Luminant MITSUBISHI HEAVY INDUSTRIES, LTD. Dominion US-APWR

US-APWR

Modifications to Standard Plant: Introduction

September 22, 2011

Mitsubishi Heavy Industries, Ltd.

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Purpose of Meeting

- During March 2011, a number of significant changes in seismic analysis were implemented, including changing from a Lumped Mass Stick Model (LMSM) to Finite Element (FE) Model for the R/B Complex SSI Analysis and performing bounding analyses with respect to cracked and uncracked concrete conditions

- During implementation of this new methodology, a number of design challenges arose which have been tracked back to unique details in soil profiles and the original time history input

Purpose of Meeting

- Today we are presenting changes and enhancements to the design inputs to mitigate these design challenges and continue to maintain required safety margins of the US-APWR Standard Plant
- We are also presenting changes to the plant layout to address issues associated with the original 4 inch gap between structures
- Stability analyses are ongoing, but indications are that foundations of Standard Plant structures will require shear keys

Introduction

- On March 31, 2011 the seismic task force held a public meeting with the NRC to identify twelve major topics and an associated path forward for each reflecting the current status
- During June 2011, the first stage of Technical Reports identifying methodology changes was submitted to the staff for review
- On June 15, 2011 and in subsequent conference calls, a path forward for the Containment Internal Structure (CIS) was established

Introduction

- The comprehensive path forward beginning on March 31, 2011 involved employing a conservative methodology with respect to concrete cracking considerations for SSI analyses:
  - ✓ Full stiffness with OBE damping
  - ✓ Reduced stiffness (up to 50% of gross cross section properties considered) with SSE damping
  - ✓ Envelope of responses for the two stiffness cases and for all generic soil profiles used to develop in-structure response spectra (ISRS) results

Issue Statement

- The SSI analyses challenges which occurred as a result of the conservative path forward include:
  - ✓ Unfavorable ISRS results at critical component locations which are pronounced for soil profiles 560-100 and 560-200
  - ✓ Sliding stability challenges for standard plant structures
  - ✓ High bearing pressure demands (low contact ratio due to foundation uplift)
  - ✓ Calculations indicate a required increase in the existing gap between structures

Current Status

- The SSI analyses used in DCD Rev. 3 considered the following inputs:
  - ✓ 8 generic soil profiles (developed using unpublished rock degradation curves)
  - ✓ Acceleration time histories of input design ground motion based on Northridge seismic event
  - ✓ 4 inch gap between all standard plant structures
- Due in part to changes in design basis methodology that were presented in March 2011, certain inputs have been identified which impact the standard design

Resolution Proposal

- The basic SSI analyses inputs used in DCD Rev. 3 shall be modified as follows:
  - ✓ *Modification to generic soil profiles:* a revision to the database of US-APWR standard plant generic profiles will be performed to eliminate excessive peaks in design ISRS and address staff concerns noted in RAI's 821-5984 and 559-5133

Resolution Proposal

- The basic SSI analyses inputs used in DCD Rev. 3 shall be modified as follows (continued):
  - ✓ *Modification to input ground motion acceleration time history:* the current time histories that are based on the Northridge earthquake seed do not provide as good a fit to the CSDRS as the revised acceleration time histories based on Nahanni earthquake seed; changing the input ground motion time histories resolves challenges associated with contact ratio and subsequent bearing pressures

Resolution Proposal

- The basic SSI analyses inputs used in DCD Rev. 3 shall be modified as follows (continued):
  - ✓ *Modification to plant layout:* since the 4” gap is being challenged by recent results of analyses, a larger 16” gap between all standard plant structures and foundations will be established; this change will resolve the negative cumulative effects of gap closure including seismic structural displacement, settlement/tilt, and sliding displacement (shear key engagement)

Resolution Proposal

- The basic SSI analyses inputs used in DCD Rev. 3 shall be modified as follows (continued):
  - ✓ *Modification to foundations:* since sliding stability challenges occur despite the above input modifications, shear keys will be introduced within the standard plant structural stability calculations to ensure a factor of safety against sliding of 1.1; standard plant structures described in the DCD will feature shear keys

Resolution Proposal

Design Challenges	Resolution Proposal: Benefit and Effects of Modifications			
	Modification to Generic Soil Profiles	**Modification to Acceleration Time History**	**Modification to Plant Layout**	**Modification to Foundations - Shear Keys**
Sliding Stability	Minor Benefit	Minor Benefit	N/A	**Major Benefit**
Contact Area / Bearing Pressure	**Major Benefit**	**Major Benefit**	N/A	N/A
Address RAI concerns	**Major Benefit**	N/A	N/A	N/A
Gap Between Structures	N/A	N/A	**Major Benefit**	N/A
ISRS at Critical Locations	**Major Benefit**	Minor Benefit	N/A	N/A

Deliverables

- Relevant deliverables will be identified in each presentation segment with additional detail regarding the design input modifications
  - ✓ *Modification to generic soil profiles*
  - ✓ *Modification to acceleration time history*
  - ✓ *Modification to plant layout*
- The need to perform modifications to foundations including the introduction of shear keys will be assessed for each standard plant structure
- Impacts on existing technical reports, calculation reports available for audit, and DCD chapters will be presented in the afternoon session

Summary

- Results from SSI and stability analyses of standard plant structures have led to modifications to generic soil profiles, input ground motion acceleration time histories, plant layout, and foundations
- Methodology remains unchanged
- Re-performing analyses cases with input changes identified earlier in the presentation
- Results in updates to Technical Reports, Calculation Reports, and the DCD

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Modifications to Standard Plant: Generic Soil Profiles

September 22, 2011

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Issue Statement

- Changes made in design basis structural models and methodology for development of seismic design basis resulted in amplification of the seismic responses for some generic soil profiles thus impacting the available design margins for some critical standard plant components.

Issue Statement

- In RAI's 821-5984 and 559-5133, NRC noted the following concerns regarding the generic soil profiles used for site-independent soil-structure interaction (SSI) analyses of US-APWR standard plant Category I and II buildings are as follows:
  - There is significant decrease of strain compatible stiffness properties of some of generic profiles with depth.
  - Site response analyses used unpublished degradation curves to represent strain compatible properties of rock materials
  - Selection of base line profiles of small strain soil properties may not provide adequate representation of variety of geological conditions within continental U.S.
  - Demonstrate that selected generic profiles provide a sufficiently wide range of possible SSI responses to ensure wide applicability of US-APWR standard design

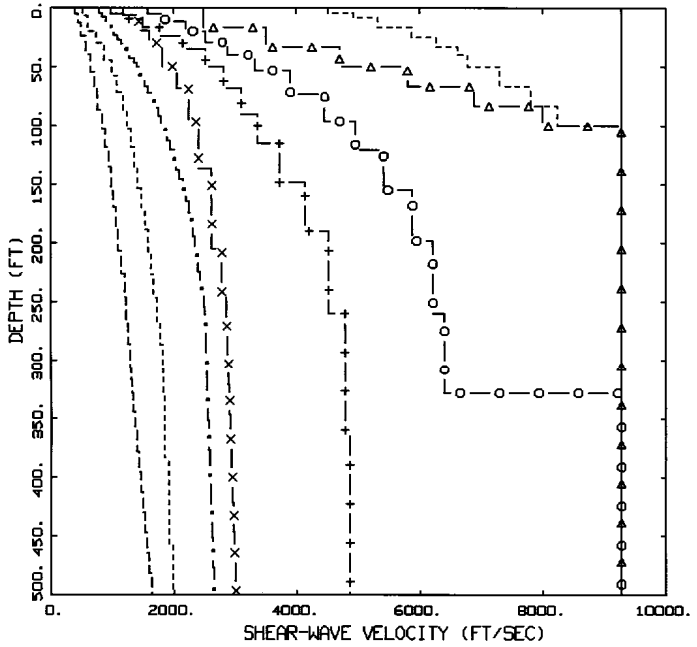
Current Status

- **In MUAP 10006(R1), site independent SSI analyses are performed for eight generic soil profiles developed as documented in MUAP 10001(R2):**
  - 270-200 (Top Strata Nominal Vs =270 m/s with 200 ft depth to baserock)
  - 270-500 (Top Strata Nominal Vs =270 m/s with 500 ft depth to baserock)
  - 560-100 (Top Strata Nominal Vs =560 m/s with 100 ft depth to baserock)
  - 560-200 (Top Strata Nominal Vs =560 m/s with 200 ft depth to baserock)
  - 560-500 (Top Strata Nominal Vs =560 m/s with 500 ft depth to baserock)
  - 900-100 (Top Strata Nominal Vs =900 m/s with 100 ft depth to baserock)
  - 900-200 (Top Strata Nominal Vs =900 m/s with 200 ft depth to baserock)
  - 2032-100 (Top Strata Nominal Vs =2032 m/s with 100 ft depth to baserock)
- **Generic soil profiles represent strain compatible properties of submerged soil, i.e. location of water table is set at plant grade elevation**
- **Generic soil profiles are truncated (≈ 40 ft) to remove the embedment soil**

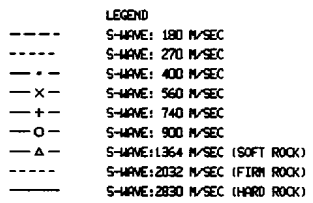
Current Status

➢ Development of Generic Profiles

- ✓ Generic profiles developed from CENA database of profiles
- ✓ Base profiles are selected with top strata nominal S wave velocities of 270 m/s, 560 m/s, 900 m/s and 2032 m/s
- ✓ Baserock set at depths of 100 ft, 200 ft or 500 ft
- ✓ Baserock model for softer profiles with nominal Vs ≤ 560 m/s represented by 1000 ft thick layer of soft rock resting on hard basement rock with Vs = 2.83 km/s

