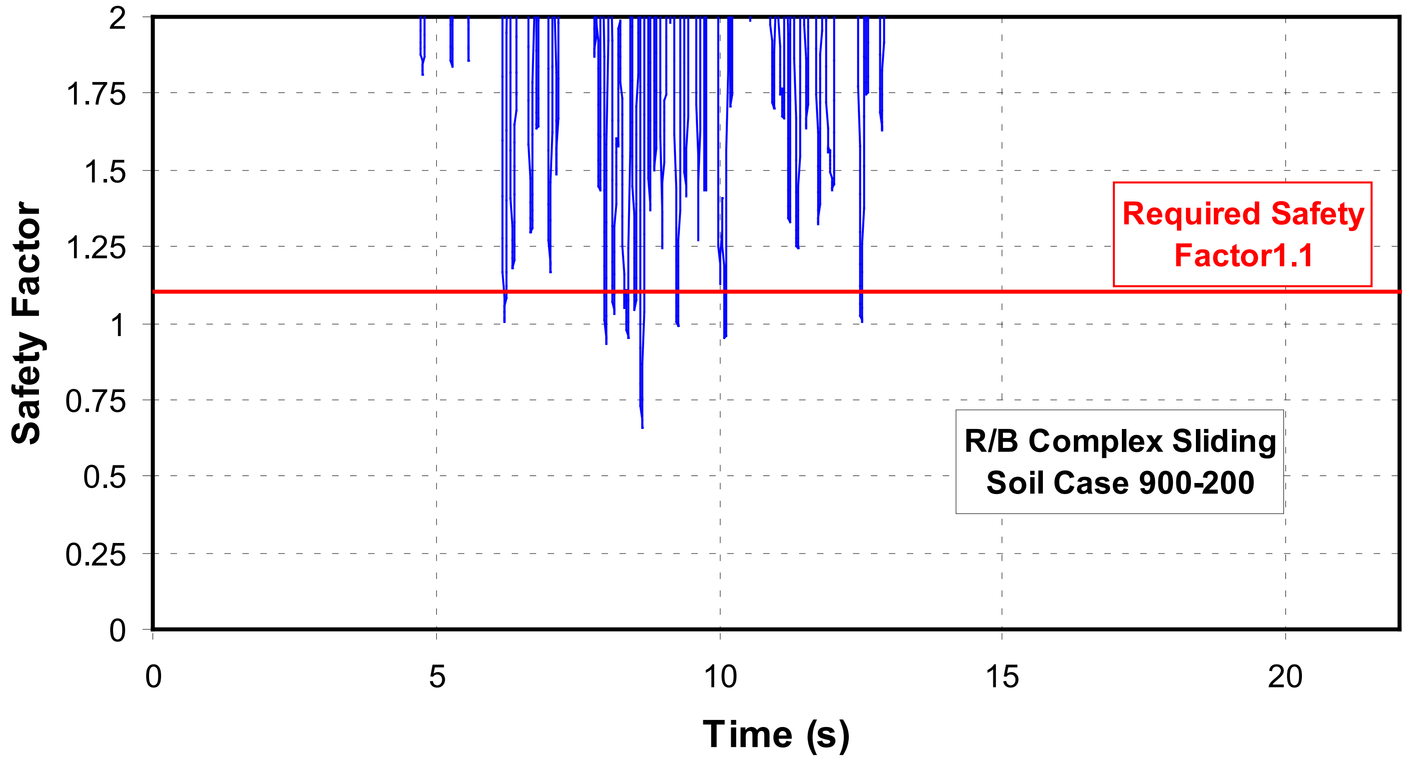
2. Current Status (5/6)

- Time histories of sliding driving and base resistance forces for most critical generic soil case 900-200



2. Current Status (6/6)

- Time history of sliding safety factor for most critical generic soil case 900-200



3. Resolution Proposal

- A COL Item is to be used to provide sliding resistance at basemat-subgrade interface when it is needed to meet sliding stability requirement
- Demonstrate the feasibility for design of shear resistance structural elements in the DCD, to ensure overall sliding stability under possible sliding failure scenarios

4. Deliverables

- Technical Report MUAP-11007 will be issued to reflect sliding stability

5. Summary

- A COL Item is to be used to provide sliding resistance at basemat-subgrade interface when it is needed to meet sliding stability requirement

