North Anna 3

North Anna 3 COLA

FSAR Sections 3.7 and 3.8 Seismic Structural Analyses

May 22, 2014 Meeting with NRC

Dominion

Outline

- Objectives
- Overview of FSAR Sections 3.7.2, 3.8.4 and 3.8.5
- Summary of FSAR changes
- Review of draft RAI questions
- Preliminary results of soil embedment sensitivity studies
- Benchmarking of Modified Subtraction Method (MSM)

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Objectives

- Present changes and corrections made to FSAR Sections 3.7.2, 3.8.4 and 3.8.5 since December 2013 FSAR submittal
- Discuss draft RAI questions and summarize planned approaches for responses
- Present preliminary results from sensitivity study on effects of soil embedment above Zone III rock on seismic design of RB/FB and CB
- Present approach and preliminary results of benchmarking of SASSI2010 Modified Subtraction Method (MSM) that is used for sensitivity SSI and SSSI analyses

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Overview of FSAR Sections 3.7.2, 3.8.4 and 3.8.5

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Overview: Section 3.7.2.4
Soil-Structure Interaction

- Site-specific SSI analyses are performed for all ESBWR Seismic Category I Buildings to address Unit 3 FIRS exceedances of CSDRS (NAPS DEP 3.7-1)
  - Reactor Building/Fuel Building (RB/FB)
  - Control Building (CB)
  - Fire Water Service Complex (FWSC)
- SSI analyses are performed following approach consistent with DCD and Fermi 3 COLA using:
  - SASSI 2010 computer program
  - Site-specific input ground motion time histories and strain-compatible subgrade profiles presented in FSAR Section 3.7.1
  - Dynamic structural models described in DCD Appendix 3A with adjusted mesh and stiffness and damping properties of reinforced concrete members reflecting Unit 3 site-specific conditions

Overview: Section 3.7.2.4
Soil-Structure Interaction

- Site-specific SSI analyses provide results for:
  - Stick member forces and maximum accelerations used for reconciliation of seismic design of Category I structures for Unit 3 site
  - Time histories of spring reactions at soil-structure interfaces used as input for stability and dynamic bearing pressure calculations
  - Maximum spring forces at exterior wall-soil interfaces used for development of seismic lateral pressure distributions
  - Acceleration time histories used for development of site-specific ISRS for different damping values for all locations in Category I buildings (FSAR presents ISRS at representative locations)
- Technical Reports, which will be available to NRC in SSI audit, present details about site-specific SSI analyses and sensitivity studies

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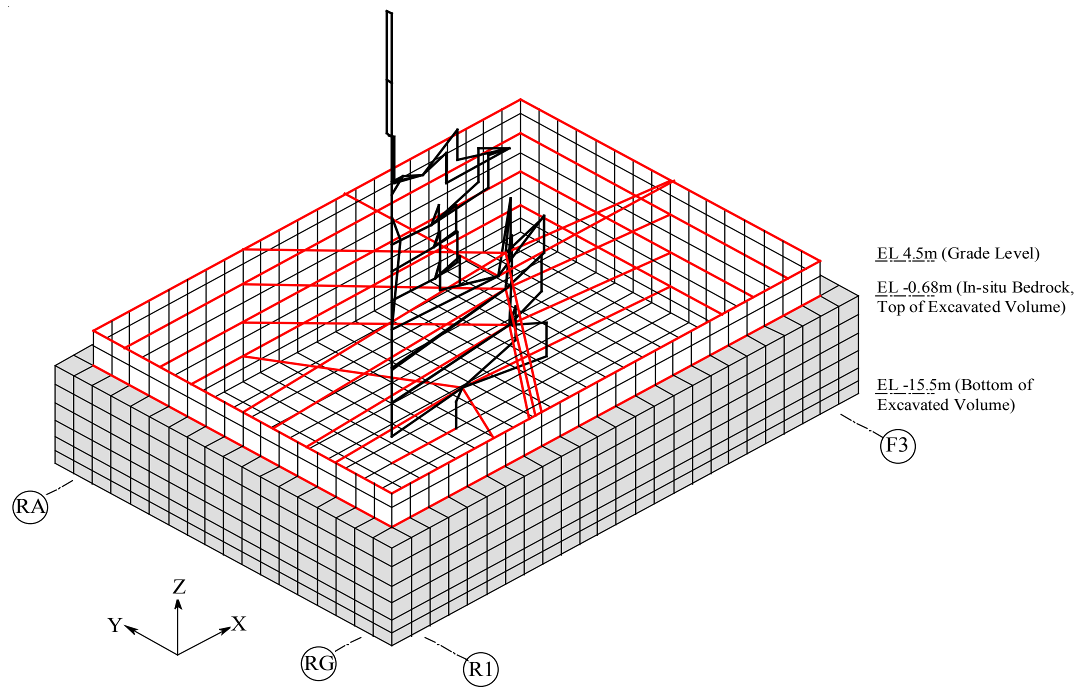
Overview: Section 3.7.2.4
Soil-Structure Interaction

Unit 3 RB/FB site-specific seismic design based on SSI responses obtained from analyses of model partially embedded in 14.9 m thick rock stratum

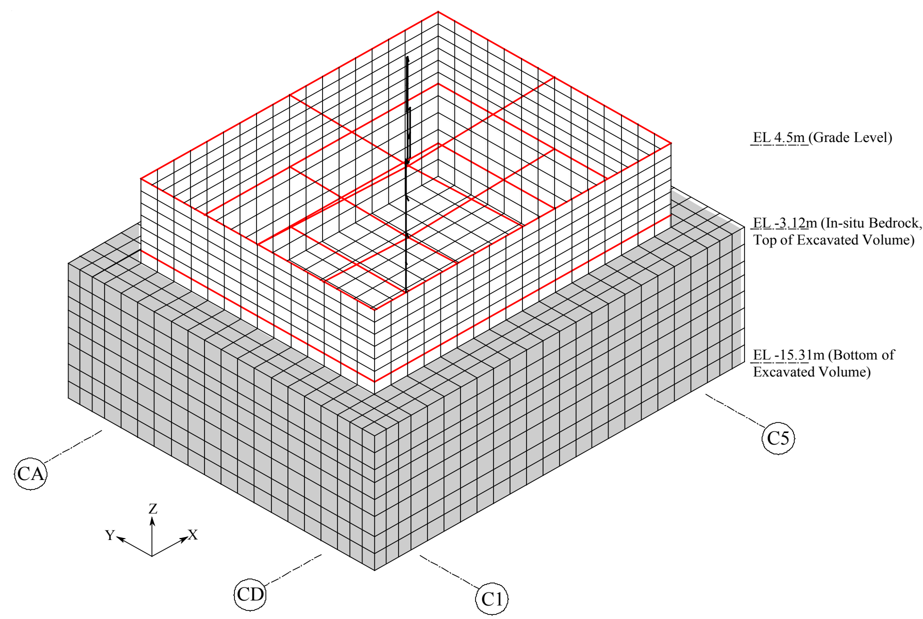
- Analyses performed for LB, BE and UB partial column profiles using corresponding in-column input ground motions developed in accordance with ISG-017
- Concrete fill around RB/FB included in the structural model
- Embedment effects from 5.2 m deep soil strata above rock top elevation are neglected (SSI analyses on fully embedded models address validity of this assumption)



Overview: Section 3.7.2.4
Soil-Structure Interaction

Unit 3 CB site-specific seismic design based on SSI responses obtained from analyses of model partially embedded in 7.3 m thick rock stratum

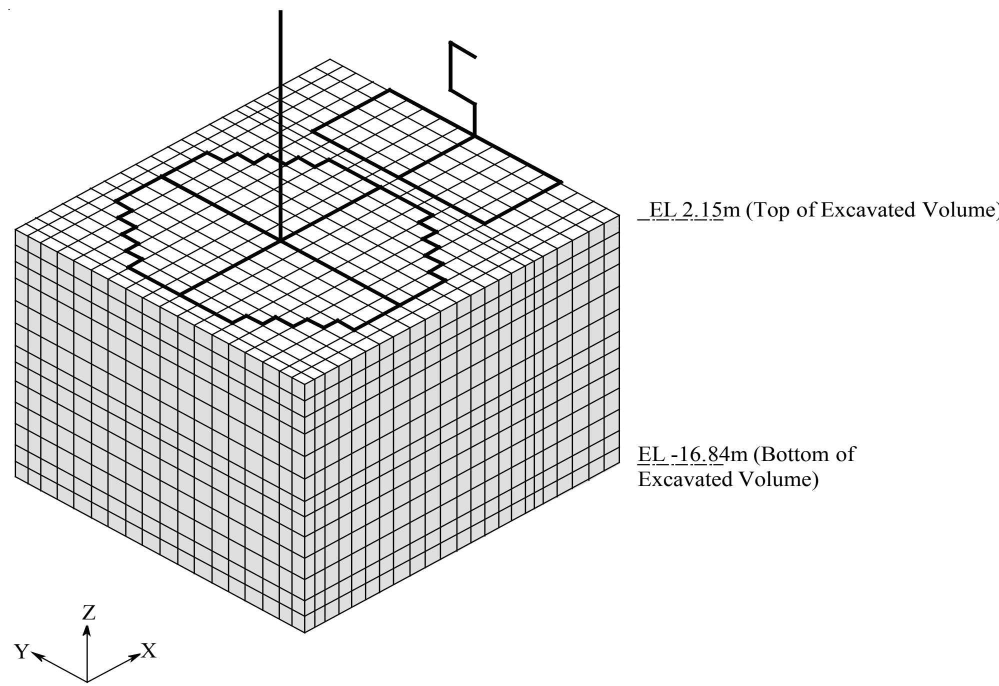
- Analyses performed for LB, BE and UB partial column profiles using corresponding in-column input ground motions developed in accordance with ISG-017
- CB model includes 4.9 m thick block of concrete below CB basemat to Zone III/IV Rock and concrete fill around CB
- Embedment effects from 7.6 m deep soil strata above rock top elevation are neglected (SSI analyses on fully embedded models preformed to address validity of this assumption)



Overview: Section 3.7.2.4
Soil-Structure Interaction

Unit 3 FWSC site-specific seismic design based on SSI responses obtained from analyses of surface mounted model

- Analyses performed for LB, BE and UB full column profiles using ground surface input motions
- FWSC structural (SASSI house) model includes 19 m deep concrete fill block embedded in in-situ soil and resting on rock surface



Overview: Section 3.7.2.4
Soil-Structure Interaction

- Some of Unit 3 site-specific seismic demands on RB/FB, CB and FWSC structures exceed SSE loads used for standard design
- Site-specific *stress* demands on structural members calculated conservatively using scale factors are all below Code-allowables, thus demonstrating applicability of standard design for Unit 3 site

Stress Check on CB Walls

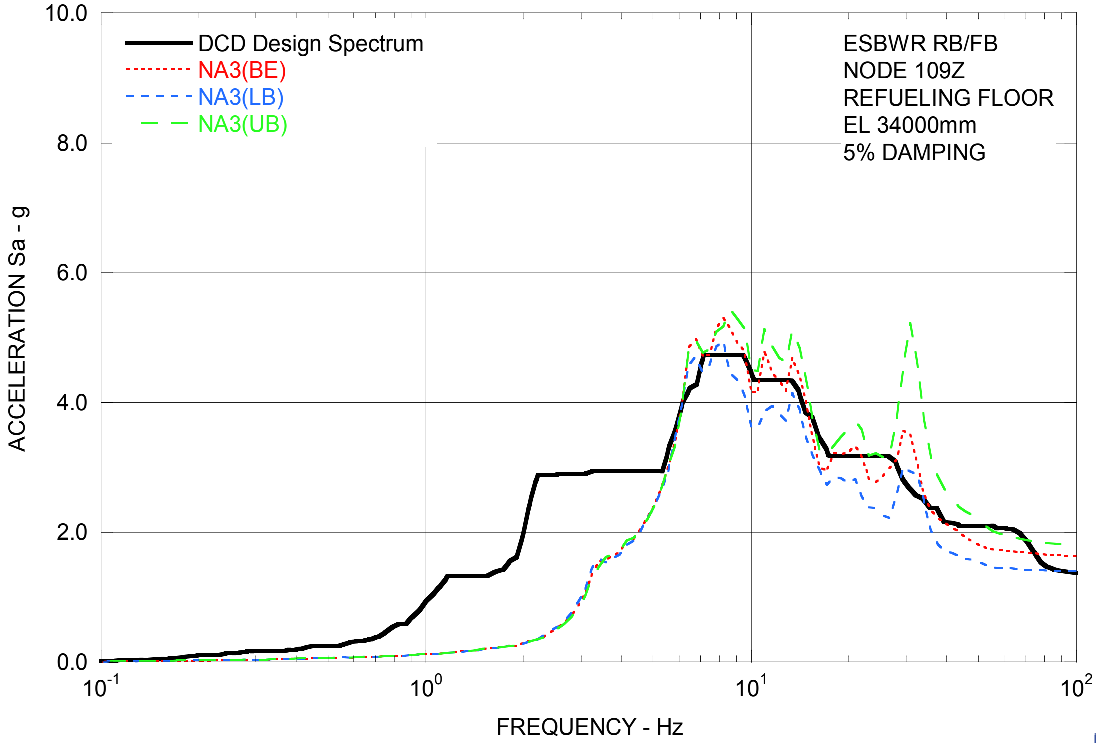
Wall Elevations (m)	Concrete DCD/ Allowable	Rebar DCD/ Allowable	NA3 Stress Estimate							
			Ratio of NA3 to DCD						Max Ratio of NA3 to DCD	Ratio of NA3 to Allowable*
			X-Shear	Y-Shear	X-Moment	Y-Moment	Torsion	Acceleration		
El. -7.4 to -2.0	0.49	0.77	0.23	0.28	0.38	0.36	0.34	1.53	1.53	1.18
El. -2.0 to 4.65	0.29	0.51	1.27	0.96	0.87	0.66	0.92	1.40	1.40	0.71
El. 4.65 to 9.06	0.58	0.57	1.43	1.12	1.08	1.08	1.22	1.37	1.43	0.83
El. 9.06 to 13.8	0.60	0.63	1.31	1.13	1.06	0.94	1.39	1.33	1.39	0.88

*** Stress ratio for walls bellow El. -2.0 and to the allowable stress is less than 1.0 when the scale factor is applied to the seismic stress alone**

Overview: Section 3.7.2.4
Soil-Structure Interaction

At some locations in RB/FB, CB and FWSC, Unit 3 site-specific ISRS exceed standard design ISRS at range of frequencies

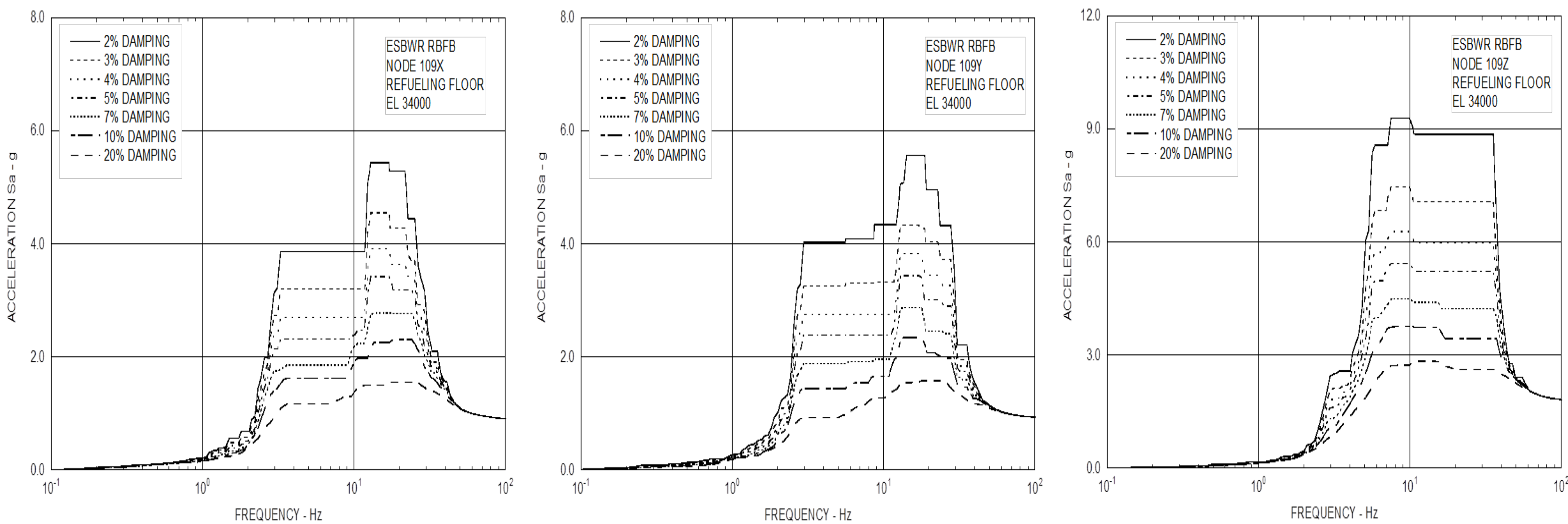
ISRS for Vertical Response of RB/FB Refueling Floor



Overview: Section 3.7.2.4
Soil-Structure Interaction

- Unit 3 site-specific SSE ISRS are developed for all locations in RB/FB, CB and FWSC and for all damping values as envelope of responses obtained from analysis of different subgrade conditions
- These site-specific ISRS together with the standard design ISRS define the SSE loads for design and qualification of Unit 3 equipment and components