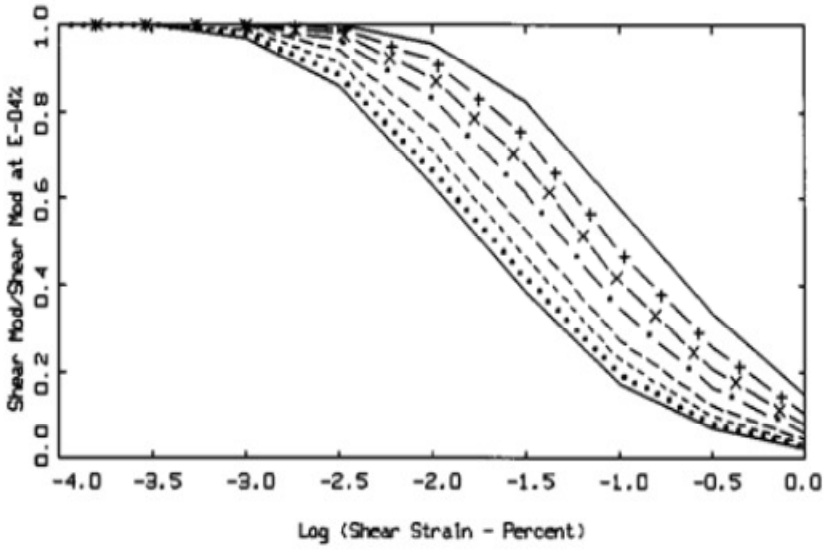


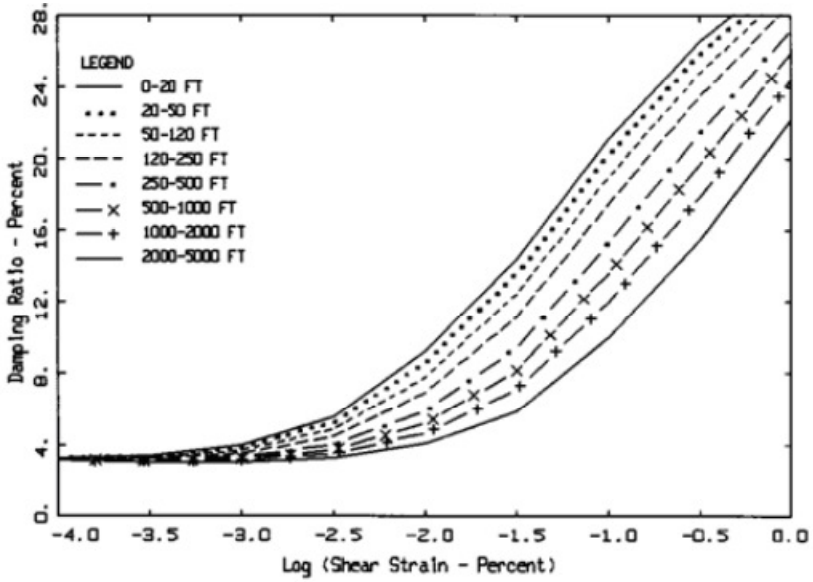
CENA SHEAR WAVE PROFILES



Current Status

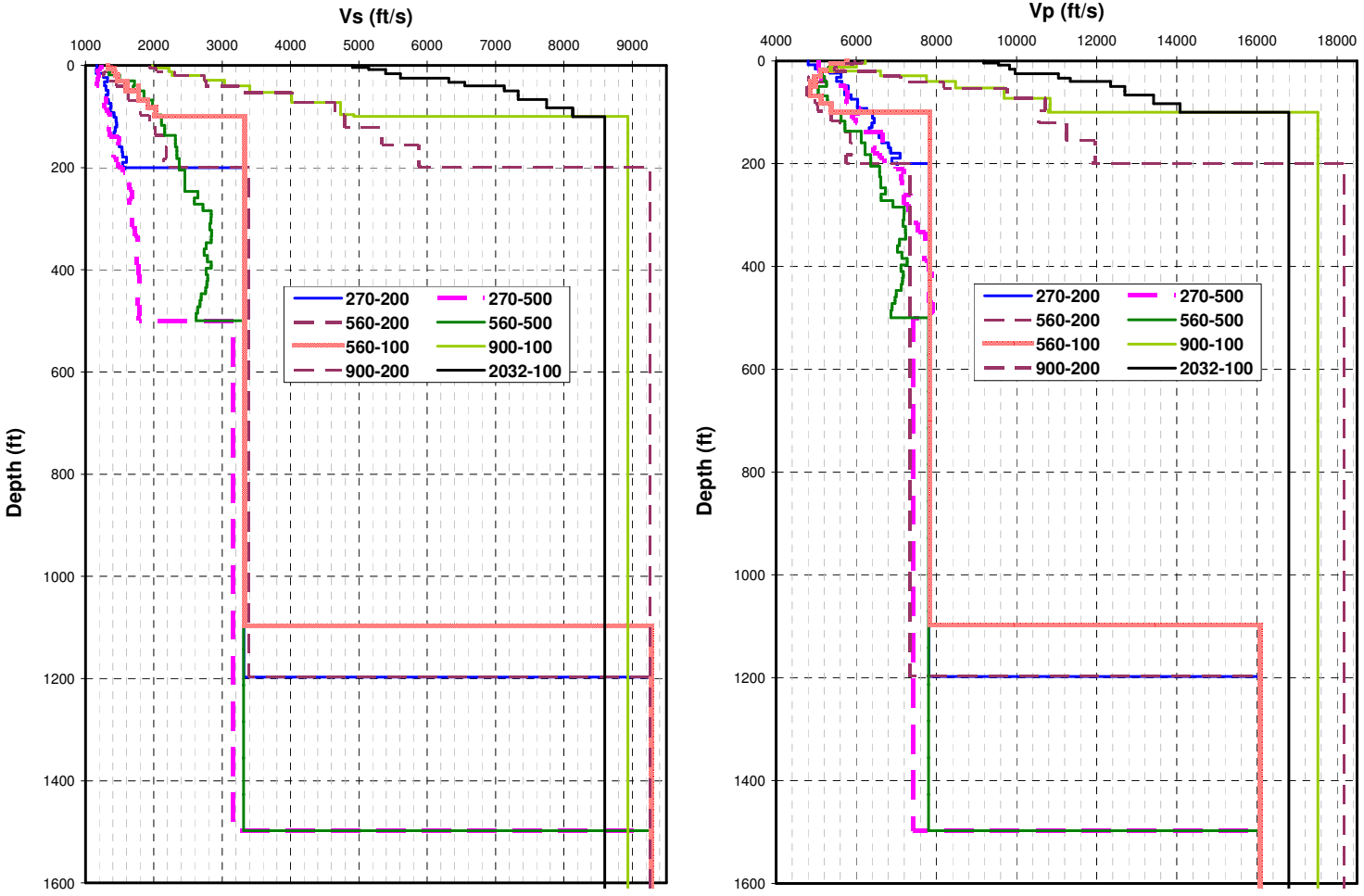
- Degradation curves used for profiles with nominal Vs ≥ 560 m/s represent strain dependent properties of rock materials





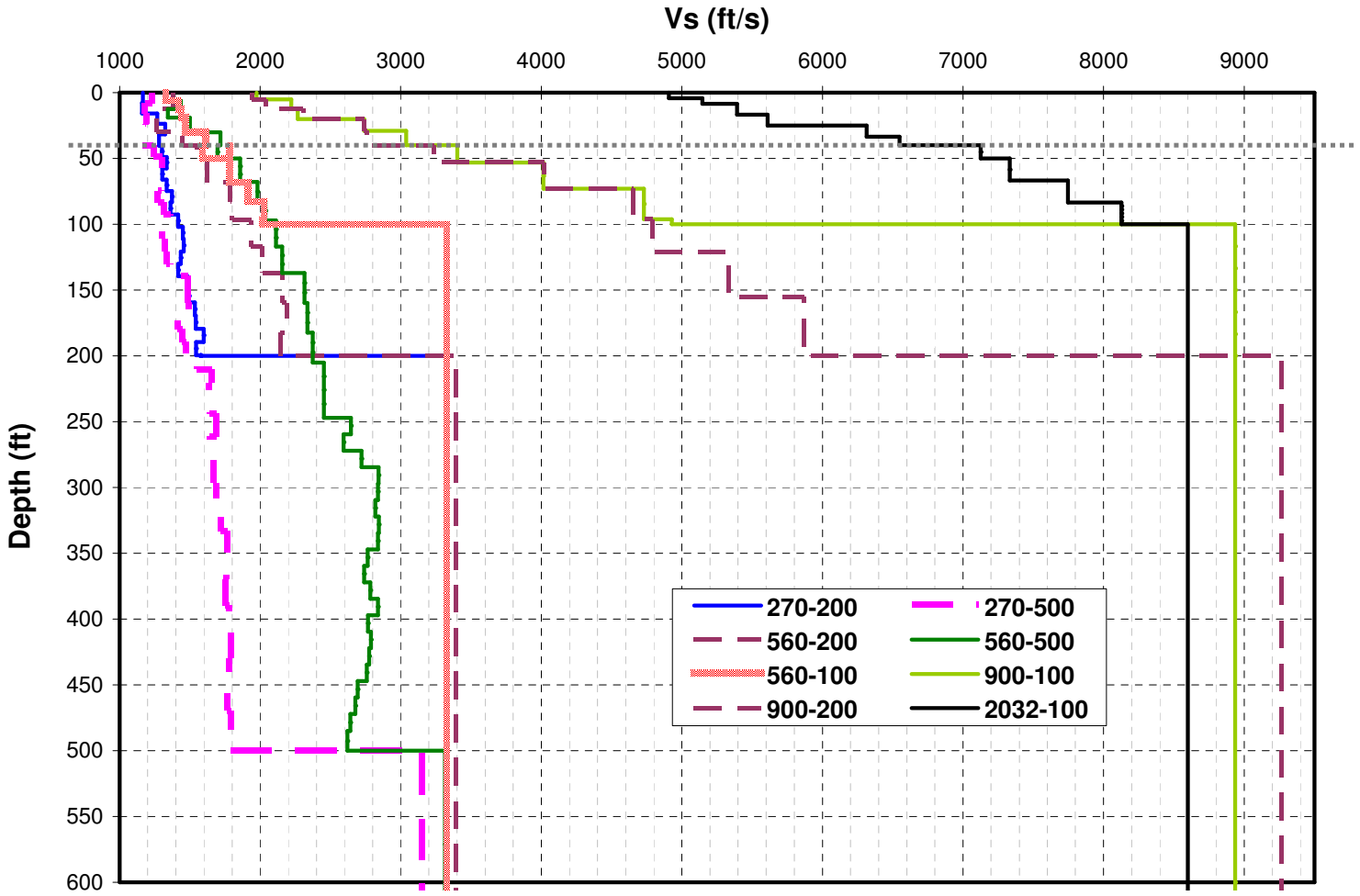
Current Status

- Strain Compatible S and P Wave Velocity Profiles per MUAP 10001(R3) and MUAP 10006(R1)