US-APWR

Gap Between Structures

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

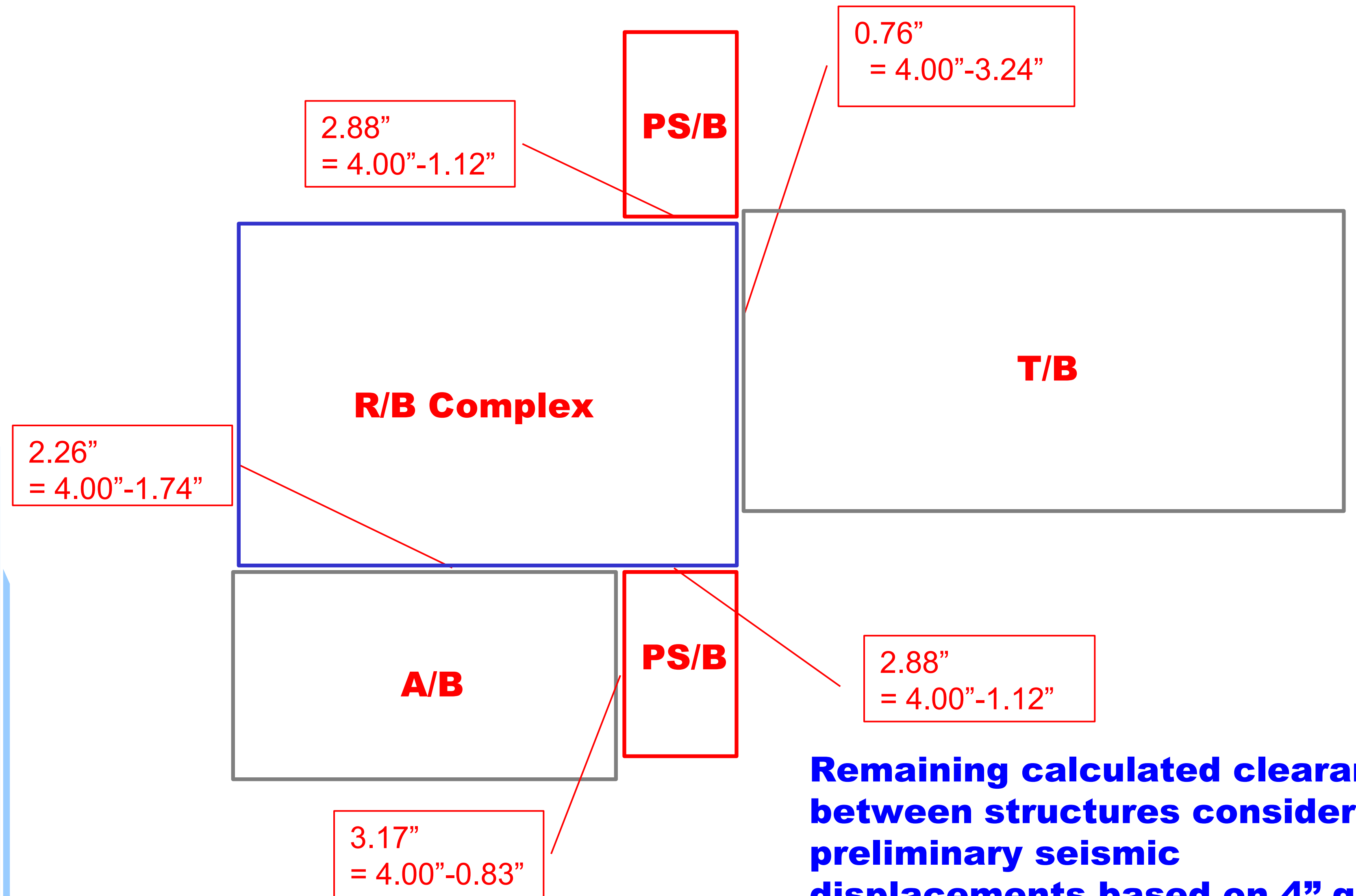
1. Issue Statement

- Evaluate gap distance between structures to account for differential settlements (tilt) or possible displacements to mobilize base shear resistance