Unit 3 site-specific ISRS for RB/FB Refueling Floor



Overview: Section 3.8.4.5.6
Below-Grade Exterior Wall Design

- Lateral loads used for standard design of below-grade exterior walls compared to Unit 3 site-specific lateral pressure demands:
  - Total lateral pressure including site-specific static, hydrostatic and dynamic pressure
  - Passive resistance pressure required for sliding stability
- Static and hydrostatic pressures calculated using site-specific soil properties and ground water level
- Dynamic pressures obtained from results of site-specific SSI analysis
- Passive resistance pressures obtained from sliding evaluation in Section 3.8.5.5.1

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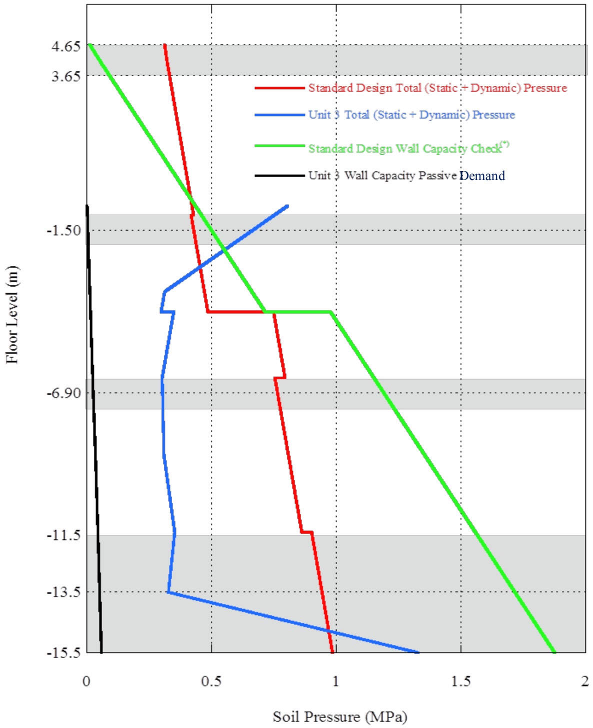
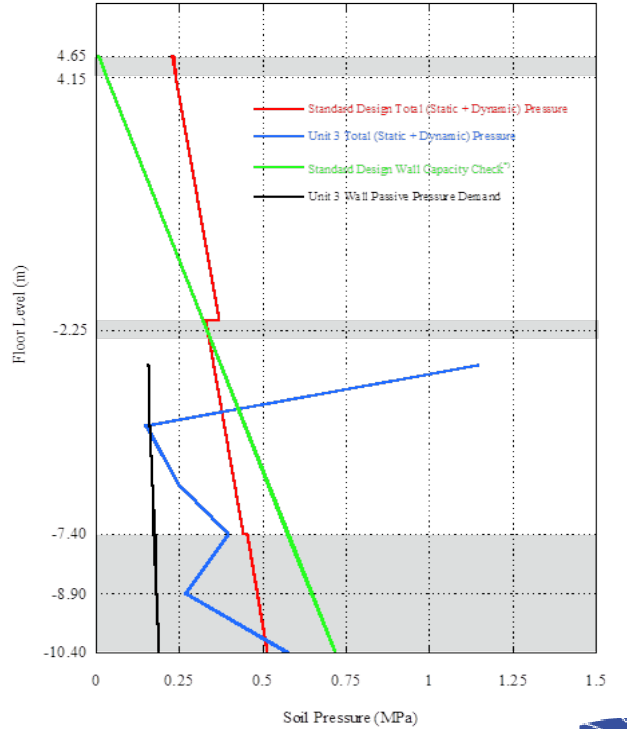
Overview: Section 3.8.4.5.6
Below-grade Exterior Wall Design

Unit 3 site-specific lateral pressure demands are bounded by corresponding standard design load except for sharp exceedances. Standard design envelopes resulting bending and shear stress demands on below-grade walls

RB/FB R1 Wall



CB CD Wall



Overview: Section 3.8.5.5.1
Foundation Stability

- Stability of Unit 3 RB/FB, CB and FWSC foundations evaluated:
  - Based on results of site-specific SSI analyses
  - Using site-specific parameters and ground water level
  - Following standard design DCD methodology
- 0.03 sec. moving window averaging applied on SSI reaction time histories used for sliding stability evaluations
- RB/FB stability evaluation neglects resistance provided by shear keys
- Large values (>500) calculated for factors of safety against overturning using the same energy method used for DCD standard design
- Lateral resistance from concrete fill/rock embedment ensures sliding stability of Unit 3 RB/FB and CB:
  - Resulting lateral pressure demands well below concrete fill and rock surrounding the buildings
- Lateral resistance from shear keys embedded in fill concrete block below the foundation ensures sliding stability of FWSC
  - Maximum required lateral resistance force demand is less than capacity of shear key and concrete fill

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Overview: Section 3.8.5.5.2
Foundation Dynamic Bearing Pressures

- Maximum toe dynamic bearing pressures calculated for RB/FB, CB and FWSC foundations:
  - Based on results of site-specific SSI analyses for spring reaction forces time histories
  - 0.03 sec. moving window averaging applied on reactions time histories
  - Considering site-specific ground water buoyancy force
  - Following standard design DCD methodology, i.e. Energy Balance Method / Modified Energy Balance Method
- Site-specific dynamic bearing pressures are all well below capacity of Unit 3 rock subgrade and below dynamic pressures considered in standard design:

Building		RB/FB	CB	FWSC
Max. Dynamic Bearing Pressure	Unit 3	1170 kPa	520 kPa	420 kPa
	DCD*	2700 kPa	2200 kPa	1200 kPa

* **maximum obtained of all generic subgrade conditions considered in DCD**

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Summary of FSAR Changes

Revisions: Section 3.7.2 and 3.8

Summary

- May 2014 FSAR markup includes changes to:
  1) Stiffness and damping properties in RB/FB model of exterior walls and some circular reinforced members to adjust them for stress level under Unit 3 seismic load demands
  2) FSAR tables, figures and text to present results of SSI analysis of RB/FB model with revised dynamic properties (Item 1)
  3) ISRS results to reflect the use of a revised methodology for addressing coupling effects between floor translation, rocking and torsion and that uses SRSS method for combining responses due to three earthquake components
  4) FWSC sliding stability evaluation to correct for errors made in calculations of lateral resistance from engineered fill placed around FWSC foundation
  5) Correct editorial and transposition errors in results from CB SSI analysis and clarify methodology descriptions
- Changes made to the FSAR only affect some of the descriptions and numerical values but have no effect on the final conclusions from Unit 3 site–specific seismic evaluations

Revisions: Section 3.7.2.4.1
Correction of RB/FB Model Dynamic Properties

- Stiffness and damping properties assigned to reinforced concrete members are based on stress results from SSI analysis for BE subgrade profiles
  - 50% reduced stiffness and SSE damping used for stick and exterior wall shell elements if in-plane shear stress exceeds concrete rupture stress of $3\sqrt{f'_c}$ psi
  - 50% reduced stiffness and SSE damping used for oscillators, stick and outer wall shell elements if out-of-plane bending stress exceeds cracking criteria of ACI 349-01, Section 9.5.2.3
- In-plane cracking evaluated based on shear stresses calculated using effective stick member shear area equal to:
  - 60% of actual area of shear walls in particular direction (per ASCE 43-05 Section 4.2.3)
  - 50% of total axial area of circular cross sections

Revisions: Section 3.7.2.4.1
Correction of RB/FB Model Dynamic Properties

- Unit 3 FWSC model properties are not changed:
  - full (uncracked concrete) stiffness and OBE damping assigned to all members
- Unit 3 CB model properties are not changed:
  - Reduced (cracked concrete) stiffness and SSE damping assigned to all members
- Unit 3 RB model properties are corrected in revised FSAR submitted in May 2014:
  - Full (uncracked concrete) stiffness and OBE damping are assigned to some stick elements in FSAR Figure 3.7.2-210 reflecting lower stress levels calculated using correct circular cross section shear area
  - Reduced (cracked concrete) stiffness and SSE damping are assigned to shell elements of RB/FB below-grade exterior walls

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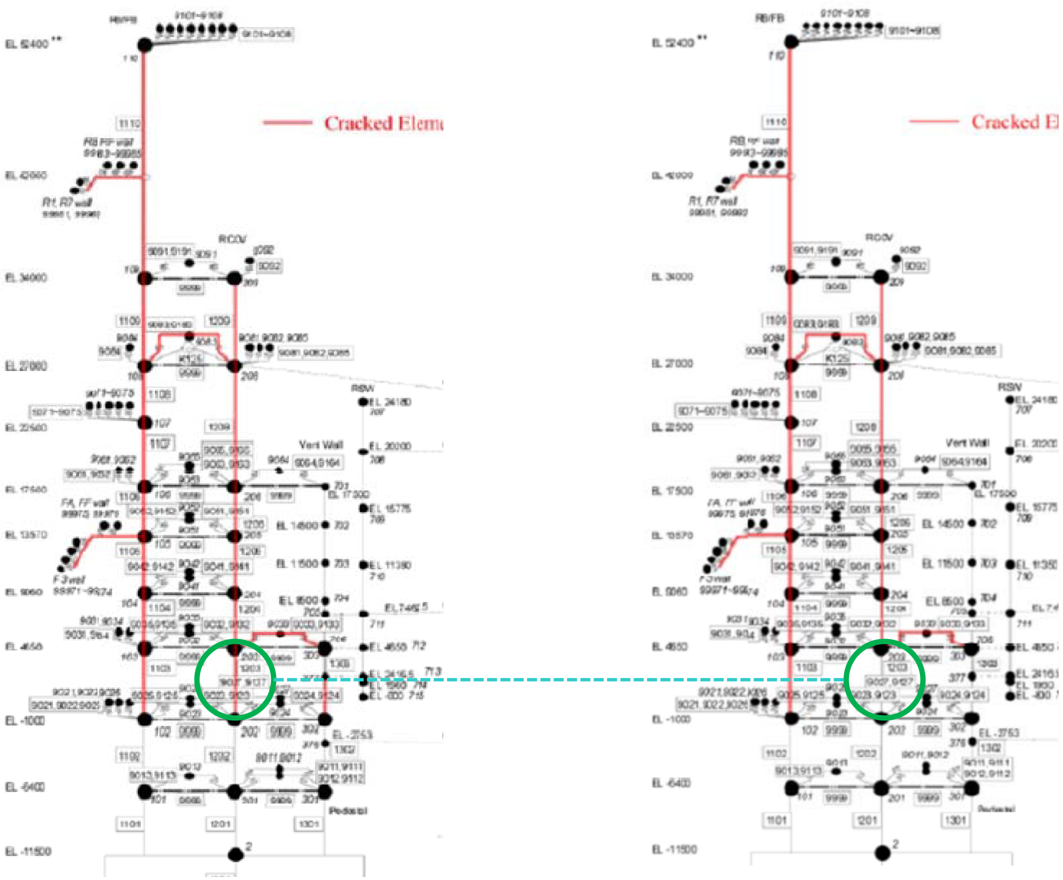
Revisions: Section 3.7.2.4.1
Correction of RB/FB Model Dynamic Properties

- Figure 3.7.2-210: Changes made to Stick members properties

RB/FB Lumped Mass Stick Model Properties

FSAR **Revised**



Revisions: Section 3.7.2.4.1
Correction of RB/FB Model Dynamic Properties

- SSI analysis are performed on RB/FB model with revised dynamic properties and documented in revised FSAR submitted in May 2014
- Revised analysis results show that corrections made to stiffness and damping properties of RB/FB structural model have minor effect on SSI response
- Seismic demands on RB/FB structures remain below allowable stresses, thus demonstrating applicability of standard design for RB/FB structures
  - Seismic load demands on Pedestal Wall slightly increase but stresses remain below allowable stress when the scale factor is applied to seismic stress alone
  - Seismic load demands on Vent Wall and RSW slightly increase but stresses remain below allowable stress when the scale factor is applied to seismic stress alone

Revisions: Section 3.8
Correction of RB/FB Model Dynamic Properties

- Plots of revised total pressure distributions presented in Figures 3.8.4-201 to 204 show that corrections made to RB/FB model properties have negligible effect on results of dynamic lateral pressures
- Re-calculated site-specific lateral pressure demands on RB/FB below-grade exterior remain enveloped by standard design
- Revision of RB/FB stiffness and damping properties result in very small increase (<6%) in magnitude of maximum lateral resistance force on exterior walls required for RB/FB sliding stability (Table 3.8.5-201)
- Revision of RB/FB stiffness and damping properties result in very small increase (<4%) in magnitude of maximum dynamic bearing pressures in Table 3.8.5-204, which remain below Unit 3 subgrade capacity and DCD dynamic bearing pressures

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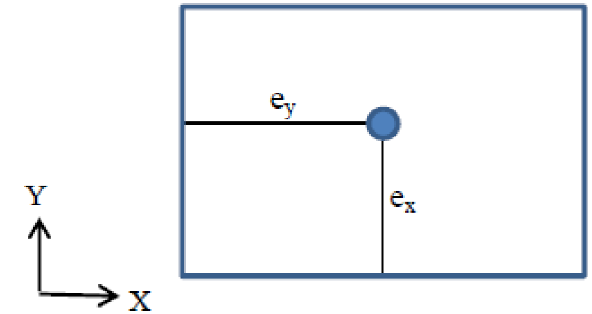
Revisions: Section 3.7.2.4.1
Revised Methodology for ISRS Development

- Ground motion excitation in three directions applied independently
- Responses due to different earthquake components combined using Time Domain Algebraic Sum (TDAS) or Square Root of Sum of Squares (SRSS) methods:
  - Maximum nodal accelerations and displacements combined using SRSS method
  - Maximum member forces, moments combined using SRSS method
  - Maximum lateral pressure results obtained from spring elements stress results combined using SRSS method
  - Seismic base reactions obtained from spring elements stress results combined using TDAS method
  - ISRS results are obtained by post-processing acceleration time history results and SRSS Method is used to combine responses due to three earthquake components

Dominion

Revisions: Section 3.7.2.4.1
Revised Methodology for ISRS Development

- Unit 3 site-specific ISRS represent building responses at the floor edges and are developed from time histories of:
  - Translational accelerations a_{ij} of floor mass in "j" direction due to "i" earthquake component
  - Rotational accelerations r_{ij} of floor mass about "j" axis due to "i" earthquake component



- ISRS in FSAR submitted December 2013 were developed by combining spectra of translational and rotational response using:

$$\boxed{F_X = f_X + f_{XZ} \qquad F_Y = f_Y + f_{YZ}} \qquad \boxed{F_Z = \sqrt{f_z^2 + f_{ZX}^2 + f_{Zy}^2}}$$

Absolute Sum for Horizontal ISRS

SRSS for Vertical ISRS

where: f_X, f_y and f_z are spectra of the time histories of floor mass translations, and

$$f_{XZ} = e_x f_{zz}; \qquad f_{YZ} = e_Y f_{zz}; \qquad f_{ZX} = e_x f_{xx} \qquad f_{ZY} = e_Y f_{yy}$$

are spectra of rotation-induced translations calculated by multiplying spectra of floor mass rotations by maximum floor edge distances

Revisions: Section 3.7.2.4.1
Revised Methodology for ISRS Development

In FSAR markup submitted May 2014, ISRS are developed using revised methodology where translational and rotational response of floor mass are combined in time domain to obtain responses at four floor corners

- Time histories of horizontal accelerations A_{ij} of floor edges in "j" direction due to "i" earthquake component:

$$A_{xx}{}^{(\pm)} = a_{xx} \pm e_x r_{xz} \qquad A_{xy}{}^{(\pm)} = a_{xy} \pm e_y r_{xz}$$

$$A_{yx}{}^{(\pm)} = a_{yx} \pm e_x r_{yz} \qquad A_{yy}{}^{(\pm)} = a_{yy} \pm e_y r_{yz}$$

$$A_{zx}{}^{(\pm)} = a_{zx} \pm e_x r_{zz} \qquad A_{zy}{}^{(\pm)} = a_{zy} \pm e_y r_{zz}$$

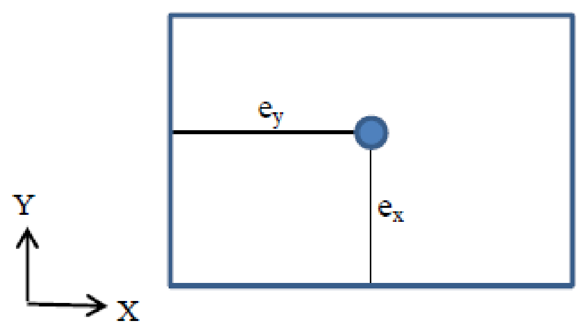
- Time histories of vertical accelerations A_{iz} at four floor edges due to "i" earthquake component:

$$A_{iz}{}^{(NE)} = a_{iz} + e_x r_{ix} + e_y r_{iy}$$

$$A_{iz}{}^{(NW)} = a_{iz} - e_x r_{ix} + e_y r_{iy}$$

$$A_{iz}{}^{(SE)} = a_{iz} + e_x r_{ix} - e_y r_{iy}$$

$$A_{iz}{}^{(SW)} = a_{iz} - e_x r_{ix} - e_y r_{iy}$$



Revisions: Section 3.7.2.4.1
Site-Specific Soil-Structure Interaction Analysis

- Response spectra are calculated for response at each one of the four floor corners

$$a_{ij}^{(NE)} \rightarrow f_{ij}^{(NE)} \qquad a_{ij}^{(NW)} \rightarrow f_{ij}^{(NW)} \qquad a_{ij}^{(SE)} \rightarrow f_{ij}^{(SE)} \qquad a_{ij}^{(SW)} \rightarrow f_{ij}^{(SW)}$$