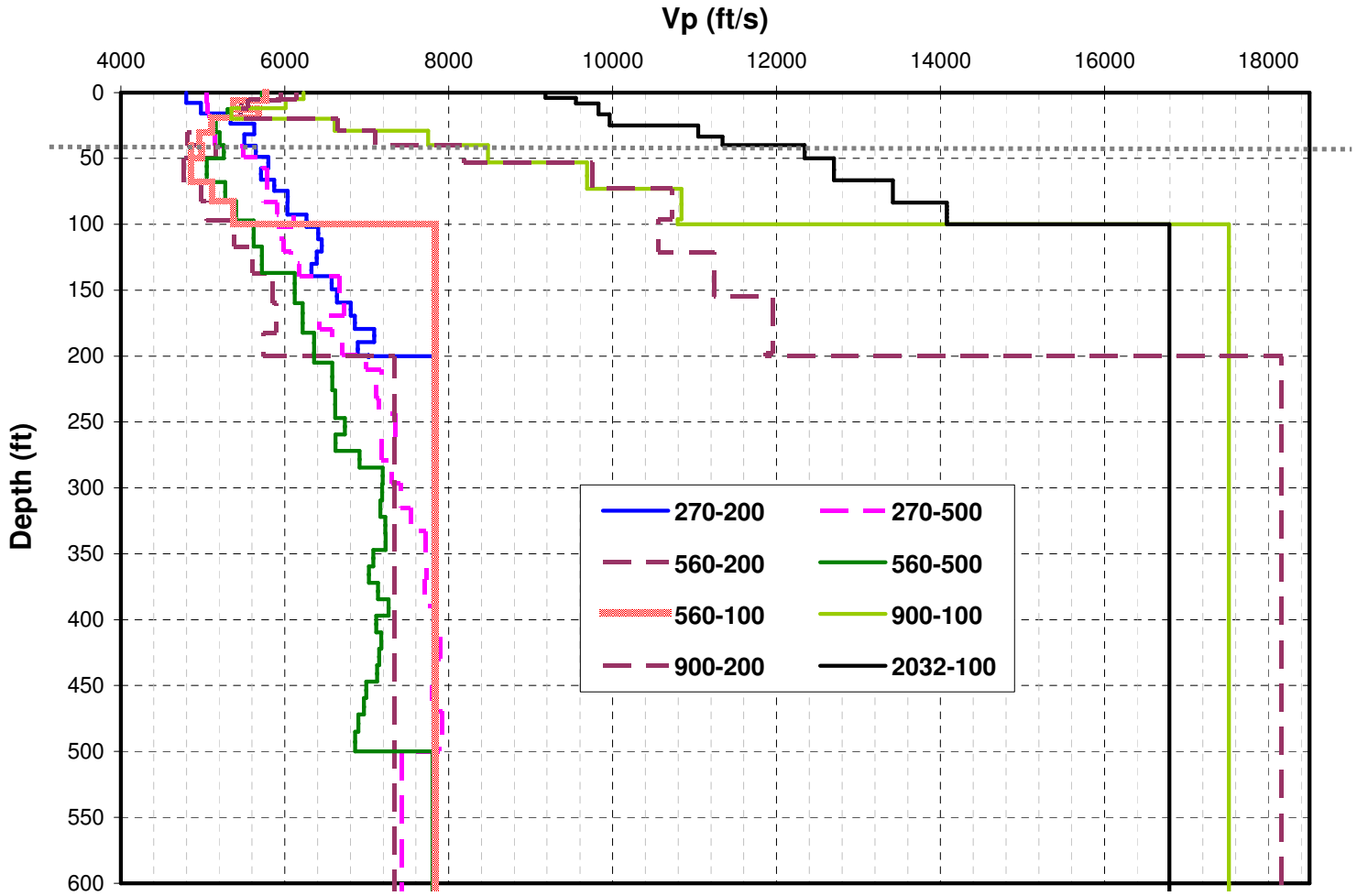
Current Status

- Top Soil Strain Compatible S-Wave Velocities per MUAP 10001(R3) and MUAP 10006(R1)



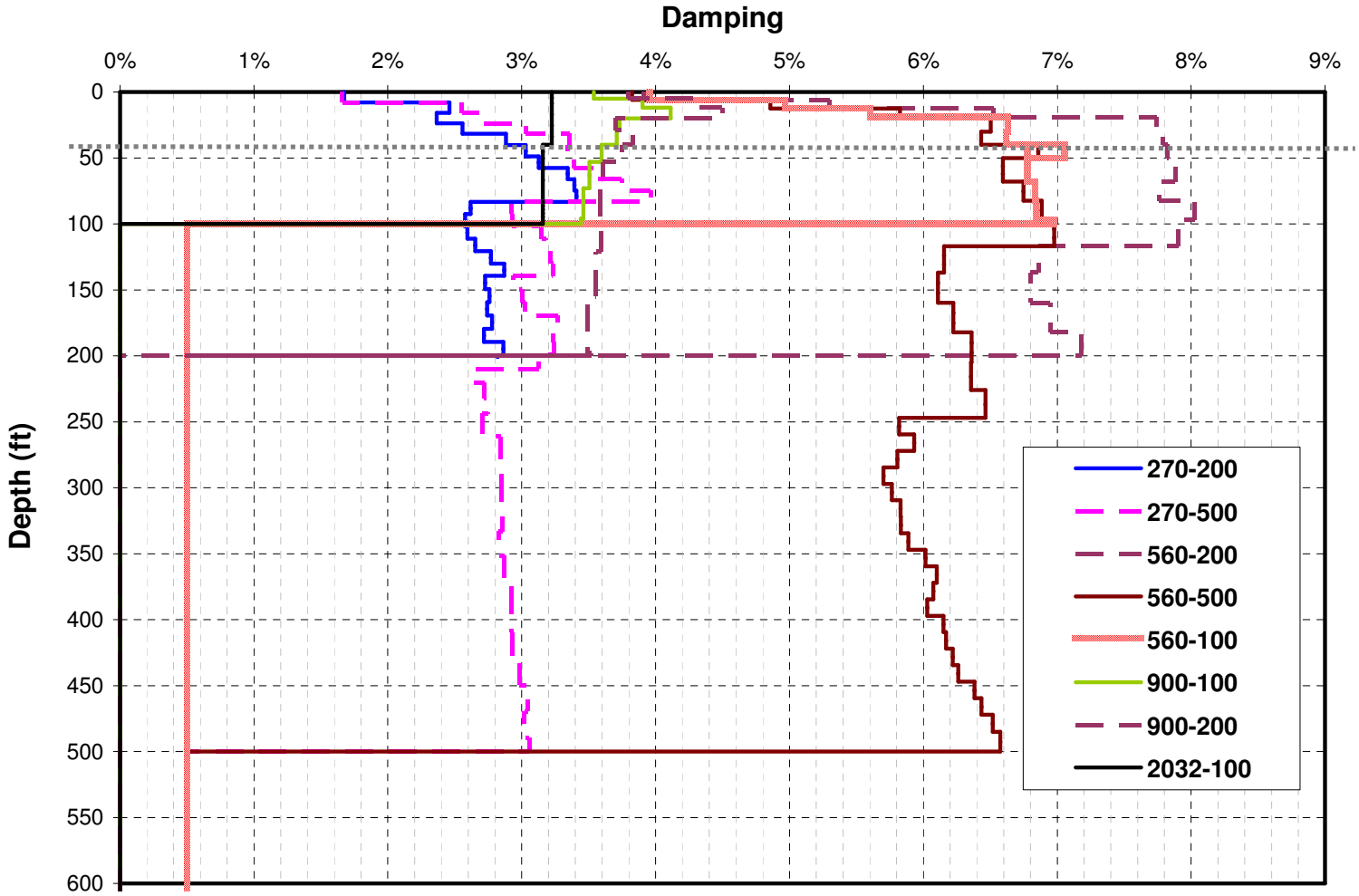
Current Status

- Top Soil Strain Compatible P-Wave Velocities per MUAP 10001(R3) and MUAP 10006(R1)



Current Status

- Top Soil Strain Compatible Damping per MUAP 10001(R3) and MUAP 10006(R1)