2. Current Status (1/3)

- Current DCD requirement
  - ✓ 2 X (Absolute Sum of Most Unfavorable Combination of Displacements) or a minimum of 4 inches
- The T/B SSI Analysis MUAP-11002 (R0) demonstrates that the remaining clearance between the R/B and T/B is less than 1 inch when only considering structural seismic displacement
- Other buildings analyzed in MUAP-10006 (R1) and MUAP-11001 (R0) provide clearances between other standard plant structures
- To date, these reports do not account for differential settlements (tilt) or displacement needed to mobilize sliding resistance of structures

2. Current Status (2/3)



Remaining calculated clearances between structures considering preliminary seismic displacements based on 4” gap

2. Current Status (3/3)

Preliminary Displacements

Structure	Preliminary Seismic (based on LMSM)	Due to Long Term Settlement and Tilt	Due to Sliding Resistance at Base	TOTAL Gap Needed
R/B – A/B	**1.74"**	**TBD**	**TBD**	**TBD**
R/B – PS/B	**1.12"**	**TBD**	**TBD**	**TBD**
R/B – T/B	**3.24"**	**TBD**	**TBD**	**TBD**
PS/B – A/B	**0.83"**	**TBD**	**TBD**	**TBD**

3. Resolution Proposal (1/2)

- Determine total displacements
  - ✓ Revise seismic displacements with respect to free field based on FEM as needed
  - ✓ Perform settlement analysis to determine long term tilt contribution
  - ✓ Calculate possible displacements required to mobilize sliding resistance
- If necessary to provide further margin, all current 4 inch gaps can be increased approximately 2 inches without changing the site layout. This can be accomplished by nominally reducing exterior wall thicknesses.

3. Resolution Proposal (2/2)

- Change current DCD requirement of 2 times absolute sum of maximum displacement under most unfavorable load combination, or minimum of 4 inches
  - ✓ Change requirement to absolute sum of each displacement contributor
    - Seismic: Absolute sum of displacements relative to free-field
    - Tilt with appropriate factor of safety
    - Displacement to mobilize sliding resistance
    - Minimum of 4 inches
- As required, increase the gap between buildings to meet the acceptance criteria

4. Deliverables

- Tracking report of DCD will modify acceptance criteria
- Technical Reports
  - ✓ MUAP-10006 will be revised to include results of gap evaluation
  - ✓ MUAP-11001 will be revised
  - ✓ MUAP-11002 will be revised
- Calculations
  - ✓ Tilt due to long-term differential settlement
- Results of Impact Assessment
  - ✓ Revise gap and/or modify design, as required.

5. Summary

- The gap between all structures is being evaluated using conservative estimates of relative dynamic displacement, sliding, and long term tilt
  - ✓ The preliminary assessment determined the need for a more accurate evaluation of building displacements in order to confirm the adequacy of the current 4” minimum gap design criteria
- More refined calculations will be performed to define the effects of tilt as well as displacement to mobilize base shear resistance
- The DCD will be revised as necessary to reflect the acceptance criteria for superstructure gap
- The gaps between the structures will be adjusted, as required to meet defined acceptance criteria

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Steel Concrete (SC) Modules

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

- Currently there are no U.S. codes or standards governing the design and analysis of SC modules
  - ✓ MHI to define acceptable design criteria for SC modules
  - ✓ ACI 349 used for basic design of SC modules, in the absence of an accepted SC-specific code
- NRC staff has questioned the fire rating for the Containment Internal Structures (CIS)

2. Current Status (1/5)

- SC modules in the US-APWR are limited to use for walls of the Containment Internal Structure (CIS)
- CIS detailed FE model prepared in ANSYS
  - ✓ Analysis for basic design addressed dead, live, fluid, accident thermal, accident pressure, and seismic load cases and combinations
- NRC feedback from submitted technical report is needed