- Response spectra for building responses at four floor edges are then enveloped to obtain nine floor spectra representing floor response in each direction due to each earthquake component

$$f_{ij} = max\left(f_{ij}^{(NE)}, f_{ij}^{(NW)}, f_{ij}^{(SE)}, f_{ij}^{(SW)}\right)$$

- Responses due to three directions of earthquake are combined using SRSS method

$$F_x = \sqrt{f_{xx}^{\ 2} + f_{yx}^{\ 2} + f_{zx}^{\ 2}} \qquad F_y = \sqrt{f_{xy}^{\ 2} + f_{yy}^{\ 2} + f_{zy}^{\ 2}} \qquad F_z = \sqrt{f_{xz}^{\ 2} + f_{yz}^{\ 2} + f_{zz}^{\ 2}}$$

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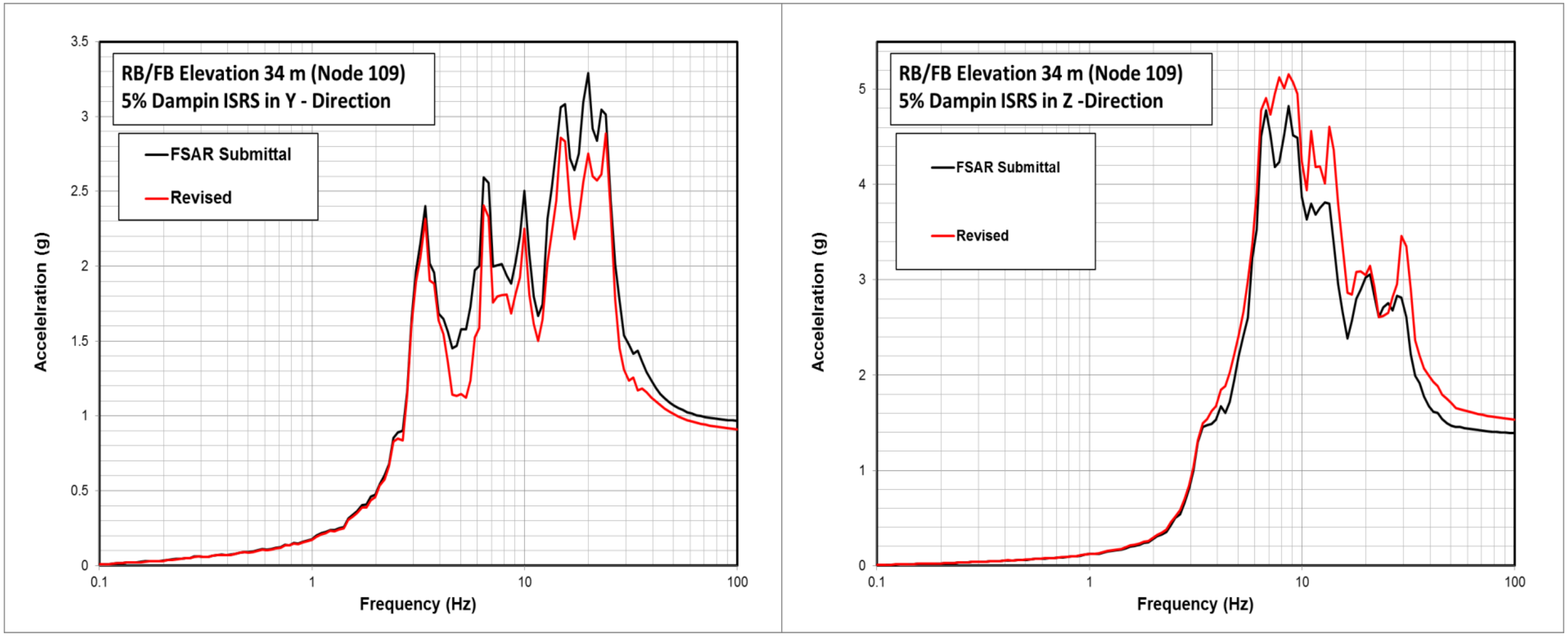
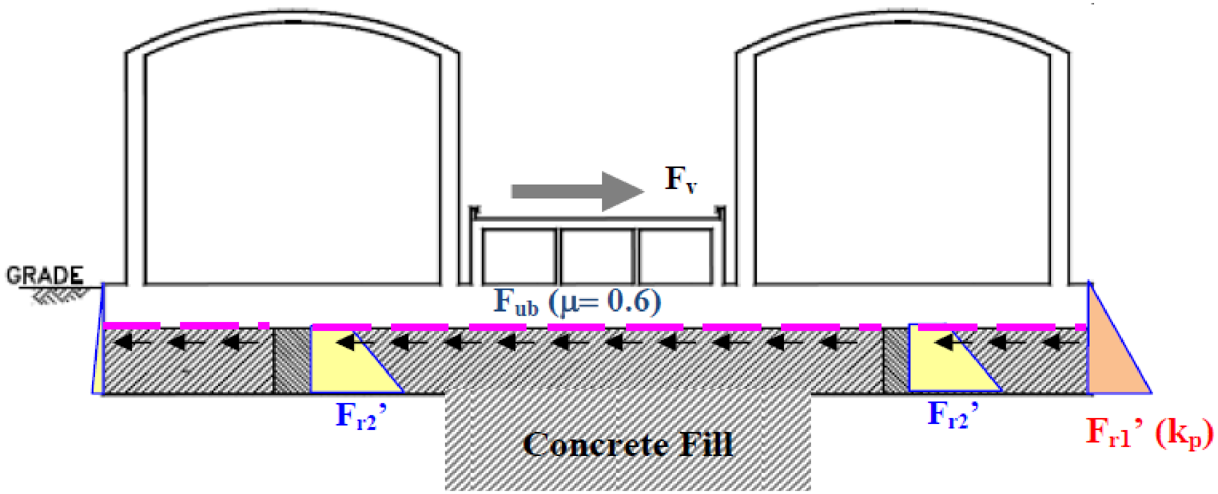
Revisions: Section 3.7.2.4.1
Revised Methodology for ISRS Development

Revision of methodology for ISRS development resulted in slightly lower horizontal ISRS and vertical ISRS with larger amplitudes (Figures 3.7.2-211 to 282)



Revisions: Section 3.7.2.4.1
Corrections to FWSC Sliding Stability Evaluation

- In FSAR submitted December 2013, following lateral resistance forces were considered:
  - F_{ub} - base friction resistance at foundation-concrete fill interface
  - F_{r2}' - bearing pressure resistance on face of shear keys embedded in concrete fill
  - F_{r1}' - bearing pressure resistance on sides of foundation embedded in engineered fill



- Incorrect assumption was made, that lateral displacements were sufficiently large to engage passive resistance of engineered fill surrounding FWSC foundation

Revisions: Section 3.7.2.4.1
Corrections to FWSC Sliding Stability Evaluation

- Due to high stiffness of concrete fill, amplitudes of lateral deformations of FWSC shear keys and foundation are small and insufficient to engage passive resistance of soft engineered fill
- In FSAR markup provided May 2014, FWSC sliding stability completely neglects lateral resistance of engineered fill Fr1'
- Results of re-evaluation show that correction made to calculations of engineered fill resistance do not affect results and conclusion of FWSC sliding evaluation
- Only description of FWSC sliding stability evaluation in FSAR is revised

Draft RAI Questions & Draft Proposed Responses

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RAI 7520: Question 03.07.01-A Effect of Backfill on FIRS & PBSRS

Draft Question:

Clarify whether and how the effect of backfill material (granular and concrete) is included in the development of FIRS and PBSRS.

Draft Response:

Backfill material is not included in the FIRS and PBSRS calculation, because:

- Backfill has limited lateral extent
- FIRS and PBSRS are calculated in the in-situ free field (away from the structures) – Consistent with ISG-17 and NEI white paper
- The FIRS and PBSRS calculation are consistent with the SSI analysis free field (site) properties.
- Backfill effect will be explicitly evaluated in the SSI analysis

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RAI 7520: Question 03.07.01-B Strain Compatible Soil Profiles

Draft Question:

Describe methodology for determining the strain compatible BE, LB & UB soil profiles consistent with FIRS for each SCI structure.

For Companion profiles (corresponding to backfill properties):

(a) Explain how they are used

(b) Explain how they are developed

(c) Clarify if probabilistic SRA was repeated

(d) Clarify the term $(V_s)_{FIRS}$

(e) Clarify GWT used for the SSI profiles

RAI 7520: Question 03.07.01-B Strain Compatible Soil Profiles

Draft Response:

Detailed description of the methodology to obtain strain compatible properties consistent with FIRS will be provided for each SCI structure.

For the Companion profiles:

(a) Explicitly included as finite elements in the SSI models to evaluate the fill effects

(b) Vs, Vp, and damping ratios are developed in the same manner as the free field profiles – further details will be provided

(c) Yes, all probabilistic SRA were repeated to determine properties

(d) The term $(V_s)_{FIRS}$ refers to BE strain compatible Vs corresponding to FIRS level of input motion (Clarification will be added to the FSAR)

(e) GWT used for the SSI profiles and its effect will be provided

- Typo (Vp of 4800 fps) will be corrected.

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RAI 7520: Question 03.07.01-C Poisson's Ratio Values

Draft Question:

- Explain the Poisson's ratio values in Table 2.5.4-208 in relation to the Poisson's ratio values used for the development of SSI analysis profiles.
- Provide specific Poisson's ratio values used in the development of the Vp profiles in Tables 3.7.1-201 through 206 and their technical justification.
- Identify the soil/rock material assumed for each layer in FSAR Tables 3.7.1-201 through 206.

RAI 7520: Question 03.07.01-C Poisson's Ratio Values

Draft Response:

- Table 2.5.4-208 values are best estimate values for the site area. Values used in SSI analysis are generally either boring specific or depth range specific.
- Specific Poisson's ratio values used in the development of the Vp profiles in Tables 3.7.1-201 through 206 will be provided in the RAI response. Justification will be provided in the RAI response.
- Soil/rock materials assumed for each layer in FSAR Tables 3.7.1-201 through 206 will be provided in the RAI response.

RAI 7520: Question 03.07.01-D NEI Check for RB/FB and CB

Draft Question:

Provide clarifications regarding the NEI check for RB/FB and CB:

(a) Explain if NEI check for partial column outcrop FIRS is performed using full column BE, LB, and UB profiles

(b) Explain why envelope of surface ARS for full column outcrop FIRS is substantially higher than those of the partial column outcrop FIRS

(c) Explain the difference between PBSRS in Figures 3.7.1-212 and 213 and those in Figures 3.7.1-216 and 217

(d) Explain whether the in-situ or backfill properties were used in performing the NEI check – provide technical justification

RAI 7520: Question 03.07.01-D NEI Check for RB/FB and CB

Draft Response:

Following ISG-17 and NEI whitepaper, the NEI check is done to ensure the development of the [probabilistic] site response motion is consistent with its application to [deterministic] SSI analysis and evaluation.

(a) The NEI check for partial column outcrop FIRS is performed consistent with the use of partial column FIRS in the SSI analysis, i.e. using partial column (soil layers removed) BE, LB, and UB profiles

(b) The term “surface” refers to the top of the soil column used in corresponding SSI analysis. Therefore, the PBSRS and surface ARS corresponding to the partial column FIRS are calculated on top of the partial soil columns (with soil layers removed). In contrast, the PBSRS and surface ARS corresponding to the full column outcrop FIRS are calculated on top of the full soil columns. The differences between the PBSRS and surface ARS corresponding to the partial and full column outcrop FIRS reflect the amplification of the soil layers.

(c) Same as (b)

(d) Consistent with the SSI analyses, which use the in-situ properties for the free field, the NEI check is performed using in-situ properties

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RAI 7520: Question 03.07.01-E FWSC Control Point & FIRS

Draft Question:

For the FWSC, the concrete fill below the base mat is represented as an integral part of the structural model used in the SSI analysis.

(a) Provide justification for defining control point at bottom of basemat and not bottom of concrete fill. If defined at bottom of concrete fill, the combined structure is embedded and NEI check should be applicable.

(b) FWSC has similar soil column compared to CB. In comparison with CB FIRS, explain why FWSC FIRS has significantly lower amplitude and is shifted towards lower frequencies.

RAI 7520: Question 03.07.01-E FWSC Control Point & FIRS

Draft Response:

As discussed in response to Question 03.07.01-B, the concrete fill is considered a local site feature and is explicitly included as FE in the SSI model. Its inclusion does not make it part of the structure.

(a) Use of bottom of foundation as the control point is justified because:

- ISG-17 & NEI white paper require definition of FIRS at foundation elevation of structure
- It is consistent with the DCD definition, such that the comparison of the CSDRS and site specific FIRS for the FWSC is applicable
- The concrete fill material is not an integral part of the structure, but is considered as a competent backfill material (LB, BE, and UB Vs: 6000, 7000, and 8000 fps)
- The concrete fill will be placed after removal of the saprolite and weathered rock (Zone III) at the footprint of the structure between the BOF and top of Zone III-IV rock.
- Bottom of foundation elevation for the FWSC is defined at Elv. 282 ft.
- Concrete fill will have a non-uniform thickness
- Consistent with ISG-17, NEI white paper and DCD, the FIRS are calculated at the foundation elevation in the in-situ free field.

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RAI 7520: Question 03.07.01-E FWSC Control Point & FIRS

Draft Response (Cont):

(b) The lower amplitude of FWSC FIRS and its frequency shift reflect the differences in material below the FIRS elevations and the increase in damping of the soil layers and their significant shear modulus reduction.

- FWSC FIRS is calculated at Elv. 282 ft on top of a 38 ft thick [BE] saprolite layer which undergoes significant softening due to seismically induced strains at 10^{-5} input.
- In contrast, the FIRS for CB is calculated at Elv. 249 ft on Zone III rock layers which experience little nonlinearity at 10^{-5} input.
- Compared to CB, the larger nonlinearity effects for the FWSC results in smaller 10^{-5} ARS, smaller AR (ratio of 10^{-5} to 10^{-4} ARS) and significantly smaller design factor (DF) at high frequencies.

RAI 7520: Question 03.07.01-F Design Ground Motion Time Histories

Draft Question:

Provide the following information regarding design ground motion time histories:

(a) Numerical results of the spectral matching checks specified in SRP 3.7.1 acceptance criteria II.1.B.ii (Option 1, Approach 2), items (a) through (d).

(b) PSD functions of the time histories and discuss whether there are any significant dips in the PSDs

Dominion

RAI 7520: Question 03.07.01-F
Design Ground Motion Time Histories

Draft Response:

a) Through several tables and figures presented in FSAR Section 3.7.1.1.5, there are several graphical and numerical checks indicated regarding the fifteen [15] spectrally-matched time histories.

Clarification Requested:

What are the specific additional numerical results of the spectral matching checks that are required?

Dominion

RAI 7520: Question 03.07.01-F
Design Ground Motion Time Histories

Draft Response (Cont):

b) As shown in FSAR Figures 3.7.1-235 through 240, 247 through 252, and 259 through - 261, since none of the response spectra of the 15 time histories exceed the target response spectra by more than 30% at any frequency range, the power spectrum density [PSD] functions of the time histories are not required under Option 1, Approach 2 of SRP 3.7.1 acceptance criterion II.1.B.ii.(d).

RAI 7520: Question 03.07.01-G Use of SSE damping

Draft Question:

Provide stress criteria used in determining acceptability for using SSE damping values in site-specific SSI analyses

Draft Response:

- FSAR Section 3.7.2.4.1.4 provides stress criteria used for determining use of SSE damping in conjunction with reduced (cracked concrete) stiffness properties for reinforced concrete members
- SSE damping is assigned only to reinforced concrete members that under Unit 3 site-specific seismic loads and load combinations experience stresses equal or higher than concrete cracking stress criteria
- OBE damping is assigned to all other structural members
- Information requested in the RAI question could be integrated with RAI question 03.07.02-E

RAI 7535: Question 03.07.03-A
Seismic Input Motions for Buried Structures

Draft Question:

Describe in the FSAR how the seismic input motions will be developed for buried structures described in FSAR Section 3.7.3.13 (buried Seismic Category I and II structures, Radwaste tunnels, and Safety Class RW-IIa radwaste piping) and provide site-specific ITAAC to address verification of the process.

Draft Response:

FSAR will be revised to describe the process for developing the seismic input motions for these structures.