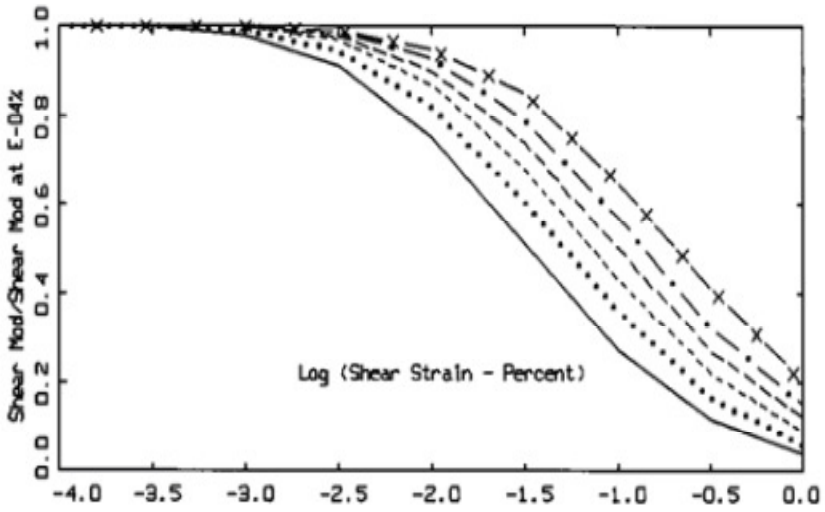


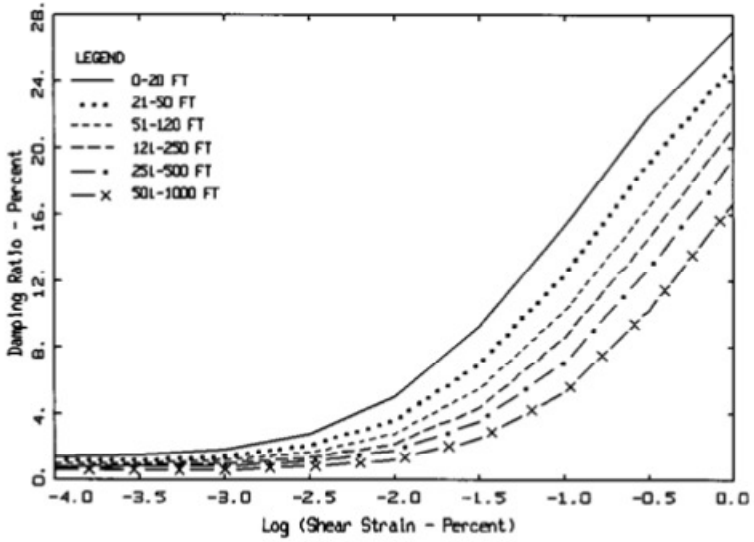
Resolution Proposal

- Modifications of standard design basis database of generic site profiles for site-independent SSI analyses are:
  - Soil Profiles 560-100 and 560-200 are removed from the standard seismic design database
  - EPRI soil degradation curves are used instead of unpublished rock degradation curves
  - Hard rock base is replaced with sedimentary rock type of profile with gradual increase of stiffness
  - Profiles with nominal S-wave velocity of 900 m/sec are modified by introducing steeper increase of rock stiffness with depth.

Resolution Proposal

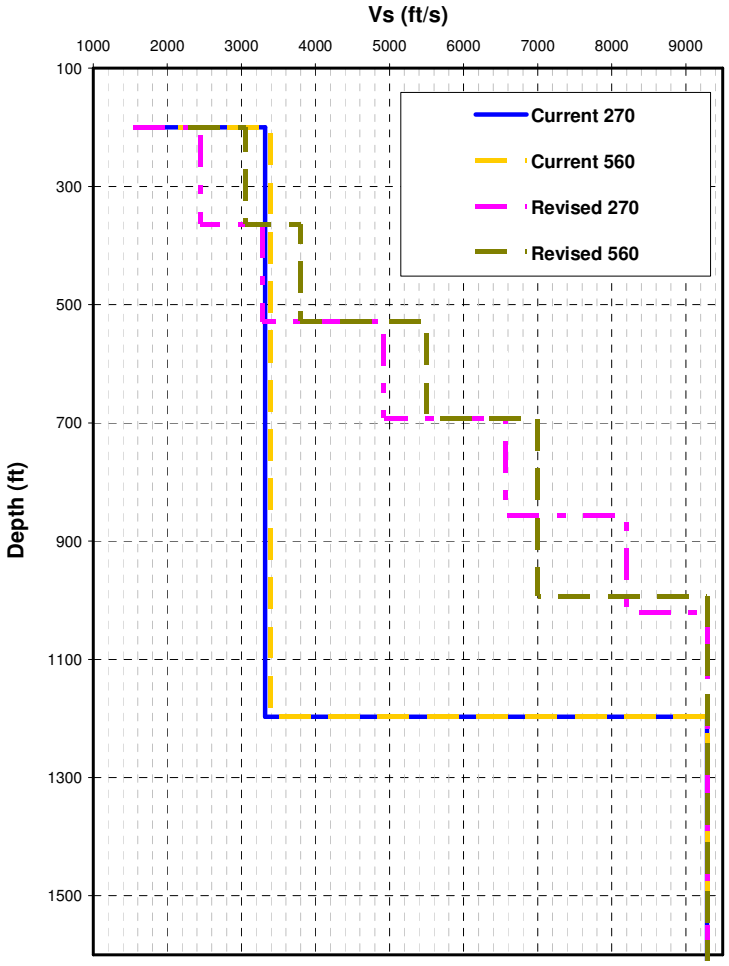
- Degradation curves published in EPRI TR-102293 are used for development of strain compatible properties of generic profiles with nominal Vs of 560 m/s and 900 m/s
- These curves represent strain dependent properties of generic soils with more linear (less strain dependent) behavior than the previously used rock degradation curves

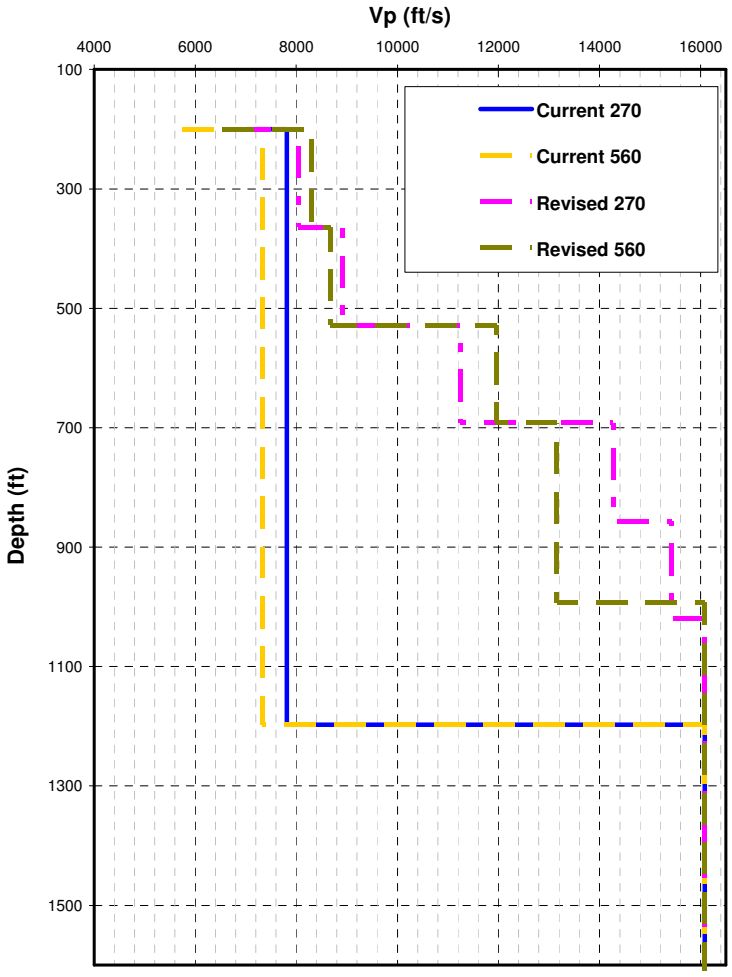




Resolution Proposal

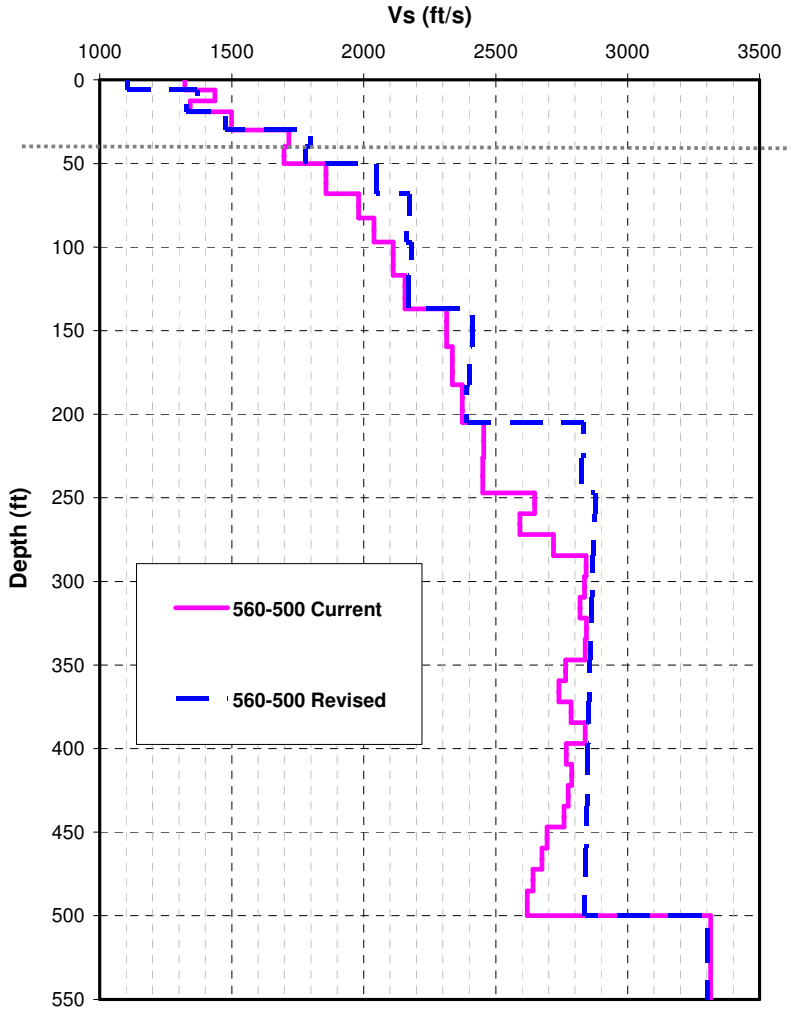
- Rock base is replaced by sedimentary or weather rock section overlying Precambrian basement material that is appropriate for both in Eastern and Western US