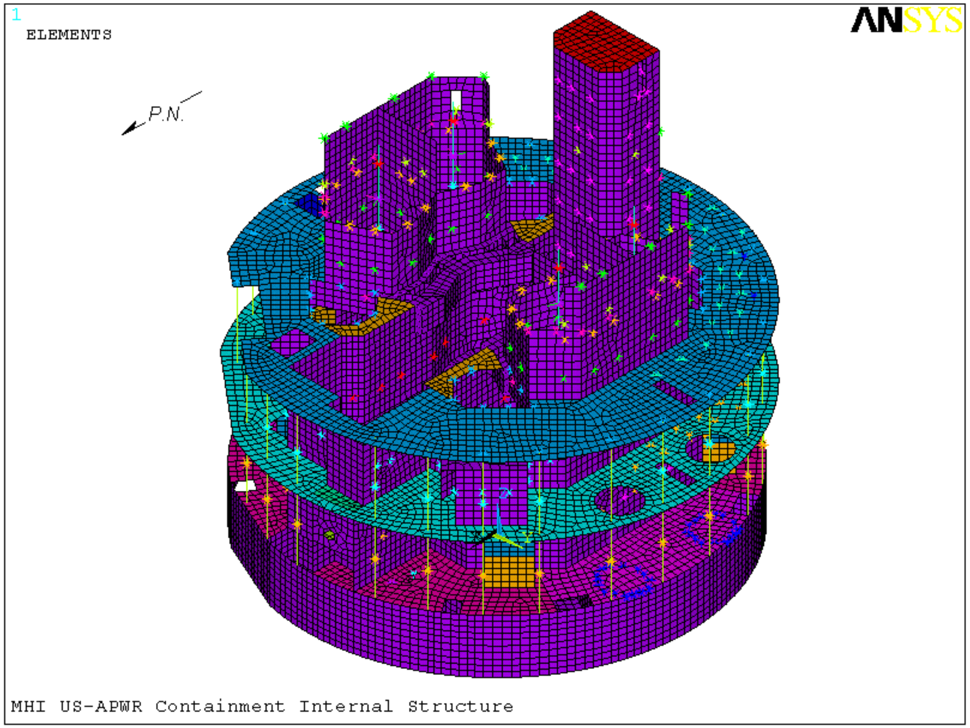
2. Current Status (2/5)

- Basic design has been completed based on the following methodologies for analysis and design of SC modules:
  - ✓ ACI 349 provisions for out-of-plane flexure combined with axial loads
  - ✓ ACI 349 provisions for out-of-plane shear capacity
  - ✓ Special provisions for in-plane shear capacity of SC modules given in JEAG and ANSI/AISC N690 Appendix N9G (proposed)
  - ✓ Design procedure evaluates concrete and steel plate thickness by calculating overall demand/capacity ratios on an element-by-element basis for each SC wall

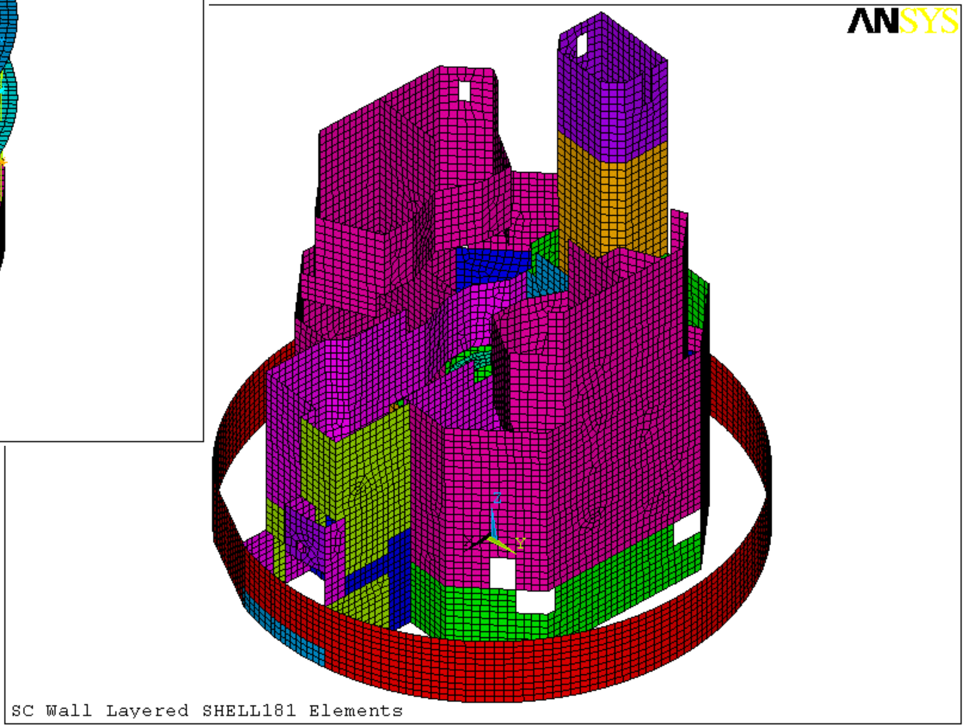
2. Current Status (3/5)