Clarification Requested:

Scope of requested site-specific ITAAC

RAI 7536: Question 03.07.02-A SASSI 2010

Draft Question:

(a) Identify use of SASSI 2010 for site-specific analyses as departure (NAPS DEP 3.7-1) to DCD Section 3.7.2, Table 3.7-3

(b) Describe verification and validation (V&V) of SASSI2010 Unit 3 site-specific SSI analyses with cut-off frequencies of up to 50 Hz

(c) Describe SASSI 2010 method used for site-specific analyses described in FSAR Section 3.7.2

(d) Include requested information in relevant FSAR Sections

RAI 7536: Question 03.07.02-A SASSI 2010

Draft Response:

(a) SASSI2010 that is later version of SASSI 2000 will be added to FSAR Table 3.7-3 as supplemental to SASSI2000

(b) Shimizu proprietary report that is available for audit documents details of SASSI2010 V&V for Unit 3 analyses with cut-off-frequencies up to 50 Hz

(c) For Unit 3 SSI analyses described in FSAR Section 3.7.2, SASSI 2010 uses method that is identical to SASSI 2000 Direct Method (DM)

- Only difference is that SASSI 2010 has enhanced numerical solver and capacity for analyses of larger models

(d) FSAR Section 3.7.2.4.1 describes that explicit direct method is used for Unit 3 SASSI 2010 analyses, FSAR Appendix 3C described SASSI 2010 V&V

Dominion

RAI 7536: Question 03.07.02-B
Input Motion Horizon for CB SSI Analysis

Draft Question:

Justify inputting SSI control motions at bottom of CB foundation and not at bottom of concrete fill that is an integral part of CB structure

Draft Response:

- As required by ESBWR DCD and ISG-017 Section 5.1, input control motion for CB site-specific SSI analysis is defined at foundation bottom, same elevation as input motion for CB standard design
- Concrete fill is not integral part of CB structure and is included in CB model only to account for its effects on SSI response
- Since horizontal extent of concrete fill is limited, FE model of concrete fill block below CB foundation is included in SASSI HOUSE model and considered embedded in in-situ soil represented in SASSI SITE model as horizontally infinite layered media
- Site-specific SSI analyses do not provide any responses at concrete fill locations for development of CB site-specific seismic design basis

Dominion

RAI 7536: Question 03.07.02-C
Input Motion for site-specific SSI Analyses

Draft Question:

Explain which set of time histories in FSAR Section 3.7.1 are used for site-specific SSI analyses described in FSAR Section 3.7.2

Draft Response:

SSI analyses of partially embedded RB/FB and CB are performed for partial (truncated column) rock profiles and use corresponding partial column spectrally matched time histories that are presented in:

- FSAR Figures 3.7.1-241 through 243 for the RB/FB SSI analyses
- FSAR Figures 3.7.1-253 through 255 for the CB SSI analyses

Dominion

RAI 7536: Question 03.07.02-D SSI Analyses Models

Draft Question:

(a) Provide maximum aspect ratio of finite element (FE) mesh and confirm if SASSI 2010 has been validated for range of FE aspect ratios used in SSI analyses models

(b) Provide maximum value of considered Poisson ratio and confirm if SASSI 2010 has been validated for range of Poisson ratios used in SSI analyses models

(c) Confirm if model passing frequencies presented in FSAR Table 3.7.2-201 are calculated on basis of maximum FE dimensions in both horizontal and vertical directions

(d) Provide basis for using FWSC model for SSI analyses of LB and BE subgrade profiles that have passing frequencies lower than 50 Hz

(e) Provide graphical comparison between subgrade profiles in FSAR Section 3.7.1 and profile used for SSI analyses and basis

(f) Clarify if sensitivity studies were performed to demonstrate that depths of SSI models lower boundaries are adequate

RAI 7536: Question 03.07.02-D SSI Analyses Models

Draft Response:

(a) Accuracy of SASSI 2010 results is validated for maximum FE mesh ratio of 1:4 that is larger than aspect ratios of FE models used for SSI analyses

(b) Accuracy of SASSI 2010 results is validated for maximum soil Poisson ratio of 0.48 considered in Unit 3 site-specific SSI analyses

— V&V report documenting SASSI 2010 validation is available for audit

(c) Model passing frequencies in FSAR Table 3.7.2-201 are calculated on basis of maximum FE dimensions in both horizontal and vertical direction using SASSI 2010 recommended 20% wavelength criterion

(d) FSAR Table 3.7.2-201 shows that cut-off-frequencies of FWSC SSI analyses for BE and LB profiles are 50 Hz and 29 Hz which are ≈50% higher than FWSC BE and LB models passing frequencies

— RAI response will demonstrate that results of SSI analyses for LB and BE profiles are accurate and that FWSC site-specific design basis envelopes FWSC responses for LB, BE and UB subgrade conditions

RAI 7536: Question 03.07.02-D SSI Analyses Models

Draft Response (Cont):

(e) Dynamic properties of subgrade profiles used for SSI analyses are same as those presented in FSAR Section 3.7.1 and have only layering adjusted to match FE mesh.

- Technical reports available for audit present adjusted layering of SSI subgrade profiles (tables are used in the reports as better method for illustrating adjustments made to profile layering)

(f) Sensitivity study is being performed on RB/FB model to demonstrate that selected lower boundary depths of SSI models are adequate.

- Results of RB/FB evaluation are applicable for CB and FWSC because RB/FB has largest foot print dimensions among all Category I buildings and is most affected by selected lower boundary depths

Dominion

RAI 7536: Question 03.07.02-E
Properties of Reinforced Concrete Members

Draft Question:

(a) Explain magnitude of in-plane shear stiffness reduction applied to elements experiencing average shear stress exceeding in-plane cracking criterion and provide technical basis for used cracking threshold

(b) Explain magnitude of out-of-plane stiffness reduction applied to elements experiencing bending moments exceeding ACI 349-01, Section 9.5.2.3 cracking moment criterion

(c) Provide justification for using only results of SSI analyses for BE profile to determine effects of concrete cracking and explain how responses obtained by this approach compare to responses obtained using cracked structure with LB profile and uncracked structure with UB profile

(d) Provide details of methodology used for determining cracking status of reinforced concrete elements and how reduced stiffness properties are assigned to structural models

Dominion

RAI 7536: Question 03.07.02-E
Properties of Reinforced Concrete Members

Draft Question (Cont):

(e) Describe how OBE and SSE damping are assigned to all uncracked and all cracked members, respectively

(f) Confirm that number of SDOF oscillators in site-specific models and their properties are adequate to capture walls and slabs out-of-plane seismic response for Unit 3 site-specific ground motion

(g) Explain and justify properties (cracked or uncracked) assigned to plate FEs modeling RB/FB, CB, and FWSC basemats and below-grade exterior walls

(h) Explain if site-specific analyses followed DCD methodology and considered 3 cases (0%, 50%, and 100%) of concrete stiffness contribution to the steel plates when modeling stiffness of containment diaphragm floor and vent wall elements

RAI 7536: Question 03.07.02-E
Properties of Reinforced Concrete Members

Draft Response:

(a) Per ASCE 43-05, 50% reduction of in-plane shear stiffness is applied to elements experiencing shear equal or greater than concrete rupture stress of $3\sqrt{f'_c}$ ($f'c$ – concrete compressive strength in psi)

(b) Per ASCE 43-05, 50% reduction of out-of-plane stiffness is applied to elements experiencing bending moments exceeding cracking moment criterion

(c) Per SRP 3.7.2, SSI analyses consider structural models with best estimate properties that for consistency are based on stress responses obtained from analyses of BE profile
  - Effects of subgrade variations on RB/FB and CB responses and resulting seismic stresses levels and concrete cracking are small

(d) Best estimate properties are assigned to different stick elements based on stress level they experience
  - Technical reports available for audit provide details of methodology used for evaluation and modeling of concrete cracking effects

Dominion

RAI 7536: Question 03.07.02-E

Properties of Reinforced Concrete Members

Draft Response (Cont):

(e) Different damping are assigned through complex stiffness matrices of each element in structural model:
- SSE damping is assigned to all cracked concrete members
- OBE damping assigned to all other members (uncracked concrete and steel members)

(f) Evaluation will be provided demonstrating that SDOF oscillators in structural models with BE properties are adequate to capture walls' and slabs' out-of-plane responses for Unit 3 site-specific ground motion

(g) Best estimate properties are assigned to FEs modeling RB/FB, CB below-grade exterior walls based on calculated stress levels. Basemats resting on stiff rock/ concrete fill are assigned with full stiffness properties because they experience little or no uplift resulting in no significant concrete cracking

(h) Evaluation will be provided to demonstrate that contribution of concrete stiffness to the steel plates of containment diaphragm floor and vent wall element are adequately addressed

RAI 7536: Question 03.07.02-F
SSI Analyses Transfer Function Results

Draft Question:

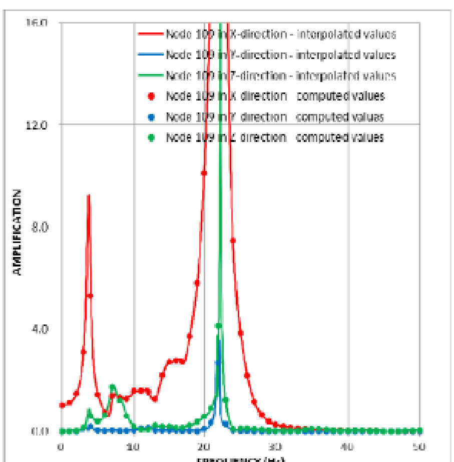
Provide transfer function results for responses at key locations from site-specific SSI analyses of RB/FB, CB and FWSC for all soil cases

RAI 7536: Question 03.07.02-F
SSI Analyses Transfer Function Results

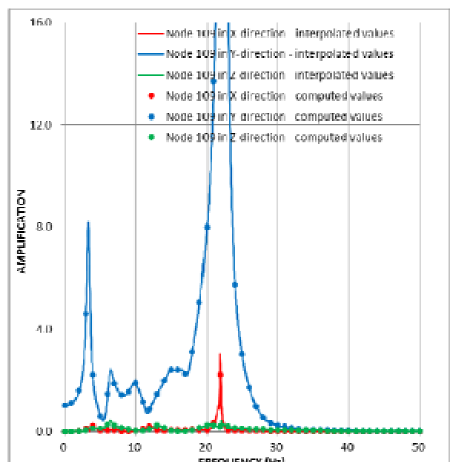
Draft Response:

- Technical reports available for audit provide plots of transfer function results from site-specific SSI analyses for responses at RB/FB, CB and FWSC key locations
- For each subgrade profile analyzed, plots are presented to show both calculated values (dots) and interpolated values (curves) of transfer function amplitudes for translations in 3 orthogonal directions due to 3 earthquake components

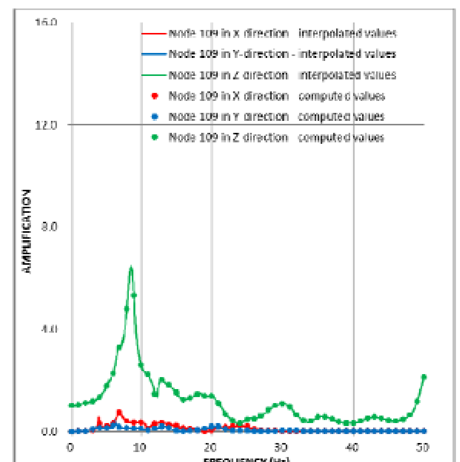
Transfer Functions Amplitudes for RB/FB Refueling Floor Response - BE Case



(a) X-Direction Input



(b) Y-Direction Input



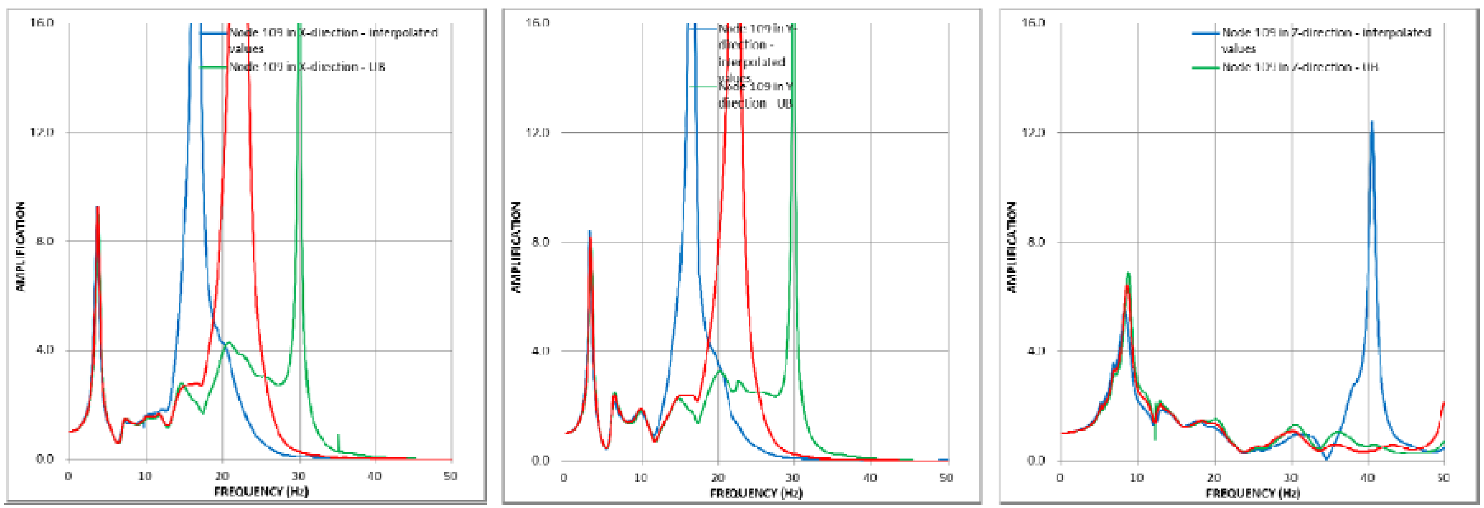
(c) Z-Direction Input

RAI 7536: Question 03.07.02-F
SSI Analyses Transfer Function Results

Draft Response (Cont):

- Transfer function plots show no numerical abnormalities in SSI analyses results
- Plots comparing transfer function results from SSI analysis of LB, BE and UB subgrade profiles are also presented to illustrate effects of variations of subgrade properties on SSI response

Comparison of Transfer Functions for RB/FB Refueling Floor Response



(a) X-Direction Input (b) Y-Direction Input (c) Z-Direction Input

Dominion

RAI 7536: Question 03.07.02-G SSSI Evaluations

Draft Question:

Provide site-specific evaluation of SSSI of RB/FB on CB response and evaluation of SSSI between CB and FWSC

Draft Response:

- Results of site-specific SSSI analysis of CB-RB/FB and CB-FWSC are used to demonstrate that Unit 3 design basis envelopes SSSI effects on seismic structural loads, ISRS and lateral pressures.
- CB-RB/FB SSSI analysis are performed using input motion defined by CB FIRS and two bounding subgrade profiles capturing full range of variations of subgrade stiffness at Unit 3 CB location:
  - CB UB full column profile that includes soil & granular fill above Zone III rock
  - CB LB truncated column profile that neglects effect of soil and granular fill
- CB-RB/FB combined model includes concrete fill and tunnel located between two buildings to capture their effect on SSSI responses (tunnel is seismically isolated from the RB/FB and CB below grade walls)

Dominion

RAI 7536: Question 03.07.02-G
Site-Specific SSSI Evaluations

Draft Response (Cont):

- SSSI effects of heavy RB/FB on smaller CB are evaluated by comparing CB responses obtained from SSSI analyses of CB-RB/FB combined model and SSI analyses of free-standing CB models
- CB-FWSC SSSI effects are evaluated based on two sets of analyses using:
  - Input motion defined by CB FIRS and full column profiles representing LB and UB subgrade properties at CB location
  - Input motion defined by FWSC FIRS and full column profiles representing LB and UB subgrade conditions at FWSC location
- CB-FWSC combined model is used that includes concrete fill below FWSC to capture its effect on SSSI responses
- SSSI effects between CB and FWSC are evaluated by comparing results of SSSI analyses of CB-FWSC combined model and SSI analyses of free-standing CB and FWSC models

Dominion

RAI 7536: Question 03.07.02-H Structural Evaluation

Draft Question:

- Provide detailed and direct stress calculations (without stress scaling) for checking integrity of structural members where site-specific seismic loads significantly exceed corresponding standard design loads (e.g., (a) RPV and RPV support structure, (b) RSW, (c) flexible slabs and walls (d) PCCS condenser, and (e) new and spent fuel racks in buffer pool and spent fuel pool)
- Demonstrate that the resulting site-specific total stress demands are bounded by code-allowable stresses in all cases or provide technical basis if other approach is used for demonstrating structural integrity
- Provide site-specific loads and evaluation of RPV and other components' supports and anchorage to building structure

RAI 7536: Question 03.07.02-H Structural Evaluation

Draft Response:

- Adequacy by conservative scale factor approach will be demonstrated by supplemental stress evaluations for critical members based on:
  - stresses generated by actual site-specific seismic loads in combination with other applicable loads
  - strength checks taking into account interaction effects of load components
  - axial load-dependent equations for shear strength in ACI 349 Chapter 11 (Note that ACI 349 Chapter 21 shear strength equations do not include axial load contribution)
- Applicability of standard design will be demonstrated by showing site-specific demands are bounded by the code-allowable stresses
- Evaluation of RPV and other components' supports and anchorage to building structure are addressed in ITAAC as discussed in responses to RAI Questions 03.07.02-I, L and K

Dominion

RAI 7536 Question 03.07.02-J

Stress Evaluation of RB/FB Flexible Walls

Draft Question:

Provide methodology and results of site-specific out-of-plane stress evaluation of RB/FB flexible walls