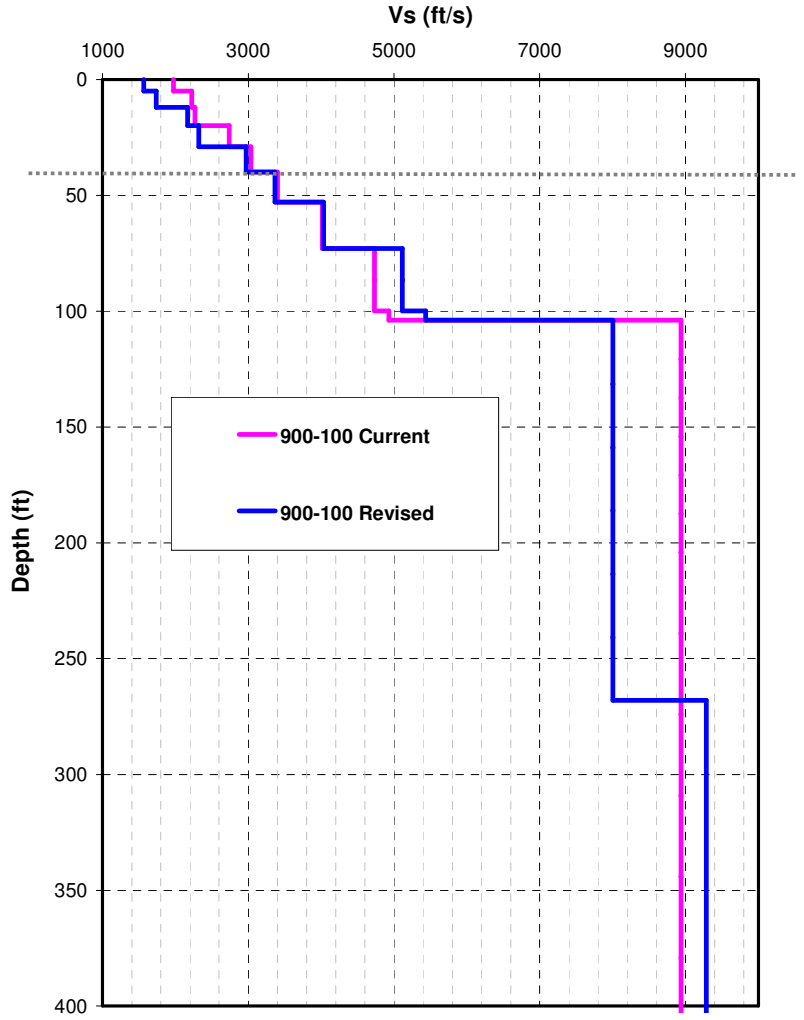
Resolution Proposal

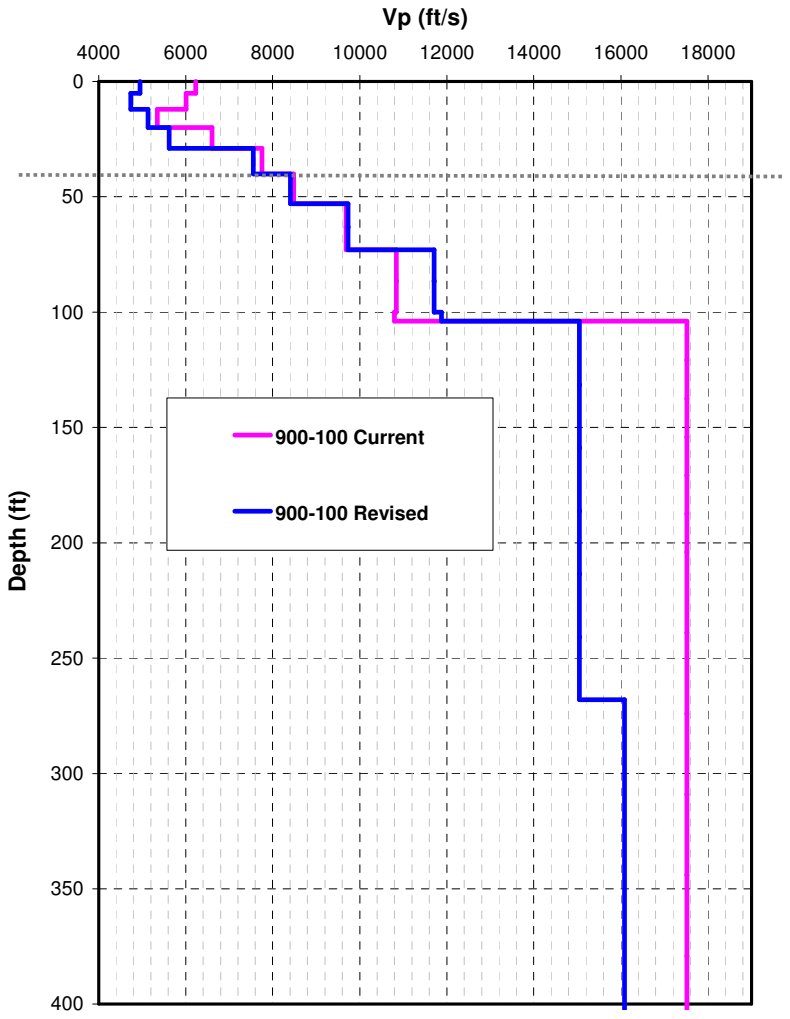
- Revised degradation curves and rock base yield strain compatible properties of generic profile 560-500 do not exhibit significant decrease in stiffness with depth



Resolution Proposal

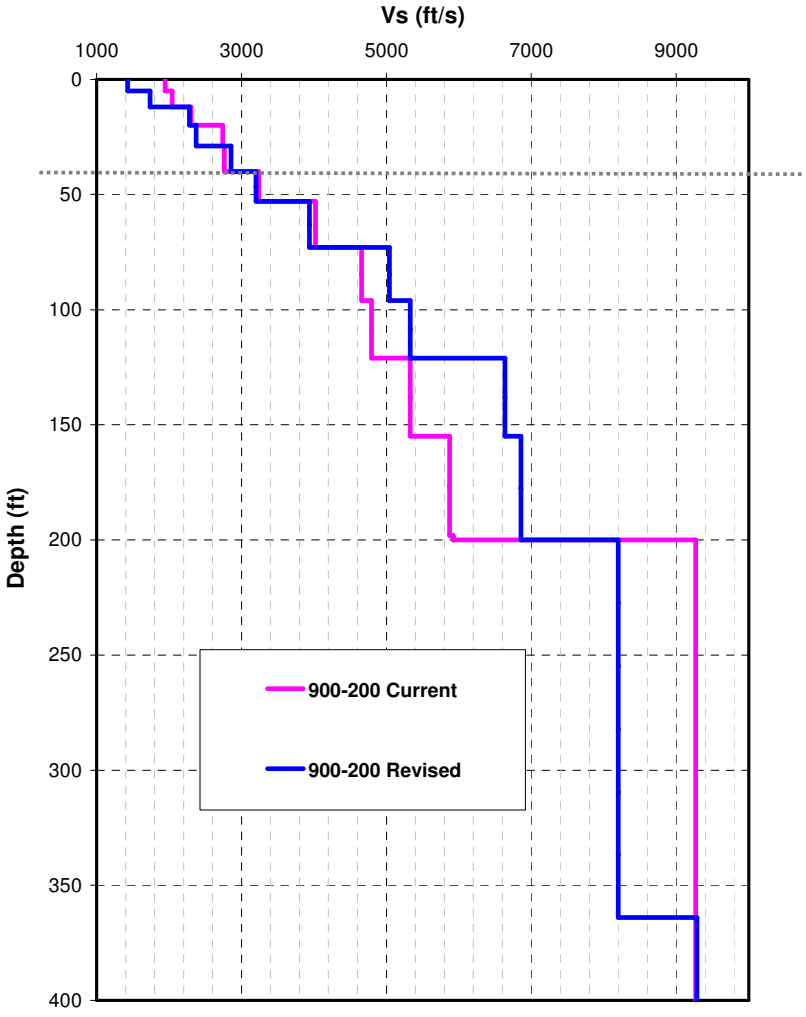
- Generic Profile 900-100 is modified by introducing steeper increase of top strata stiffness with depth