- ✓ SC modules are not designated as fire barriers since the PCCV serves as the exclusive fire barrier
  - DCD Chapter 9 provides limits on combustibles
  - DCD Appendix 9A Provides the Fire Hazards Analysis

2. Current Status (4/5)



CIS detailed ANSYS model used for static, thermal, and response spectrum analyses



Extent of 36”- 67” SC walls in the CIS

2. Current Status (5/5)

- Summary of SC Wall Design Procedure for Basic Design:
  1. Calculate SC wall element stress resultants (forces)
  2. Calculate plate thickness required for in-plane shear (using proposed N690 provisions)
  3. Using remaining plate thickness, calculate D/C ratios for axial forces and moments acting in normal and tangential directions on each plane (per ACI 349-01 Chapter 10 provisions)
  4. Recognizing that the plates are in a state of plane-stress, determine overall D/C ratio considering Von Mises failure criterion
  5. Using ACI 349-01 Chapter 11 provisions, evaluate out-of-plane shear capacity of concrete core and size transverse shear reinforcement, if required

3. Resolution Proposal (1/2)

- US-APWR Seismic Task Force is actively working with AISC N690 SC Subcommittee members to ensure appropriate application of draft code provisions to enhance current approach where necessary
  - ✓ Formulating technical approaches for calculation of capacities for out-of-plane flexure combined with in-plane axial loads, in-plane shear, and out-of-plane shear
  - ✓ Evaluating procedures for calculating overall demand/capacity ratios
    - Membrane stresses in steel plates must be combined appropriately
- MHI will perform a review of current methodology and incorporate aspects of upcoming AISC N690 revision as applicable

3. Resolution Proposal (2/2)

- SC modules are only used for the Containment Internal Structures (CIS)
  - ✓ The PCCV serves as the exclusive fire area boundary for the containment which is further separated into non-fire rated zones; therefore, SC modules are not designated as fire barriers
  - ✓ DCD Chapter 9 limits combustibles throughout the plant
  - ✓ DCD Appendix 9A, Fire Hazards Analysis, provides fire area and fire zone designations

4. Deliverables

- Technical Report for SC module structural design criteria and methodology will be issued
- Tracking report of Section 3.8.3 of DCD will reflect updates to design criteria and methodology

5. Summary

- MHI is currently using aspects of ACI 349 and AISC N690 to evaluate basic design of SC modules
- Detailed design approach will incorporate AISC N690 provisions based on draft available from subcommittee members to enhance current approach where applicable
- SC modules are not designated as fire barriers

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Steel Liner Plate Strains Near PCCV Penetrations

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

1. Issue Statement

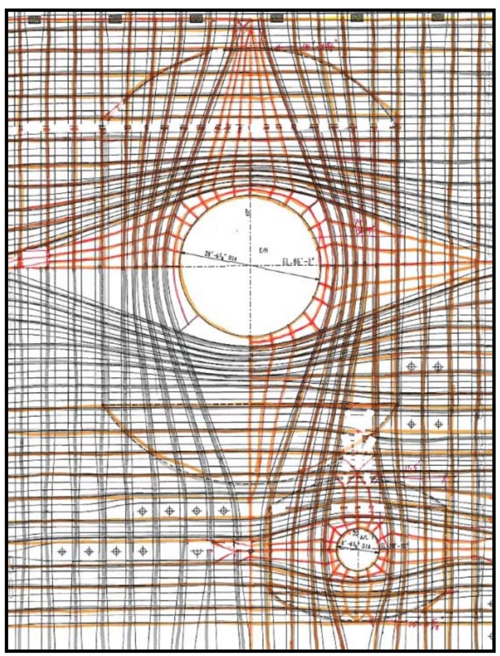
- PCCV steel liner plate strains near penetrations, particularly near large openings (e.g. equipment hatch, personnel airlocks, main steam piping, and feedwater piping), have not been calculated to date