Draft Response:

Table 3.7.2-216 (g) is included in FSAR markup submitted May 2014 to demonstrate based on DCD methodology that standard design envelopes site-specific out-of-plane demands on RB/FB flexible walls

	Concrete	Rebar	NA3 Stress Estimate									
Out-of-plane Elevations(m)	DCD/ Allowable	DCD/ Allowable	wWi (kN)	Oscillator	Acceleration (g)	wAeq (g)	Wb (kN)	Acceleration (g)	NA3 wAave(g)	DCD wAave(g)	Ratio of NA3 to DCD	Ratio of NA3 to Allowable
El. 42.00	0.40	0.70	8.13	99981	1.81	1.77	7.58	1.21	1.51	1.48	1.02	0.71
			0.54	99982	1.13							
			4.56	99983	1.28	1.06	8.48	0.98	1.03	1.52	0.67	
			5.1	99984	0.97							
			2.28	99985	0.83							
El. 13.57			8.09	99971	1.25	1.46	8.87	0.84	1.18	1.19	0.99	
			2.38	99972	2.13							
			0.23	99973	1.77							
			0.21	99974	1.64							
	0.35	0.64	4.93	99975	1.29	1.34	2.69	0.83	1.18	1.09	1.08	0.69
			0.86	99976	1.66							

wWi : Weight of the i-th oscillator in the dynamic analysis model
wAeq : Equivalent acceleration of all oscillators
Wb : Wall weight
wAave : Weighed average acceleration

Dominion

RAI 7536: Question 03.07.02-I, K and L
Evaluation of Equipment and Components

Draft Question:

Provide comparison of site-specific seismic demands with standard design loads and site-specific seismic analyses and evaluations for:

- RPV, RPV support structures and anchorage (Question 03.07.02-I)
- Spent fuel pool and buffer pool structures and storage racks (Question 03.07.02-K)
- PCCS Condensers and support structures (Question 03.07.02-L)

Dominion

RAI 7536: Question 03.07.02-I, K and L
Evaluation of Equipment and Components

Draft Response:

- For DCD ITAAC 2.1.1-3 #6, site-specific analysis and evaluation will be performed on more refined dynamic model of RPV with seismic input defined by Unit 3 SSE ISRS
- For DCD ITAAC 2.5.6-1 #1 and #2, site-specific analysis and evaluation will be performed of fuel pool and buffer pool structures and storage racks with seismic input defined by Unit 3 SSE ISRS
- For DCD ITAAC 2.15.4-2 #5, site-specific analysis and evaluation will be performed of PCCS Condensers and supporting structures with seismic input defined by Unit 3 SSE ISRS
- Departure and exemption follow guidance in DC/COL-ISG-1 to adjust seismic ITAAC for site-specific ground motion effects

Dominion

RAI 7536: Question 03.07.02-M
Definition of Unit 3 SSE ISRS

Draft Question:

(a) Confirm if peak-broadened site-specific design ISRS are developed for all locations

(b) Confirm if envelope of site-specific design ISRS and corresponding standard plant design basis ISRS are used for SSCs' design and qualification

(c) Revise FSAR Sections 3.7.2.4.1.7 and 3.7.2.4.1.8 to clearly document design commitments for Unit 3 application

Dominion

RAI 7536: Question 03.07.02-M Definition of Unit 3 SSE ISRS

Draft Response:

(a) Technical Reports available for audit document peak-broadened site-specific design ISRS for all locations within RB/FB, CB and FWSC

(b) Unit 3 seismic structures, systems, and components will be designed and qualified for both DCD ISRS and site-specific ISRS

(c) FSAR Section 3.7.2.4.1.8 states:

> "The seismic design of systems and components is evaluated to both the ISRS input from the standard design CSDRS and the ISRS input from the Unit 3 FIRS."

COLA Part 10 defines Unit 3 site-specific SSE for purposes of performing ITAAC for seismic qualification of structures, systems, and components

RAI 7536: Question 03.07.02-N ISRS Results

Draft Question:

(a) Provide comparison of site-specific and standard design ISRS for SDOF oscillators modeling RB/FB and CB flexible walls and slabs

(b) Provide peak-broadened site-specific design ISRS for all SDOF oscillators

(c) Correct FSAR Figure 3.7.2-211

(d) Correct FSAR Figure 3.7.2-261

Draft Response:

(a) Technical Reports available for audit present comparison of site-specific and standard design ISRS for variety of SDOF oscillator responses

(b) Technical Reports available for audit document peak-broadened site-specific design ISRS for all SDOF oscillators

(c) Figure 3.7.2-211 has been corrected in FSAR markup provided May 2014

(d) FSAR Figure 3.7.2-261 will be revised

RAI 7536: Question 03.07.02-O

SSI Analysis of Non-Seismic Category I Structures

Draft Question:

- Clarify if granular fill meets requirement in FSAR Table 2.0-201 for minimum shear wave velocity
- Clarify how methodology for site-specific SSI analyses of Category I structures is applicable to Turbine Building (TB), Radwaste (RW) Building, Service Building (SB), and Ancillary Diesel Building (ADB) that are founded on granular fill subgrade

Draft Response:

- Unit 3 granular fill has shear wave velocity greater than 1000 fps (FSAR Table 2.5.4-208) and thus meets competent material requirements of FSAR Table 2.0-201 and SRP 3.7.1 Section II.1.A
- Site-specific analyses of of TB, RW Building, SB, and ADB will be performed using same SASSI 2010 methodology that is applicable for SSI analyses of foundations supported by any kind of competent subgrade material, rock, soil, concrete and/or granular fill

Dominion

RAI 7536: Question 03.07.02-P

FSAR Sections 3.7.2.8.1 and 3.7.2.8.3 Inconsistences

Draft Question:

Clarify and/or correct inconsistences in FSAR Sections 3.7.2.8.1 and 3.7.2.8.3 related to descriptions of seismic gaps between TB, SB and RB/FB

Draft Response:

Wording of FSAR will be revised to read as follows:

- FSAR Section 3.7.2.8.1:

  "The seismic gaps between the Turbine Building and the Reactor Building are no less than the calculated maximum relative displacements between the two buildings during an SSE event, considering out-of-phase motion."

- FSAR Section 3.7.2.8.3:

  "The seismic gaps between the Service Building and the Reactor Building/Fuel Building are no less than the calculated maximum relative displacements between the two buildings during an SSE event, considering out-of-phase motion."

Dominion

RAI 7537: Question 03.08.04-A
Lateral Soil/Rock Pressures

Draft Question:

(a) Provide plots with separate comparisons of static and dynamic site-specific and standard design pressures

(b) Provide a summary of calculations showing site-specific out-of-plane bending moments and shear forces in below-grade exterior walls are bounded by standard design

(c) Explain how the adequacy of below-grade exterior walls is verified at elevations above the top of the Zone III rock.

(d) Explain how the pressures computed from site-specific SSI analyses would be affected if the structural fill were to be considered in the SSI analyses of the RB/FB and CB.

RAI 7537: Question 03.08.04-A Lateral Soil/Rock Pressures

Draft Response:

(a) Separate plots will be provided comparing static and dynamic site-specific and standard design pressures

(b) Technical reports available for audit provide calculations showing site-specific out-of-plane bending moments and shear forces in below-grade exterior walls are bounded by standard design

(c) Lateral pressure results from ongoing SSI analyses of fully embedded RB/FB and CB models for full column profiles will be used to show that standard design envelopes lateral pressure demands from soil above rock

- SSI analyses of fully embedded models will be documented in technical reports that will be available for audit.

Dominion

RAI 7537: Question 03.08.04-B Alkali-Silica Reaction

Draft Question:

Explain measures to prevent Alkali-Silica Reaction (ASR) concrete degradation as described in Information Notice 2011-20

Draft Response:

Dominion will implement ASTM Testing Standards C1260 and C1293 for testing concrete aggregate for Seismic Category I and RTNSS structures. The FSAR will be revised to reference these ASTM Standards

RAI 7538: Question 3.8.5-A Sliding Stability Evaluation

Draft Question:

(a) Explain reason for using moving average window and its impact on sliding stability evaluation results

(b) Clarify how sliding stability is evaluated

(c) Provide technical basis for using value of 0.6 static coefficient of friction and explain if reinforcement is needed at concrete fill interfaces

(d) Provide description and magnitude of all lateral resisting forces

(e) Provide allowable bearing pressures for embedment and magnitude of deformations to justify use of static friction resistance

(f) Provide results of shear key evaluations

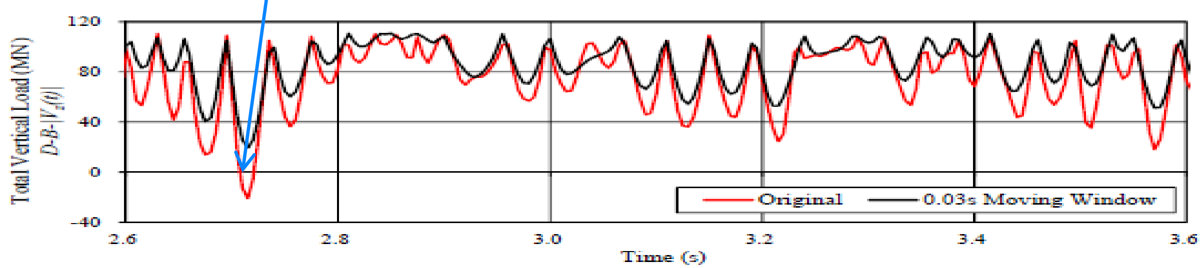
Dominion

RAI 7538: Question 3.8.5-A Sliding Stability Evaluation

Draft Response:

(a) There are a few short instances of time when CB base is not in contact with subgrade shown as spurious peaks in base reaction time history

CB Vertical Base Reaction – UB Soil Case



Moving average window filters out high frequency content from base reaction time histories that produces short duration effects leaving low frequency content that governs global motion and seismic stability of building

Alternative stability evaluations will be performed to demonstrate sliding stability of CB based on:

- —Considering distribution of reaction forces at SSI interfaces at base and sides of embedded model obtained directly from SSI analyses
- —Set of unfiltered time histories of SSI reactions at base and sides of CB model
- —Using dynamic sliding coefficient

Dominion

RAI 7538: Question 3.8.5-A
Sliding Stability Evaluation

Draft Response (Cont):

(b) Sliding stability evaluated for 2 horizontal directions separately following standard design methodology described in DCD Section 3.8.5.5

(c) Sliding evaluations use minimum value of 0.60 for coefficient of frictionamong those of concrete fill (ACI 349-01 Subsection 11.7.9) and Zone III and Zone III-IV rock (FSAR Table 2.5.4-208). No shear friction reinforcement is needed at foundation-concrete fill interfaces

(d) Will provide magnitudes of resisting forces described in FSAR Section 3.8.5.5.1 and DCD Section 3.8.5.5

(e) Will provide allowable lateral bearing pressures for fill concrete and Zone III rock embedment and SSI analyses results for displacement magnitudes

- — Stability evaluations neglect lateral resistance from engineered fill

(f) Shear keys are needed only for FWSC stability

Standard design of FWSC shear keys using lateral load of 64 MN envelopes Unit 3 demand of 43 MN

FWSC shear keys are embedded in concrete fill with shear resistance that is sufficient to resist lateral load demands

RAI 7538: Question 03.08.05-B Sliding Stability Evaluation

Draft Question:

- Evaluate whether site-specific dynamic bearing pressure demands on RB/FB, CB and FWSC basemats are bounded by standard design
- Confirm that RB/FB, CB, and FWSC foundation dynamic bearing pressure demands are less than the allowable dynamic bearing capacities of underlying rock or concrete fill materials

Draft Response:

- Standard design bounds site-specific dynamic bearing pressure demands on RB/FB, CB and FWSC basemats:
  - —Standard design considered bounding subgrade stiffness and maximum bearing pressure that was calculated for all DCD generic subgrade conditions
  - —Bearing pressure loads used for standard design of RB/FB, CB and FWSC basemats envelope site-specific dynamic bearing pressure demands
- Comparison will be provided to demonstrate that dynamic bearing demands are less than subgrade allowable dynamic bearing capacities

Dominion

Preliminary Results of Sensitivity Studies

Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

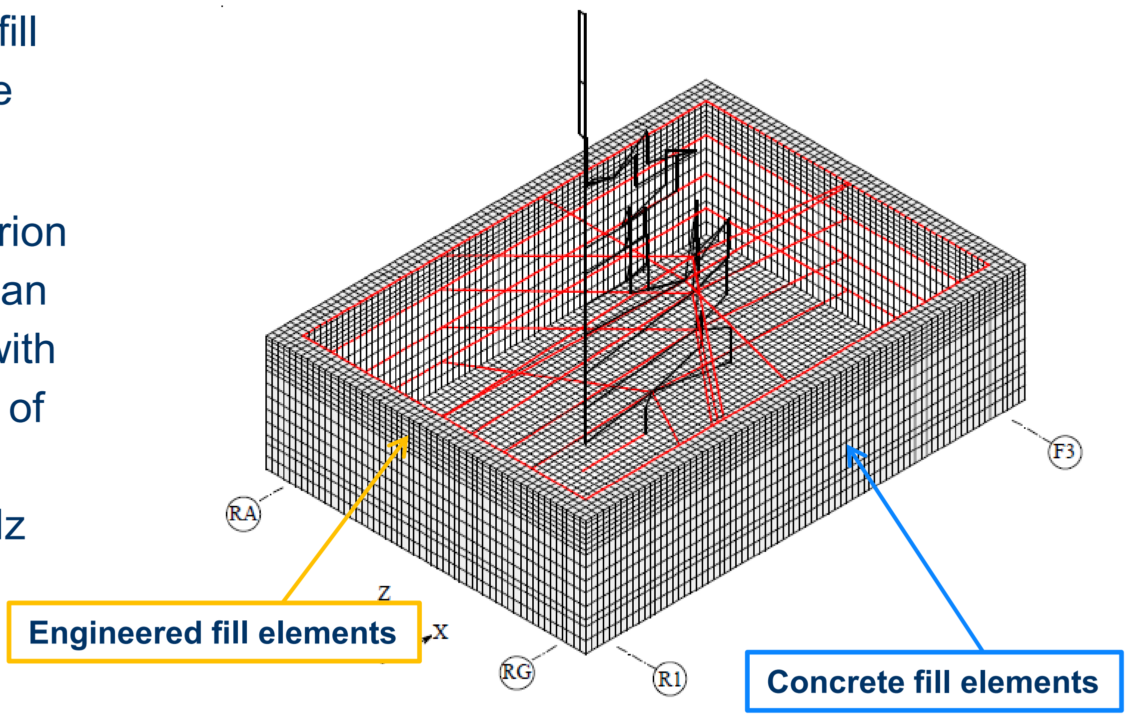
- Objective: Justify assumption that effects of in-situ soil and engineered fill on top of rock on seismic design can be neglected
- Site-specific evaluations of soil embedment effects on RB/FB and CB design are based on results of SSI analyses of models for full column soil profiles presented in FSAR Section 3.7.1 that include soil embedment above rock
  - Results for transfer functions, ISRS, maximum accelerations and member forces are compared with standard design and Unit 3 site-specific design basis
- Preliminary results are available from SSI analyses of:
  - RB/FB for UB full column profile
  - CB for LB and UB full column profiles

Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Soil embedment effects on RB/FB design evaluated based on results of SSI analyses of model embedded in full column profiles representing strain-compatible dynamic properties of in-situ rock and soil

Engineered fill and concrete fill around RB/FB included in the structural model

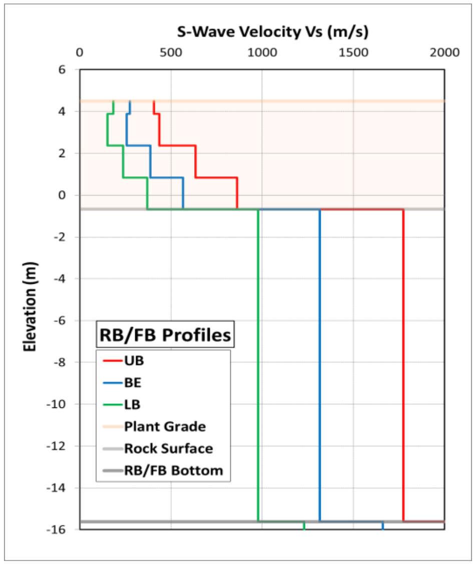
Based on SASSI 20101 criterion for element size to be less than 20% of wave length, model with UB soil properties is capable of transmitting waves with frequencies higher than 55 Hz