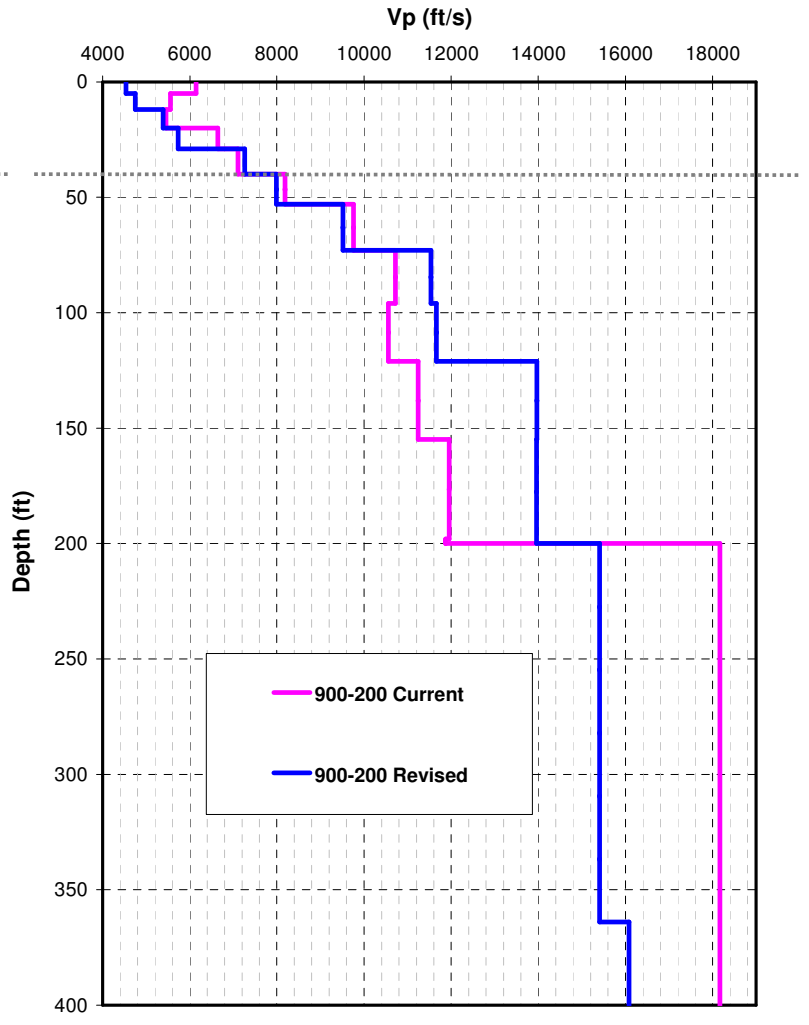




Resolution Proposal

- Generic Profile 900-200 is modified by introducing steeper increase of top strata stiffness with depth





Resolution Proposal

- **Generic Soil Profiles 560-100 and 560-200 are removed from the standard design basis database:**
  - The reflection of seismic waves at interface between the top softer soil strata and the baserock reduces SSI geometric damping resulting in sharp peak responses at resonant frequencies
  - US-APWR DCD COL Item 3.7(25) requires site-specific SSI evaluation for every COL application to ensure safety of the plant for any site-specific condition
- **Removal of Soil Profiles 560-100 and 560-200 does not significantly affect the applicability of US-APWR standard design because:**
  - COL applicants with similar site conditions can undertake remediation measures of top soil if necessary to mitigate the impact on design from SSI response amplifications
  - Removal of 560-100 and 560-200 profiles has a minor effect on the frequency distribution of SSI responses considered by US-APWR standard design

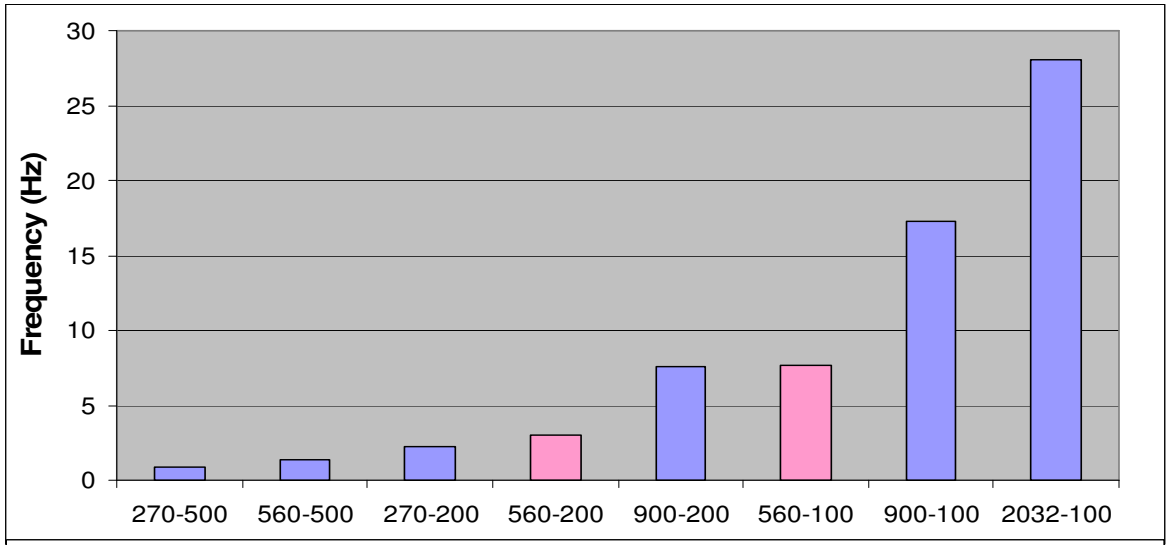
Resolution Proposal

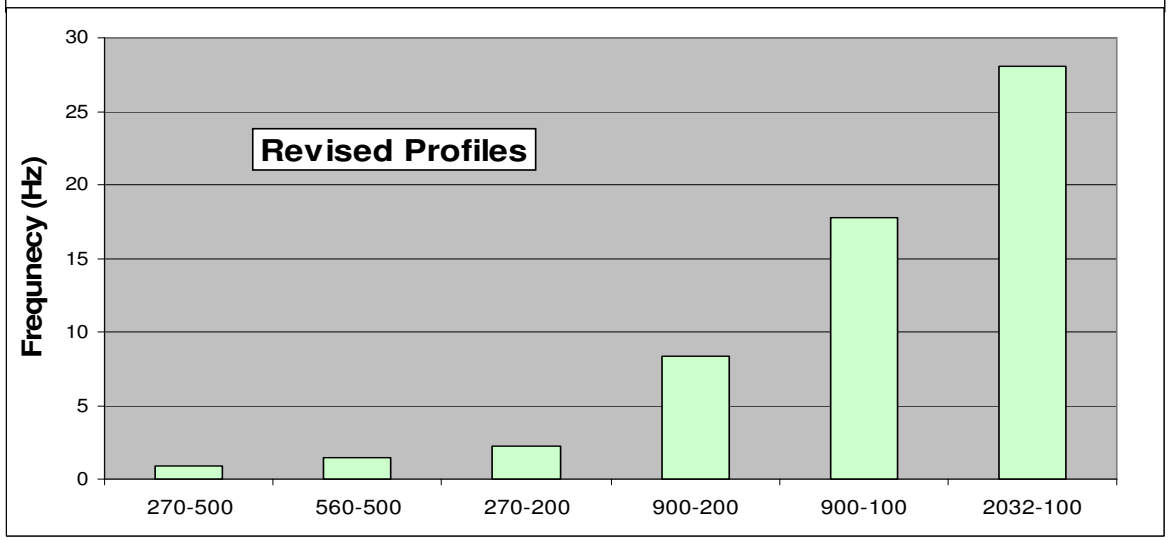
- **Shear Column Frequencies of Top Soil Strata**

Profile	Depth	Revised Profiles		Current Profiles	
		Truncated	Full	Truncated	Full
270-500	500	0.9	0.8	0.9	0.8
270-200	200	2.2	1.7	2.2	1.7
560-500	500	1.4	1.2	1.3	1.2
560-200	200	Removed		3.0	2.2
560-100	100			7.7	4.2
900-200	200	8.3	5.1	7.5	5.0
900-100	100	17.8	7.7	17.3	8.2
2032-100	100	28.1	16.8	28.1	16.8