2. Current Status

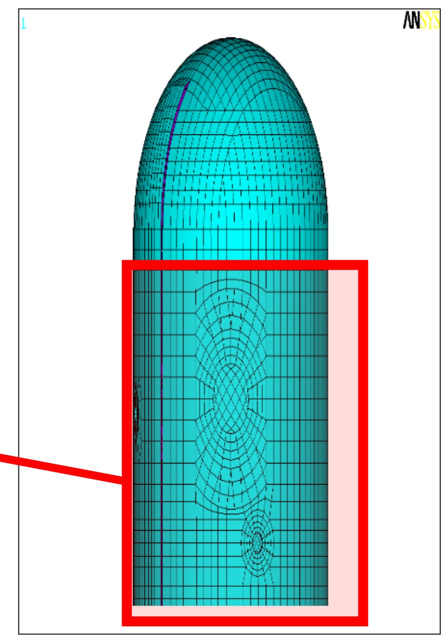
- Currently only liner strains in general areas away from discontinuities have been evaluated

3. Resolution Proposal

- Strain results near penetrations will be documented by evaluation analysis/design calculation
- Develop submodels with refined mesh and calculate liner strains in the vicinity of large openings



Proposed Increased Mesh Fidelity



Original ANSYS Model

4. Deliverables

- Calculations for strain results near penetrations will be available for audit

5. Summary

- Final detailed assessments will be performed based on dynamic reanalysis for:
  - ✓ Equipment hatch
  - ✓ Personnel airlocks
  - ✓ Penetrations for main steam and feedwater piping
- Calculations for strain results near penetrations will be available for audit

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Conclusion

March 31, 2011

Mitsubishi Heavy Industries, Ltd.

Conclusion

- Review of the twelve topics (B through M)

Morning Session	A – Introduction
	B – Seismic Design Basis Models
	C – Effect of Concrete Cracking
	D – Soil Profiles
	E – Structure-Soil-Structure Interaction (SSSI)
	F – Water Table Effects
	G – Embedment Effects on Seismic Response
	H – High Frequency Consideration in CSDRS
Afternoon Session	I – Foundation Analysis
	J – Sliding Stability
	K – Gap Between Structures
	L – Steel Concrete (SC) Modules
	M – Steel Liner Plate Strains Near PCCV Penetrations
	N – Conclusion

Conclusion

- Establishing the Path Forward: Obsolete Tech Reports and DCD Appendices

Obsolete DCD App. & TR	Title	Superseded by	
		MUAP-10001	MUAP-10006
Appendix 3H	Model Properties for Lumped Mass Stick Models of R/B-PCCV-Containment Internal Structure on a Common Basemat, and PS/Bs on Individual Basemats	X	
Appendix 3I	In-Structure Response Spectra		X
MUAP-08002	PS/B Enhanced Information for PS/B Design	X	X
MUAP-08005	Dynamic Analysis of the Coupled RCL-R/B-PCCV-CIS Lumped Mass Stick Model	X	X

Conclusion

- Establishing the Path Forward: Deliverables
- Schedule for Deliverables will be Provided

Topic	Deliverable
B, D	Tech Report MUAP-10001 Rev. 3
B, D, E, F, G, K	Tech Report MUAP-10006 Rev. 2
B	Tech Report MUAP-11006 Rev. 0
B, J	Tech Report MUAP-11007 Rev. 0
C	New Calculation Report - PCCV Reduced, Full Stiffness
	New Calculation Report - R/B & PS/B Reduced, Full Stiffness
	New Calculation Report - CIS Best Estimate Stiffness
D	Revised Response to RAI 659-5133, Q 03.07.01-17
E	Tech Report MUAP-11011 Rev. 0
E, K, L	DCD Tracking Report
F	Revised Response to RAI 660-5134, Q 03.07.02-60
I	New Calculation Report - Soil Foundation Adequacy
K	Tech Report MUAP-11001 Rev. 1
	Tech Report MUAP-11002 Rev. 1
	New Calculation Report - Dynamic Differential Displacements
	New Calculation Report - Tilt due to Long-term Differential Settlement
L	Tech Report for SC Module Criteria/Methodology
M	New Calculation Report - Submodeling for Strain near PCCV Penetrations

Note: Calculation Reports will be prepared for NRC audit.

Conclusion

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- Opportunity for Questions or Comments