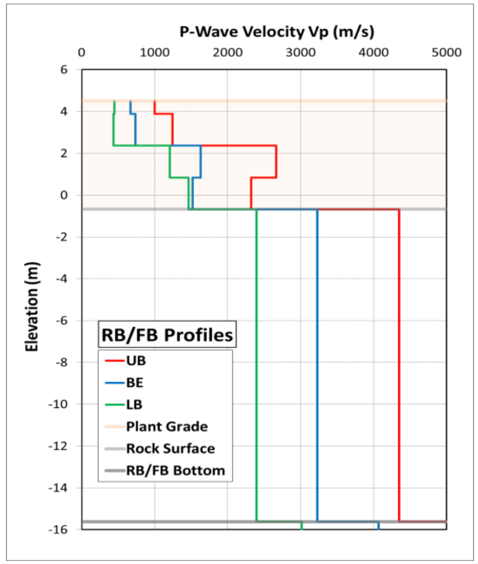


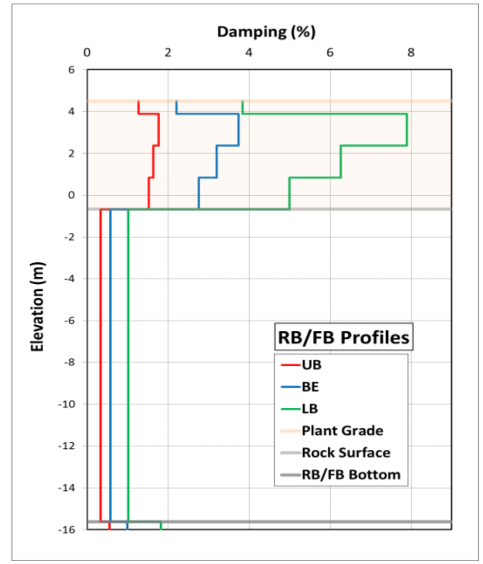
Sensitivity Studies: Section 3.7.2

Soil Embedment Sensitivity Study

- RB/FB Embedment Soil Properties





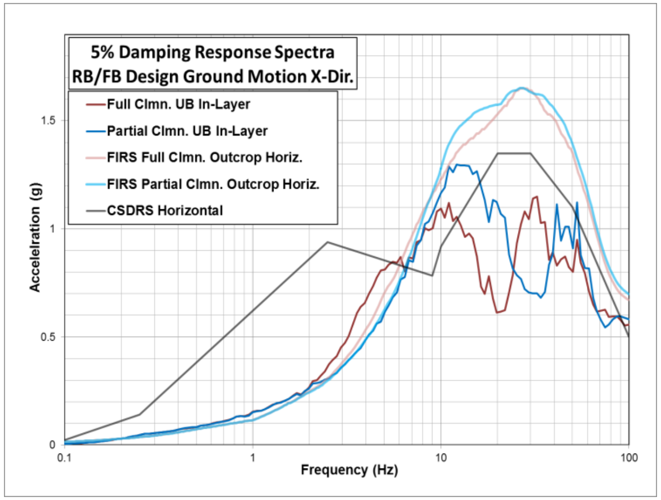


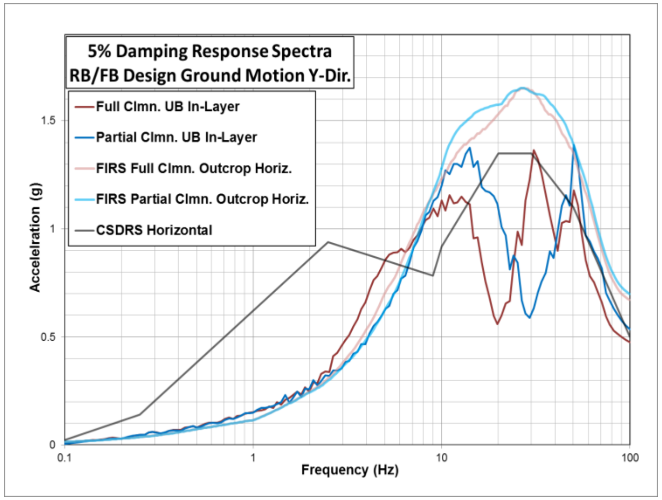
RB/FB Embedment Depths and Shear Column Frequencies

Soil Case	Rock Embedment			Full Embedment			Soil Embedment		
	Depth	$V_{s\ ave}$	f_{sc}	Depth	$V_{s\ ave}$	f_{sc}	Depth	$V_{s\ ave}$	f_{sc}
	m	m/s	Hz	m	m/s	Hz	m	m/s	Hz
LB	14.9	978	16.4	20.1	516	6.4	5.2	218	10.5
BE		1317	22.0		772	9.6		352	17.0
UB		1774	29.7		1145	14.2		566	27.3

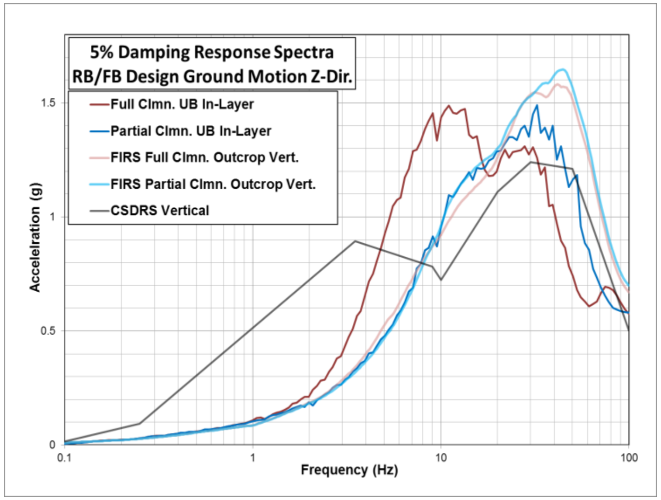
Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Input Ground motion at RB/FB bottom for SSI analyses of UB Profiles



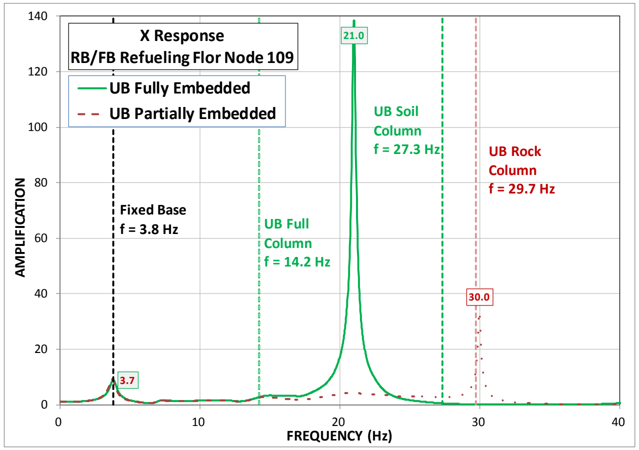


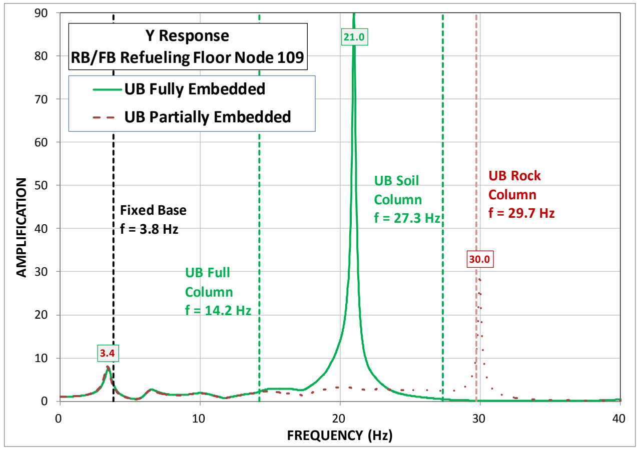
In-layer motions enhanced to meet NEI check

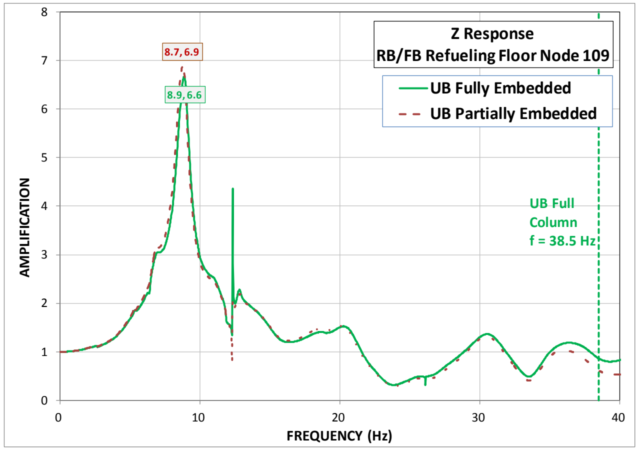


Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Preliminary transfer functions for RB/FB Refueling Floor response







Small effects of SSI and soil embedment on RB/FB response

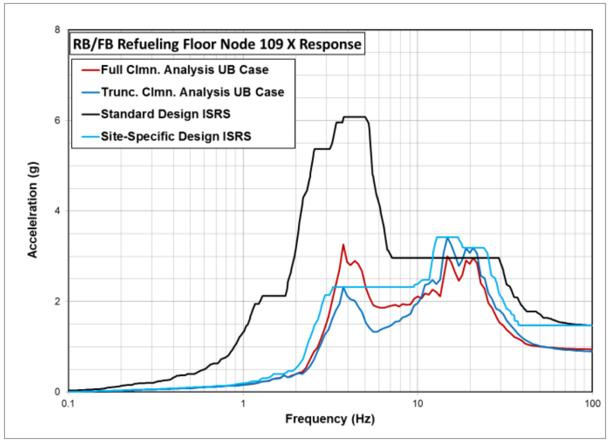
Addition of embedment has no effect on responses at frequencies close to natural frequencies of RB/FB structures

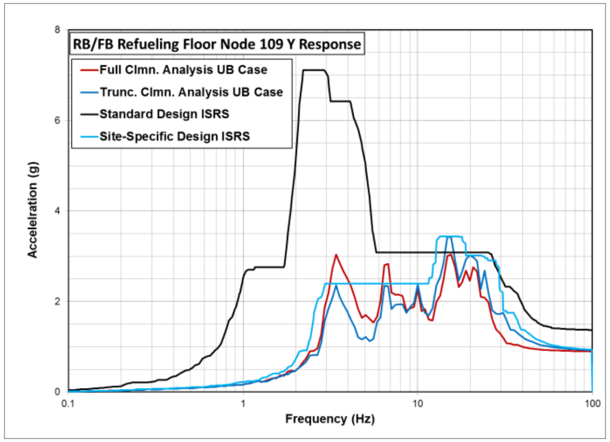
Large peaks in transfer function reflect different embedment soil column frequencies

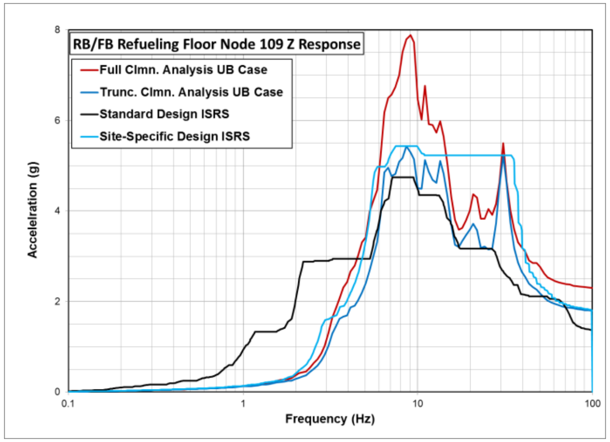
Dominion

Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Preliminary RB/FB Refueling Floor ISRS Results







Addition of soil embedment resulted in no significant ISRS peak frequency shifts

Some vertical ISRS peaks close to natural frequency of RB/FB structure exceed design basis ISRS

Exceedances reflect ≈70% higher energy content of input in-layer motion resulting from NEI check

Dominion

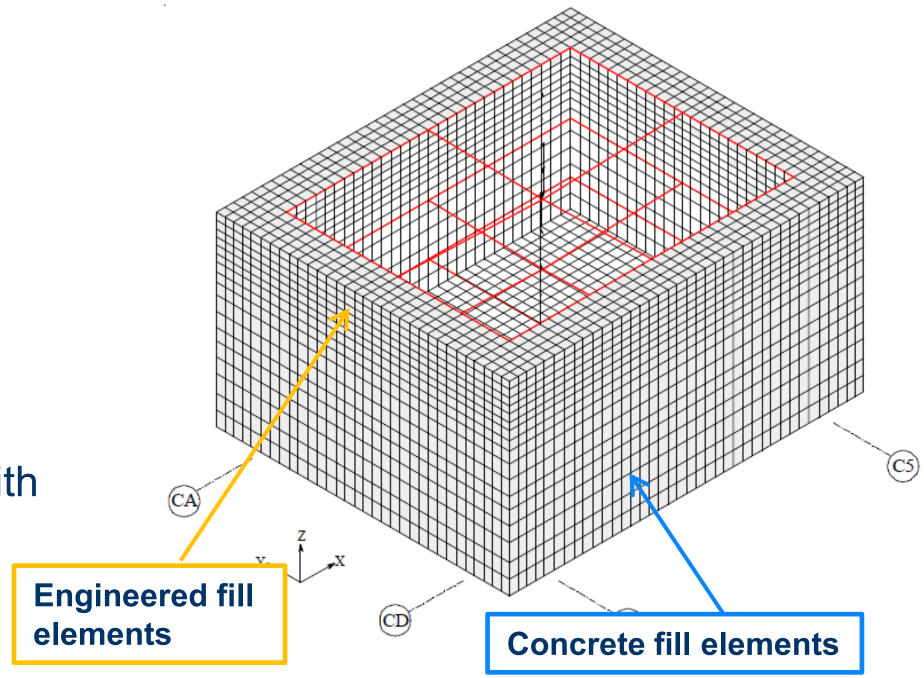
Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Effects of soil embedment on CB design evaluated based on results of SSI analyses of model embedded in full column profiles representing strain-compatible dynamic properties of in-situ rock and soil

Engineered fill and concrete fill around RB/FB included in the structural model

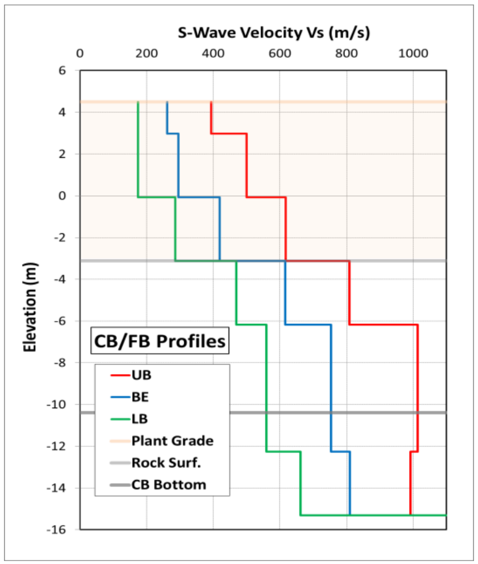
Structural model includes 4.9 ft thick block of concrete fill below CB basemat to Zone III/IV

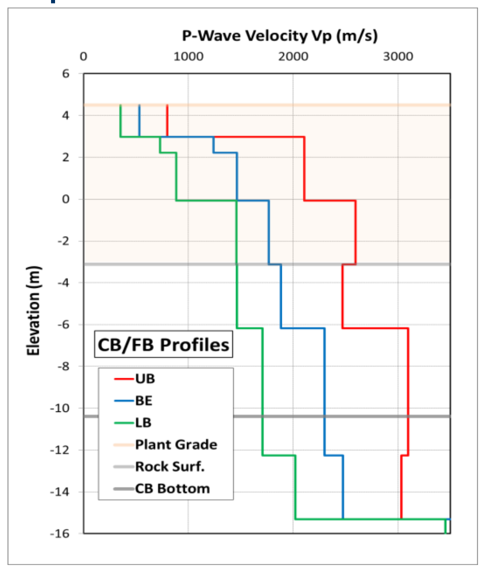
Model with UB soil properties capable of transmitting waves with frequencies higher than 54 Hz (24 Hz for LB soil properties)

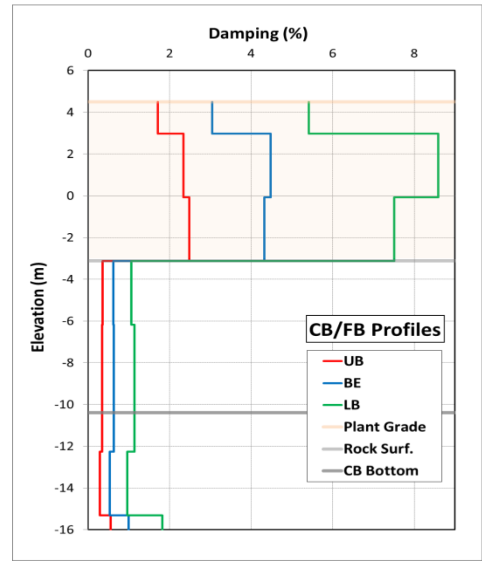


Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- CB Embedment Soil Properties







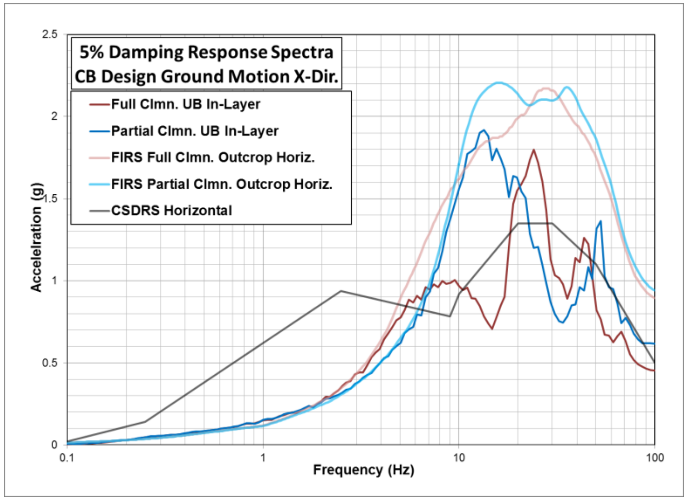
CB Embedment Depths and Shear Column Frequencies