Resolution Proposal

- Shear Column Frequencies of Top Soil Strata

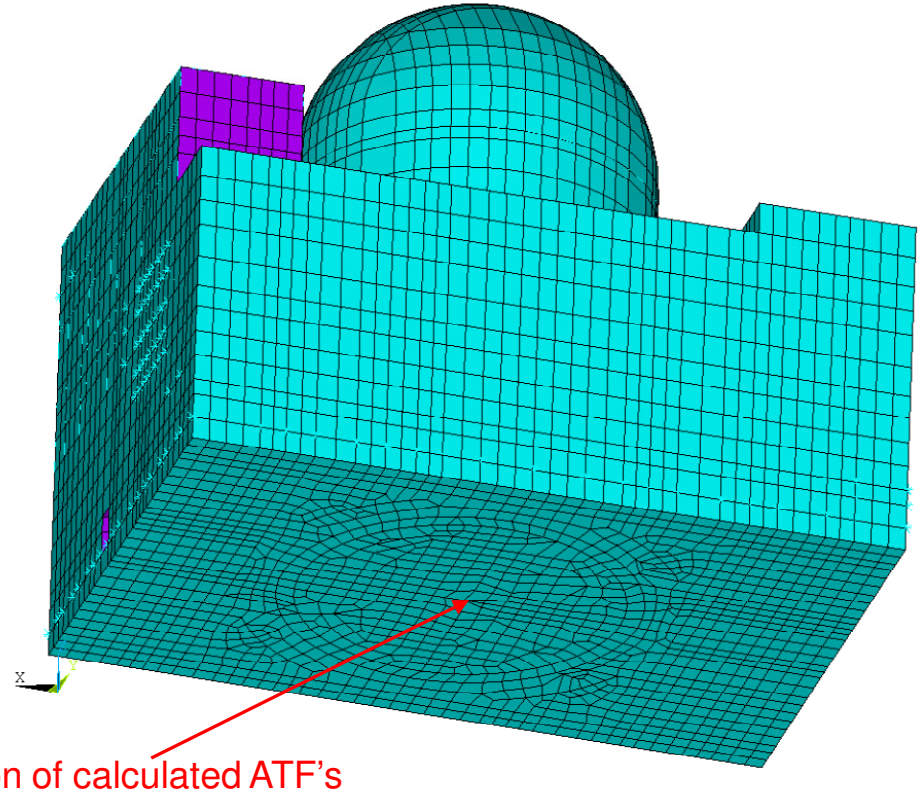




Resolution Proposal

➢ Peak Frequencies of Response at SSI Interface

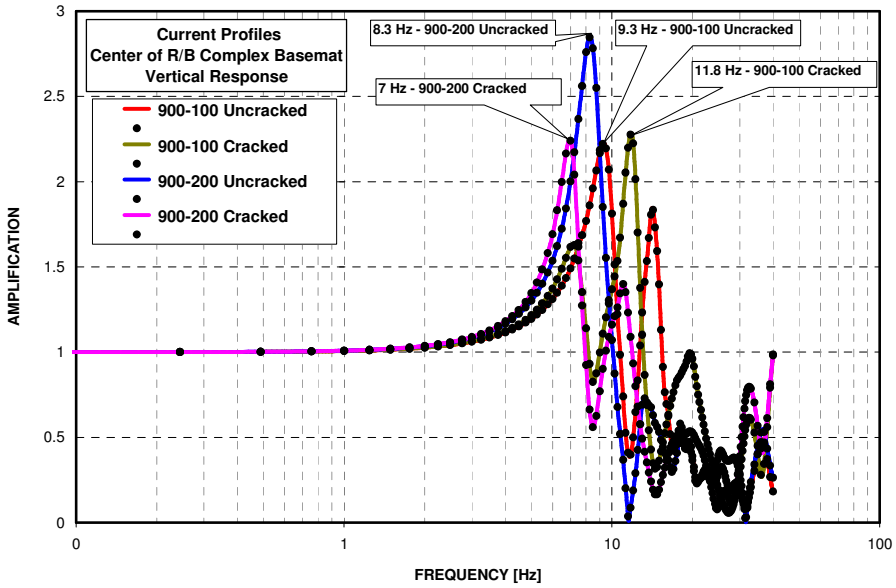
- For each of the current and revised generic profiles, acceleration transfer functions (ATF's) are calculated at center of basemat bottom using the R/B Complex Finite Element Model with full (uncracked concrete) properties and reduced (cracked concrete) properties



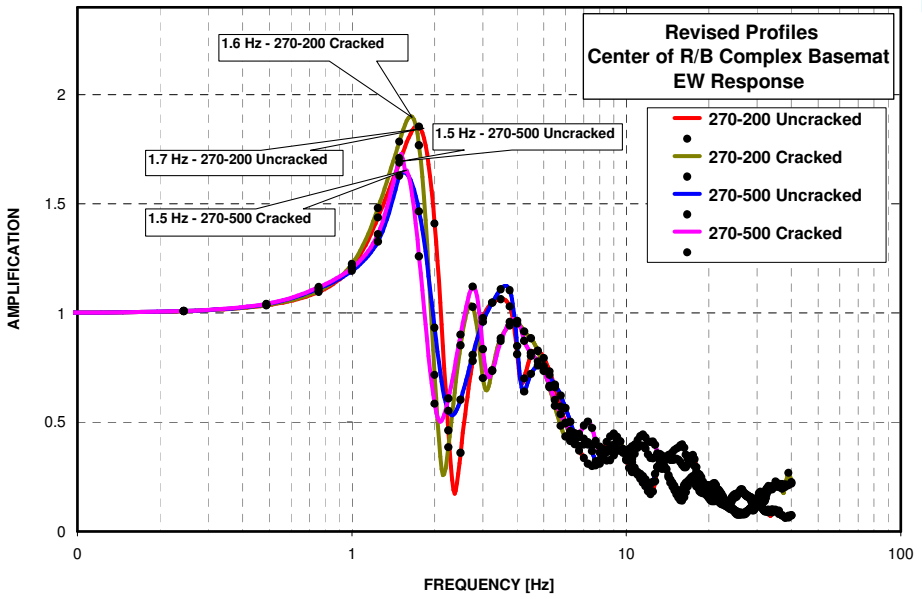
Resolution Proposal

➢ Peak Frequencies of Response at SSI Interface

- Frequencies where first peaks of the transfer functions occur are summarized for comparison



Preliminary Results



Resolution Proposal

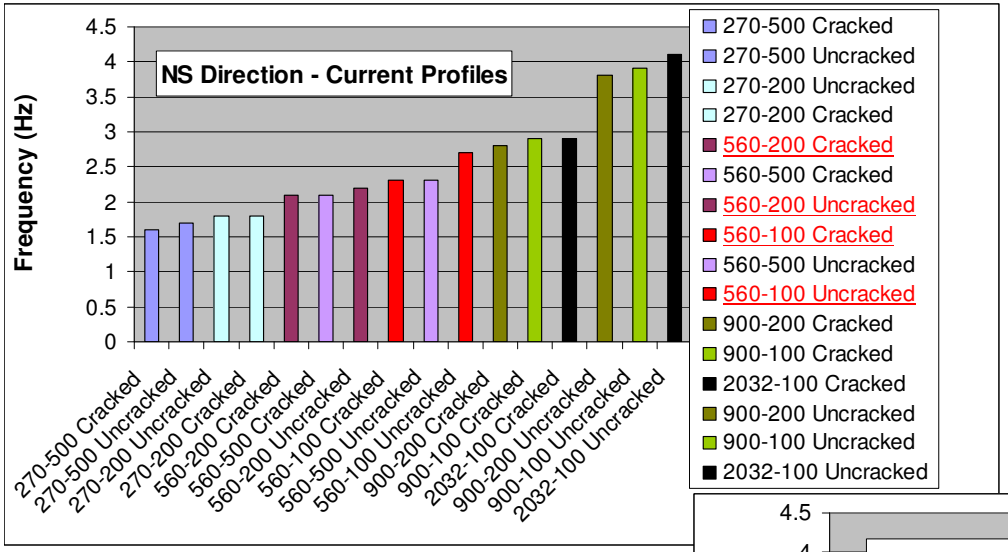
➢ Peak Frequencies of Response at SSI Interface

Preliminary Results

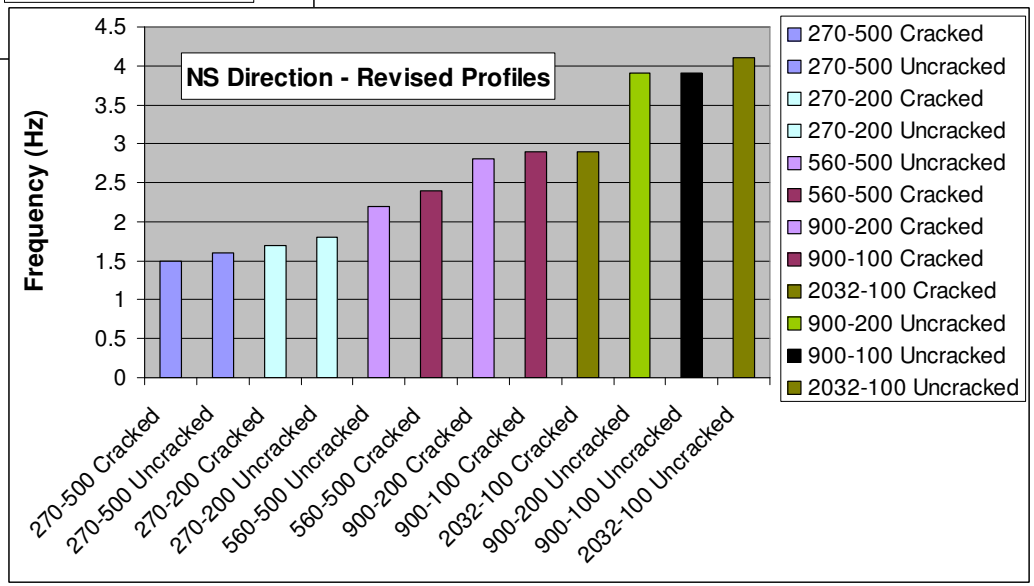
Soil Profile	Current Profiles			Revised Profiles		
	Peak Frequency (Hz)			Peak Frequency (Hz)		
	NS	EW	Vertical	NS	EW	Vertical
270-500 Cracked	1.6	1.6	1.6	1.5	1.5	2.2
270-500 Uncracked	1.7	1.6	1.6	1.6	1.5	2.2
270-200 Cracked	1.8	1.7	2.9	1.7	1.6	2.4
270-200 Uncracked	1.8	1.8	2.9	1.8	1.7	2.4
560-500 Cracked	2.1	2.0	3.2	2.4	2.3	3.7
560-500 Uncracked	2.3	2.2	3.3	2.2	2.1	3.7
560-200 Cracked	2.1	2.0	3.3	**Removed**		
560-200 Uncracked	2.2	2.1	3.4			
560-100 Cracked	2.3	2.2	4.5	**Removed**		
560-100 Uncracked	2.7	2.6	4.5			
900-200 Cracked	2.8	2.8	7.0	2.8	2.8	7.0
900-200 Uncracked	3.8	3.8	8.3	3.9	3.8	8.5
900-100 Cracked	2.9	2.9	7.3	2.9	2.9	7.2
900-100 Uncracked	3.9	3.9	9.3	3.9	3.9	9.0
2032-100 Cracked	2.9	2.9	7.3	2.9	2.9	7.3
2032-100 Uncracked	4.1	4.0	9.4	4.1	4.0	9.6