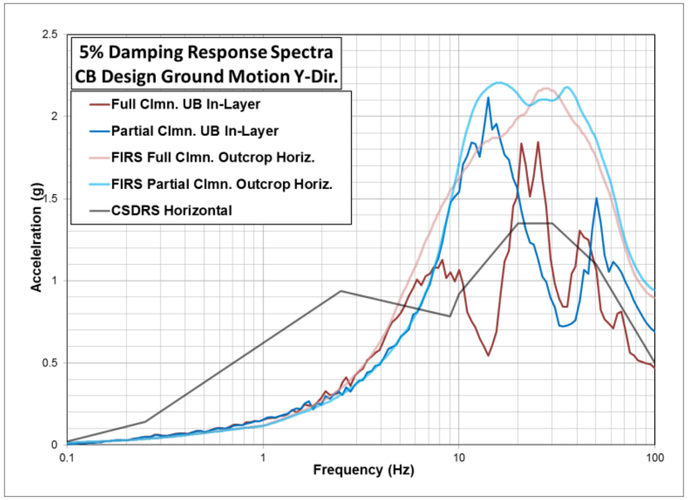
Soil Case	Rock Embedment			Full Embedment			Soil Embedment		
	Depth	Vs ave	fsc	Depth	Vs ave	fsc	Depth	Vs ave	fsc
	m	m/s	Hz	m	m/s	Hz	m	m/s	Hz
LB		518	18.9		292	4.9		206	6.8
BE	7.3	689	25.1	14.9	439	7.3	7.6	325	10.7
UB		917	33.4		653	10.9		512	16.8

Dominion

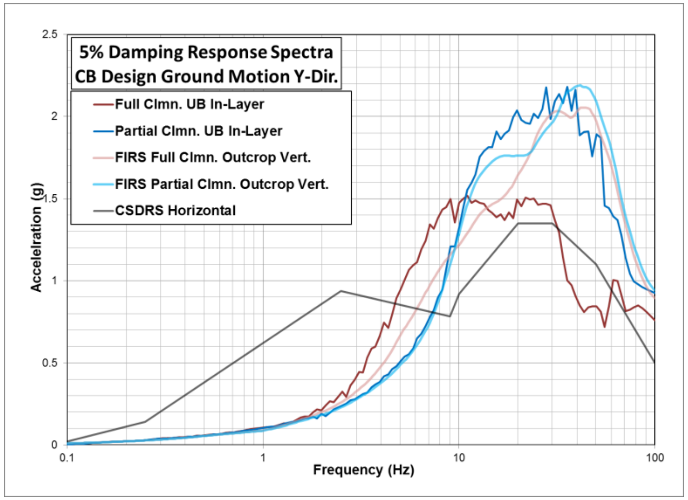
Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Input Ground motion at CB bottom for SSI analyses of UB Profiles



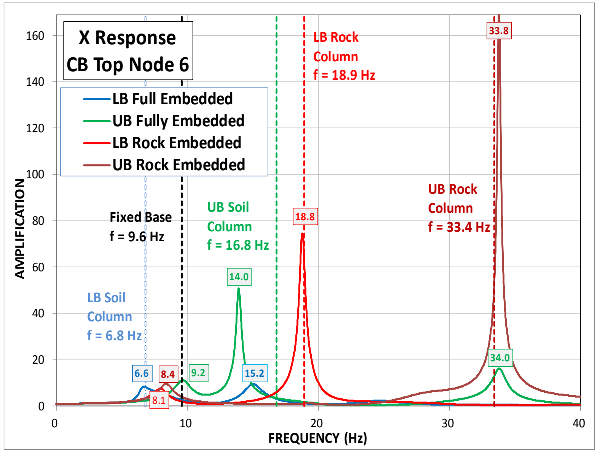


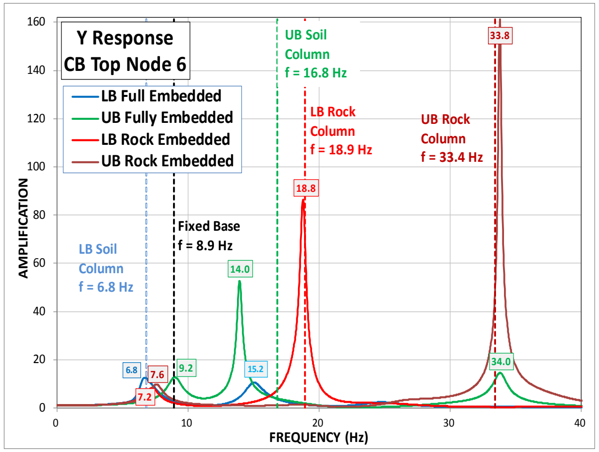
In-layer motions enhanced to meet NEI check

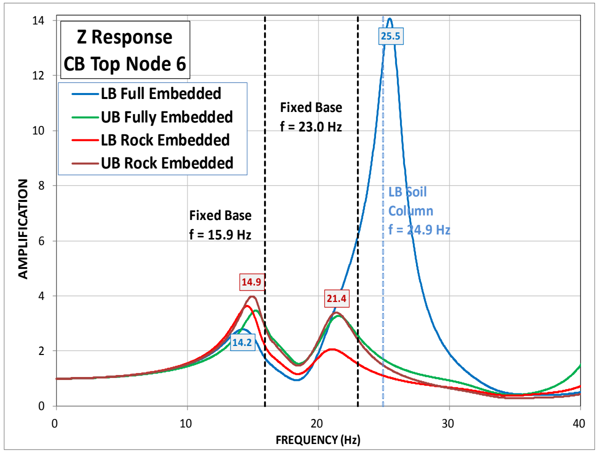


Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Preliminary transfer functions for CB Roof Response





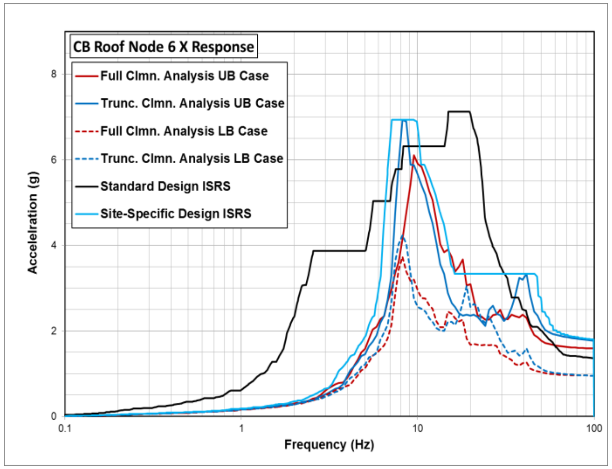


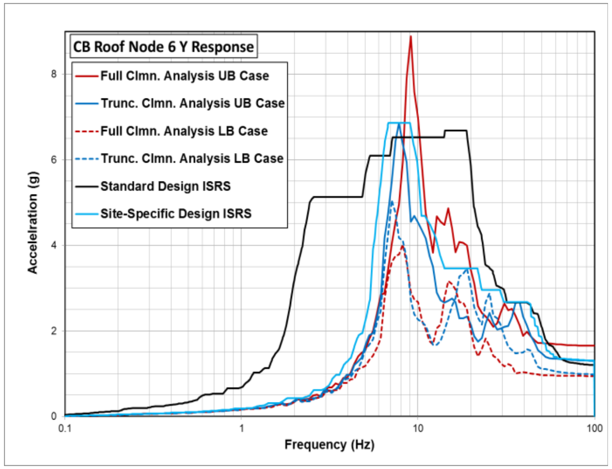
Addition of embedment can affect responses of deeply embedded CB structure at frequencies close to natural frequencies

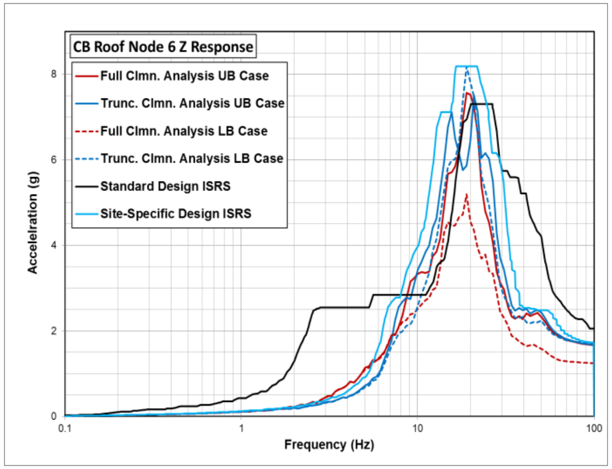
Large peaks in transfer function reflect different embedment soil column frequencies

Sensitivity Studies: Section 3.7.2
Soil Embedment Sensitivity Study

- Preliminary CB Roof ISRS Results







Addition of soil embedment shifted ISRS peaks to higher frequencies

Some of horizontal ISRS peaks exceed design basis ISRS due to SSI resonance effects

Sensitivity Studies: Section 3.7.2
Next Steps

- Preliminary results indicate that ISRS at select locations and frequencies may exceed those presented in FSAR for RB/FB and CB
- It may be necessary to revise FSAR to supplement Unit 3 RB/FB and CB seismic design basis with SSI responses obtained from fully embedded models
- Unit 3 RB/FB and CB site-specific design basis will be developed based on envelope of responses from:
  - Partially embedded models
  - Fully embedded models
- Description of SSI analyses and responses of partially embedded models will remain in FSAR
- Additional analyses are being performed for:
  - RB/FB for LB and BE full column subgrade profile
  - CB for BE full column subgrade profile

Modified Subtraction Method (MSM) Benchmarking

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

- Sensitivity studies are based on results of SSI and SSSI analyses performed on large numerical models
  - Inclusion of softer in-situ soil and engineered fill above Unit 3 Zone III rock in fully embedded models requires more refined mesh to enable transmittal of waves with high frequencies
  - Combined model for SSSI analyses include two buildings and excavated soil between the buildings
- SSI sensitivity analyses are performed using MSM implemented by specifying as interaction nodes:
  - All nodes at sides and bottom of excavated volume
  - All the nodes at top (ground level) surface of the excavated volume
  - Nodes on horizontal planes in the interior of the excavated volume

Dominion

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Use of MSM for sensitivity study SSI and SSSI analyses is verified based on:

- Results of MSM benchmarking analysis of Unit 3 FWSC model that demonstrated negligible differences between results of SSI analysis performed using DM and MSM with 7 (1 internal) planes of interaction nodes
- Results of ESBWR Fermi Unit 3 (EF3) benchmarking analyses that demonstrated accuracy of MSM analysis of RB/FB, CB and FWSC models used for EF3 COLA SSI and SSSI analyses of full column profiles
- Unit 3 sensitivity analyses use enhanced MSM models with at least two additional planes of interaction nodes in excavated soil volume interior

Dominion

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Unit 3 MSM benchmarking analysis was performed as follows:

a. Determine initial locations of the internal plane(s) of interaction nodes based on calculations of shear waves' equivalent arrival time

b. Perform Eigen value analyses of excavated volumes for RB/FB, CB fully embedded models and FWSC model by establishing pinned support conditions at interaction nodes

c. Based on the results of Eigen value analysis, determine among Unit 3 RB/FB, CB and FWSC models, the model that is most sensitive to errors due to MSM approximation

d. Perform benchmark analysis on the FWSC model, which is most sensitive to errors due to MSM approximation

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Optimal location of plane of interaction nodes is determined based on shear column equal arrival time calculations

Calculation of Location of Internal Plane of Interaction Nodes for FWSC Excavated Volume

Layer	Elevation at Top of Layer (m)	Elevation at Bottom of Layer (m)	Shear Wave Velocity, Vs (m/sec)	Thickness, h (m)	Traveling Time, h/Vs (sec)	Total Traveling Time, Σ(h/Vs) (sec)
1	2.15	-1.60	343	3.75	0.01093	0.01654
2	-1.60	-4.25	473	2.65	0.00561	
2	-4.25	-6.78	473	2.53	0.00534	0.01653
3	-6.78	-8.00	593	1.22	0.00206	
4	-8.00	-9.52	810	1.52	0.00188	
5	-9.52	-14.40	1001	4.88	0.00488	
6	-14.40	-16.84	1028	2.44	0.00237	

Note: Optimal location of interaction node plane is at EL -4.25 m.

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

- Preliminary results of Eigen value analyses indicate that FWSC excavated volume model is most sensitive to errors due to MSM approximation

Model	7 planes		8 planes		9 planes	
	Freq.	Dir.	Freq.	Dir.	Freq.	Dir.
RB/FB	59.1 Hz	X				
CB	41.9 Hz	X	51.0 Hz	X		
FWSC	32.8 Hz	X & Y	35.3 Hz	X	56.0	Y

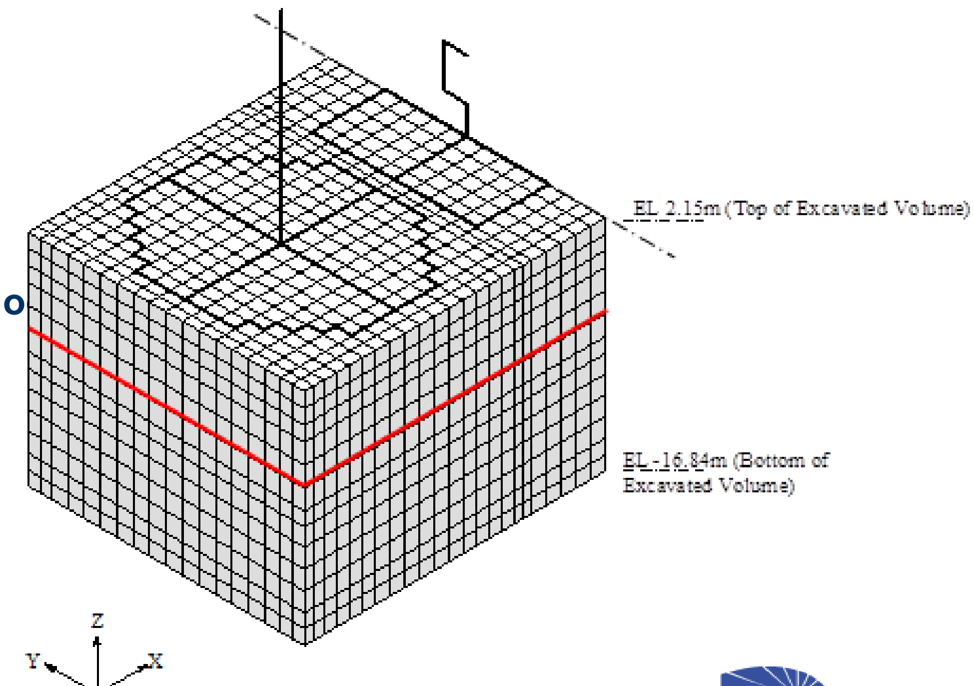
Dominion

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

MSM benchmarking performed based on responses obtained from two analyses of FWSC using:

- MSM with 7 planes of interaction nodes
- Direct Method (DM) with all nodes of excavated volume specified as interaction nodes

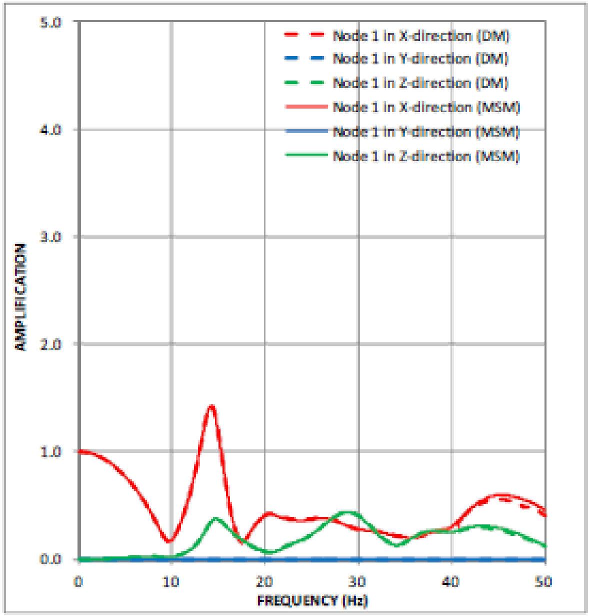
MSM Excavated Volume Mo



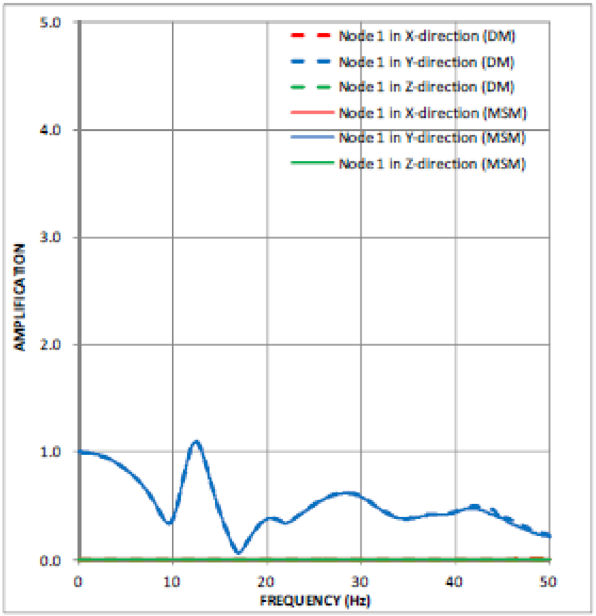
Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Comparisons of preliminary transfer function results show negligible differences between MSM and DM solutions

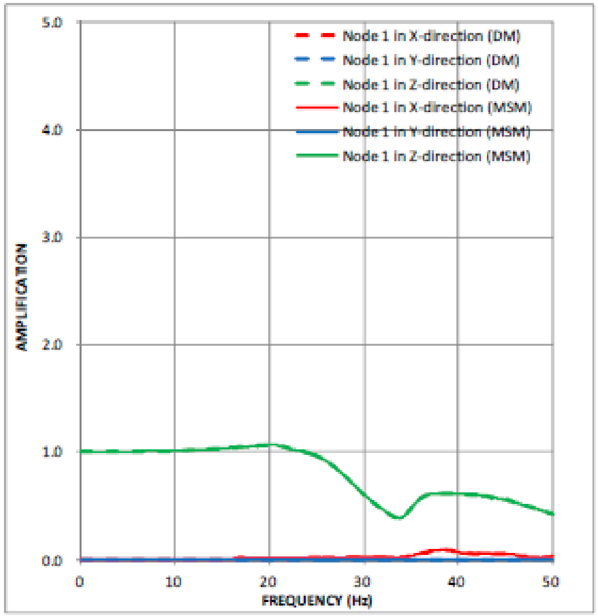
FWSC Basemat Response



X-Direction Earthquake



Y-Direction Earthquake



Z-Direction Earthquake

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Comparisons of preliminary maximum acceleration results show negligible differences (<1%) between MSM and DM solutions

FWSC Maximum Nodal Accelerations

MSM						DM						Ratio MSM/DM					
evation (m)	Node No.	Stick Model	X-dir. (g)	Y-dir. (g)	Z-dir. (g)	Elevation (m)	Node No.	Stick Model	X-dir. (g)	Y-dir. (g)	Z-dir. (g)	Elevation (m)	Node No.	Stick Model	X-dir.	Y-dir.	Z-dir.
19.70	10	FWS	1.82	1.36	0.75	19.70	10	FWS	1.82	1.37	0.75	19.70	10	FWS	100%	100%	100
17.25	9	FWS	1.69	1.27	0.75	17.25	9	FWS	1.69	1.27	0.75	17.25	9	FWS	100%	100%	100
15.53	8	FWS	1.55	1.17	0.74	15.53	8	FWS	1.55	1.17	0.74	15.53	8	FWS	100%	100%	100
13.81	7	FWS	1.39	1.06	0.73	13.81	7	FWS	1.39	1.06	0.73	13.81	7	FWS	100%	100%	100
12.10	6	FWS	1.23	0.94	0.72	12.10	6	FWS	1.22	0.94	0.72	12.10	6	FWS	100%	100%	100
11.00	5	FWS	1.11	0.86	0.71	11.00	5	FWS	1.11	0.86	0.71	11.00	5	FWS	100%	100%	100
9.90	4	FWS	0.99	0.80	0.70	9.90	4	FWS	0.99	0.80	0.70	9.90	4	FWS	100%	100%	100
8.81	3	FWS	0.88	0.78	0.69	8.81	3	FWS	0.88	0.78	0.69	8.81	3	FWS	100%	100%	100
6.73	2	FWS	0.61	0.68	0.66	6.73	2	FWS	0.61	0.68	0.66	6.73	2	FWS	100%	100%	100
4.65	8002	FWSC	0.46	0.57	0.63	4.65	8002	FWSC	0.46	0.57	0.63	4.65	8002	FWSC	100%	100%	100
2.15	8001	FWSC	0.47	0.52	0.69	2.15	8001	FWSC	0.47	0.52	0.69	2.15	8001	FWSC	100%	99%	100
19.70	11	Oscillator	--	--	1.75	19.70	11	Oscillator	--	--	1.74	19.70	11	Oscillator	--	--	100
12.10	60	Oscillator	0.10	0.07	--	12.10	60	Oscillator	0.10	0.07	--	12.10	60	Oscillator	100%	100%	--
8.81	30	Oscillator	0.88	0.78	--	8.81	30	Oscillator	0.88	0.78	--	8.81	30	Oscillator	100%	100%	--

evation (m)	Node No.	Stick Model	X-dir. (g)	Y-dir. (g)	Z-dir. (g)	Elevation (m)	Node No.	Stick Model	X-dir. (g)	Y-dir. (g)	Z-dir. (g)	Elevation (m)	Node No.	Stick Model	X-dir.	Y-dir.	Z-dir.
8.25	405	FPE	0.54	0.83	0.61	8.25	405	FPE	0.53	0.84	0.61	8.25	405	FPE	102%	99%	100
6.45	402	FPE	0.50	0.71	0.60	6.45	402	FPE	0.49	0.71	0.60	6.45	402	FPE	101%	100%	100

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Comparisons of preliminary maximum displacements results show negligible differences (<1%) between MSM and DM solutions

FWSC Maximum Displacements Relative to Free Field

MSM

n	Node No.	Stick Model	X -dir. (mm)	Y-dir. (mm)	Z-dir. (mm)
0	10	FWSC	2.04	1.39	0.17
5	9	FWSC	1.90	1.30	0.17
3	8	FWSC	1.77	1.20	0.17
1	7	FWSC	1.63	1.09	0.16
0	6	FWSC	1.58	1.00	0.16
0	5	FWSC	1.61	0.94	0.15
0	4	FWSC	1.63	0.89	0.15
1	3	FWSC	1.65	0.85	0.14
3	2	FWSC	1.70	0.89	0.13
5	8002	FWSC	1.79	1.05	0.13
5	8001	FWSC	1.77	1.08	0.46
0	11	Oscillator	--	--	0.45
0	60	Oscillator	438.60	278.50	--
1	30	Oscillator	1.65	0.85	--

n	Node No.	Stick Model	X -dir. (mm)	Y-dir. (mm)	Z-dir. (mm)
5	405	FPE	1.81	0.97	0.05
5	402	FPE	1.82	1.03	0.08

DM

Elevation (m)	Node No.	Stick Model	X -dir. (mm)	Y-dir. (mm)	Z-dir. (mm)
19.70	10	FWSC	2.04	1.39	0.17
17.25	9	FWSC	1.90	1.30	0.17
15.53	8	FWSC	1.77	1.20	0.17
13.81	7	FWSC	1.63	1.10	0.16
12.10	6	FWSC	1.58	1.01	0.16
11.00	5	FWSC	1.61	0.94	0.15
9.90	4	FWSC	1.63	0.90	0.15
8.81	3	FWSC	1.66	0.85	0.14
6.73	2	FWSC	1.70	0.90	0.13
4.65	8002	FWSC	1.79	1.06	0.13
2.15	8001	FWSC	1.77	1.08	0.46
19.70	11	Oscillator	--	--	0.45
12.10	60	Oscillator	438.60	278.70	--
8.81	30	Oscillator	1.66	0.85	--

Elevation (m)	Node No.	Stick Model	X -dir. (mm)	Y-dir. (mm)	Z-dir. (mm)
8.25	405	FPE	1.81	0.98	0.05
6.45	402	FPE	1.82	1.04	0.08

Ratio MSM/DM

Elevation (m)	Node No.	Stick Model	X -dir.	Y-dir.
19.70	10	FWSC	100%	100%
17.25	9	FWSC	100%	100%
15.53	8	FWSC	100%	100%
13.81	7	FWSC	100%	99%
12.10	6	FWSC	100%	99%
11.00	5	FWSC	100%	100%
9.90	4	FWSC	100%	100%
8.81	3	FWSC	100%	100%
6.73	2	FWSC	100%	99%
4.65	8002	FWSC	100%	100%
2.15	8001	FWSC	100%	100%
19.70	11	Oscillator	--	--
12.10	60	Oscillator	100%	100%
8.81	30	Oscillator	100%	100%

Elevation (m)	Node No.	Stick Model	X -dir.	Y-dir.
8.25	405	FPE	100%	99%
6.45	402	FPE	100%	100%

Dominion

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Comparisons of preliminary maximum element force results show negligible differences (<3%) between MSM and DM solutions

FWSC Maximum Member Forces

MSM

MSM/DM

Elevation (m)	Node No.	Elem No.	Shear X-dir. (MN)	Shear Y-dir. (MN)	Moment X-dir. (MN-m)	Moment Y-dir. (MN-m)	Torsion (MN-m)
19.70	10	9			2.3	1.6	
17.25	9		3.9	2.9	11.7	8.7	0.61
17.25	9	8			16.0	12.0	
15.53	8		9.6	7.2	32.5	24.3	1.86
15.53	8	7			36.8	27.6	
13.81	7		13.4	10.1	59.8	44.9	3.05
13.81	7	6			64.0	48.0	
12.10	6		16.8	12.7	92.8	69.7	4.13
12.10	6	5			96.0	72.1	
11.00	5		19.3	14.5	117.2	88.1	4.89
11.00	5	4			119.7	89.9	
9.90	4		21.0	15.9	142.7	107.5	5.42
9.90	4	3			145.0	109.1	
8.81	3		22.6	17.1	169.6	127.9	5.87
8.81	3	2			172.6	130.2	
6.73	2		37.0	28.8	249.4	190.0	6.40
6.73	2	1			252.5	192.5	
4.65	1		38.7	30.3	333.0	255.6	6.78

Elevation (m)	Node No.	Elem No.	Shear X-dir. (MN)	Shear Y-dir. (MN)	Moment X-dir. (MN-m)	Moment Y-dir. (MN-m)	Torsion (MN-m)
8.25	405	402,			1.01	4.62	
4.65	404	401	2.73	4.13	8.57	15.43	3.79

DM

Elevation (m)	Node No.	Elem No.	Shear X-dir. (MN)	Shear Y-dir. (MN)	Moment X-dir. (MN-m)	Moment Y-dir. (MN-m)	Torsion (MN-m)
19.70	10	9			2.3	1.6	
17.25	9		3.9	2.9	11.7	8.8	0.63
17.25	9	8			16.0	12.0	
15.53	8		9.6	7.2	32.5	24.4	1.91
15.53	8	7			36.9	27.7	
13.81	7		13.4	10.1	59.9	45.0	3.14
13.81	7	6			64.1	48.2	
12.10	6		16.8	12.7	92.8	69.8	4.25
12.10	6	5			96.1	72.3	
11.00	5		19.3	14.6	117.3	88.3	5.04
11.00	5	4			119.7	90.2	
9.90	4		21.0	15.9	142.8	107.7	5.59
9.90	4	3			145.0	109.4	
8.81	3		22.6	17.1	169.6	128.2	6.06
8.81	3	2			172.6	130.4	
6.73	2		37.0	28.7	249.3	190.2	6.62
6.73	2	1			252.4	192.8	
4.65	1		38.7	30.3	332.8	255.8	7.02

Elevation (m)	Node No.	Elem No.	Shear X-dir. (MN)	Shear Y-dir. (MN)	Moment X-dir. (MN-m)	Moment Y-dir. (MN-m)	Torsion (MN-m)
8.25	405	402,			1.03	4.63	
4.65	404	401	2.7	4.1	8.40	15.49	3.68

Ratio

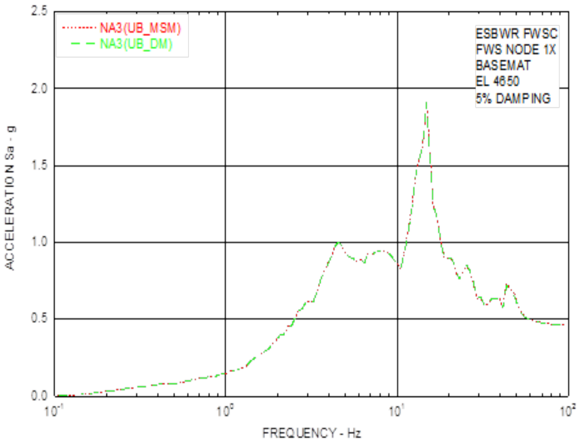
Elevation (m)	Node No.	Elem No.	Shear X-dir.	Shear Y-dir.	Moment X-dir.	Moment Y-dir.	Torsion
19.70	10	9			101%	101%	
17.25	9		100%	100%	100%	100%	97%
17.25	9	8			100%	100%	
15.53	8		100%	100%	100%	100%	97%
15.53	8	7			100%	100%	
13.81	7		100%	100%	100%	100%	97%
13.81	7	6			100%	100%	
12.10	6		100%	100%	100%	100%	97%
12.10	6	5			100%	100%	
11.00	5		100%	100%	100%	100%	97%
11.00	5	4			100%	100%	
9.90	4		100%	100%	100%	100%	97%
9.90	4	3			100%	100%	
8.81	3		100%	100%	100%	100%	97%
8.81	3	2			100%	100%	
6.73	2		100%	100%	100%	100%	97%
6.73	2	1			100%	100%	
4.65	1		100%	100%	100%	100%	97%

Elevation (m)	Node No.	Elem No.	Shear X-dir.	Shear Y-dir.	Moment X-dir.	Moment Y-dir.	Torsion
8.25	405	402,			98%	100%	
4.65	404	401	102%	100%	102%	100%	103%

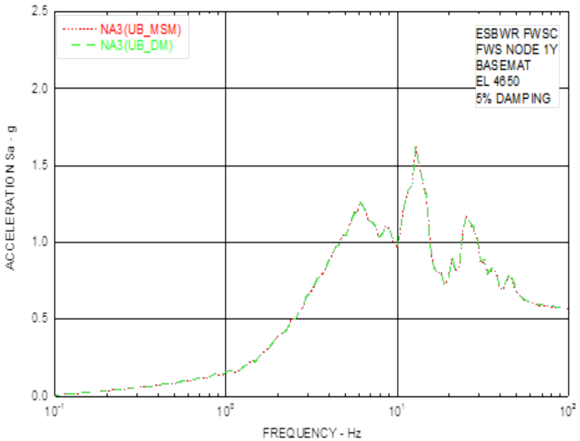
Sensitivity Studies: Section 3.7.2
MSM Benchmarking

- Comparisons of preliminary ISRS results show MSM and DM solutions to be virtually identical

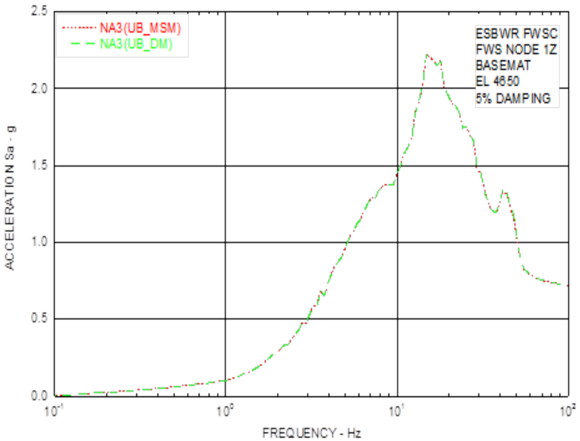
FWSC Basemat



X-Direction Earthquake



Y-Direction Earthquake



Z-Direction Earthquake

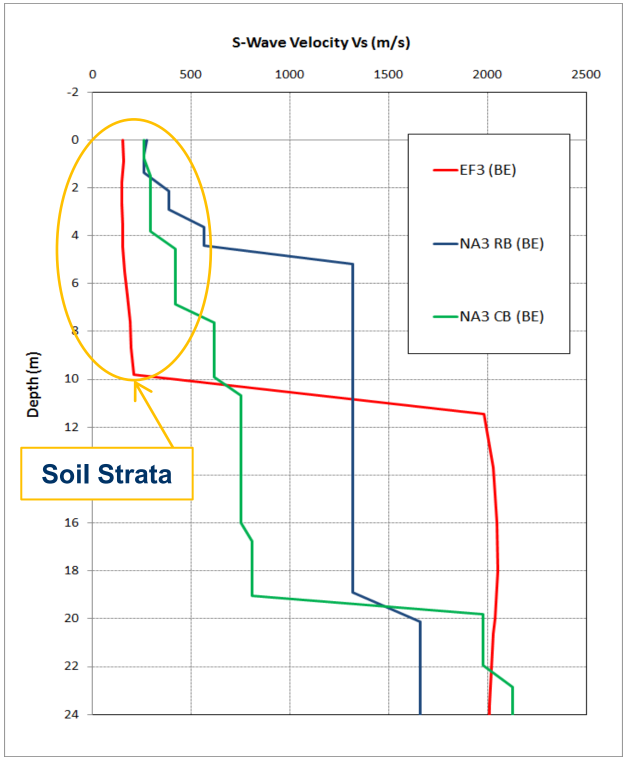
Dominion

Sensitivity Studies: Section 3.7.2
MSM Benchmarking

Conclusions of EF3 MSM benchmark studies are applicable for Unit 3 sensitivity analyses because:

- Properties of structural SSI models used for two COLAs are almost identical
- Geometry and dimensions of excavated volumes are almost identical with similar mesh configurations
- Unit 3 excavated volume models are less sensitive to errors due to MSM approximation due to considerably higher stiffness properties of Unit 3 embedment soil

Comparison of EF3 and Unit 3 (NA3) shear velocity profiles



Questions?