Resolution Proposal

➢ Peak Frequencies of NS Response at SSI Interface

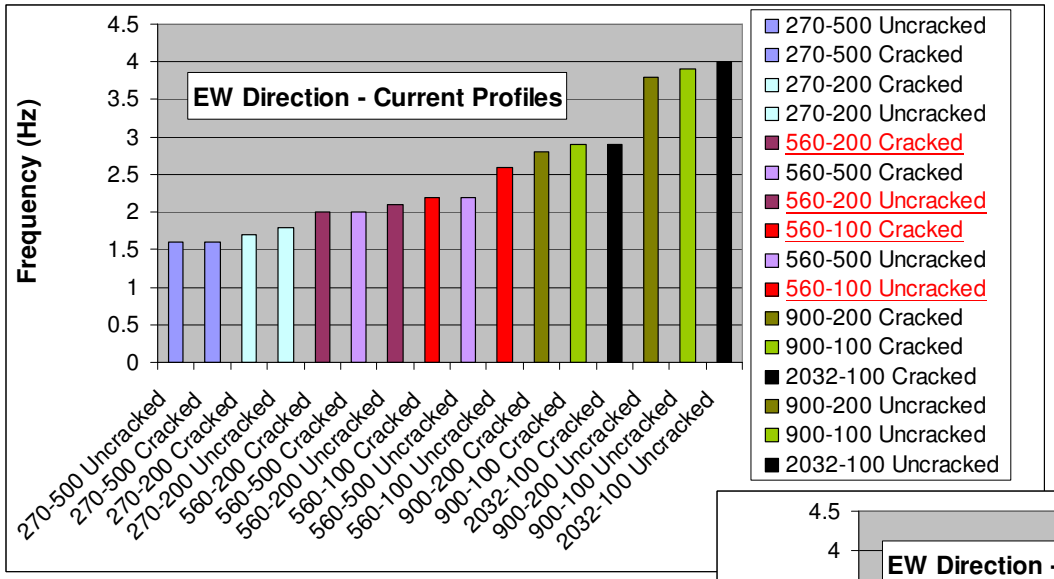


Preliminary Results

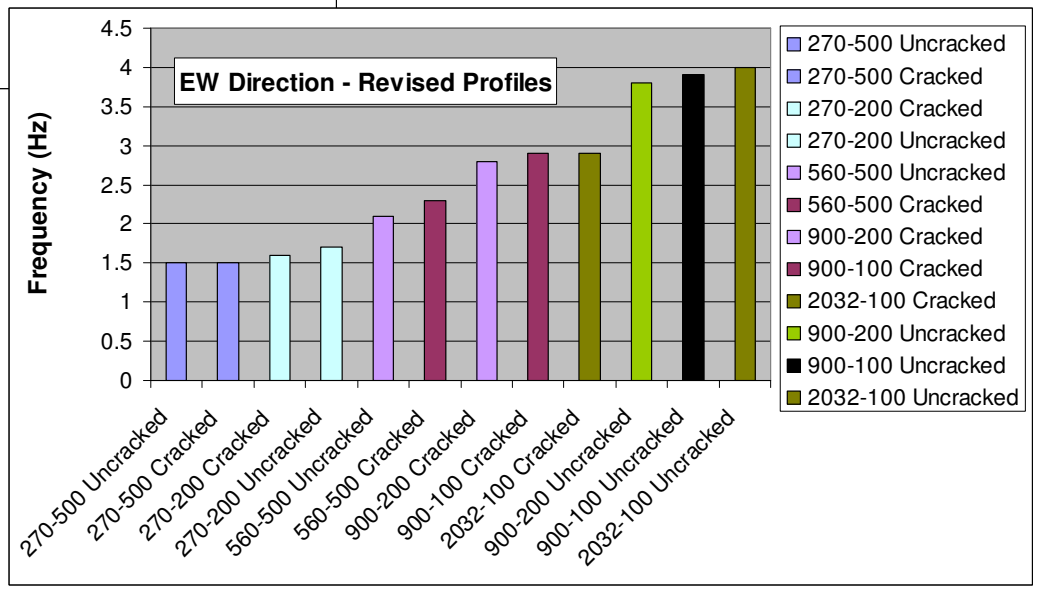


Resolution Proposal

➢ Peak Frequencies of EW Response at SSI Interface

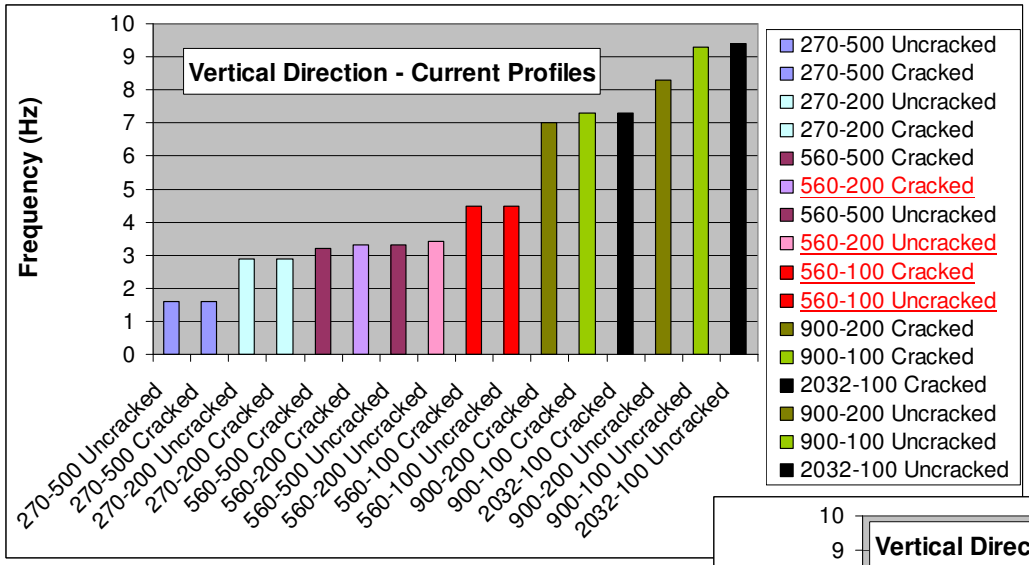


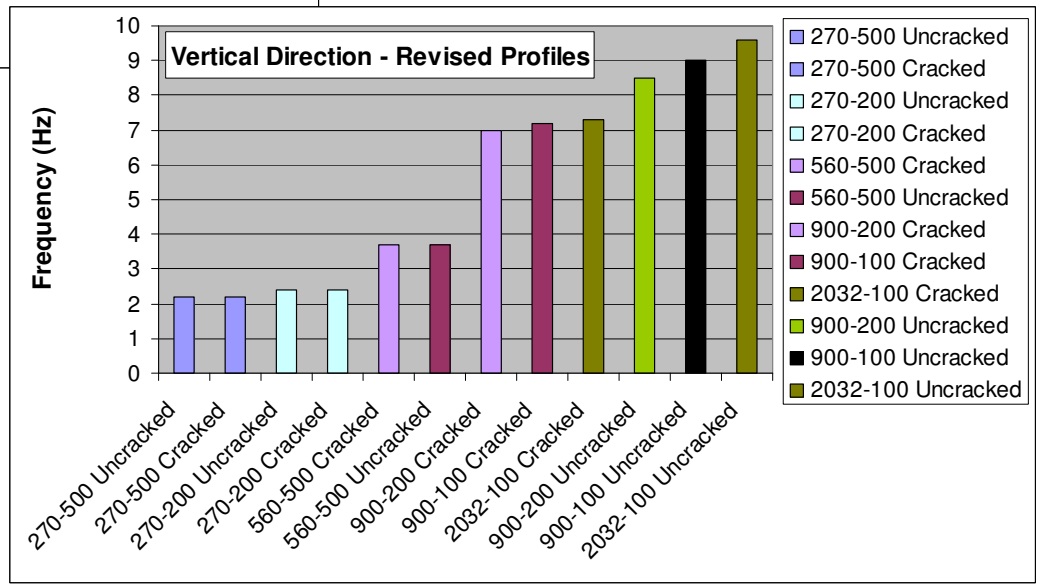
Preliminary Results



Resolution Proposal

➢ Peak Frequencies of Vertical Response at SSI Interface

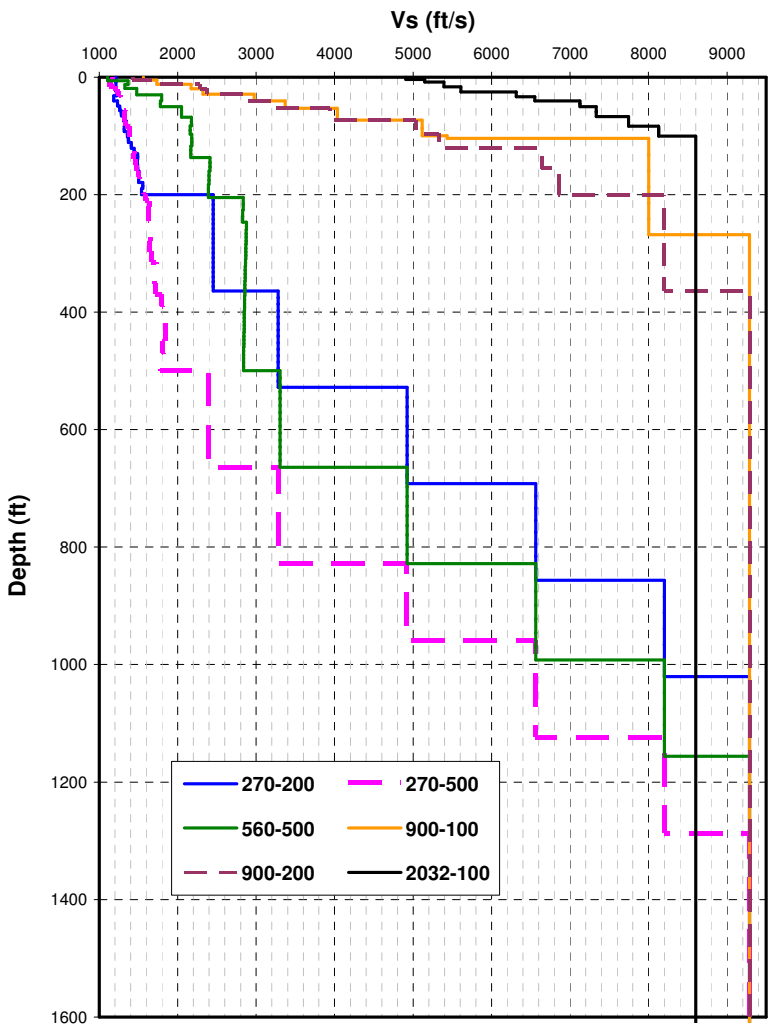


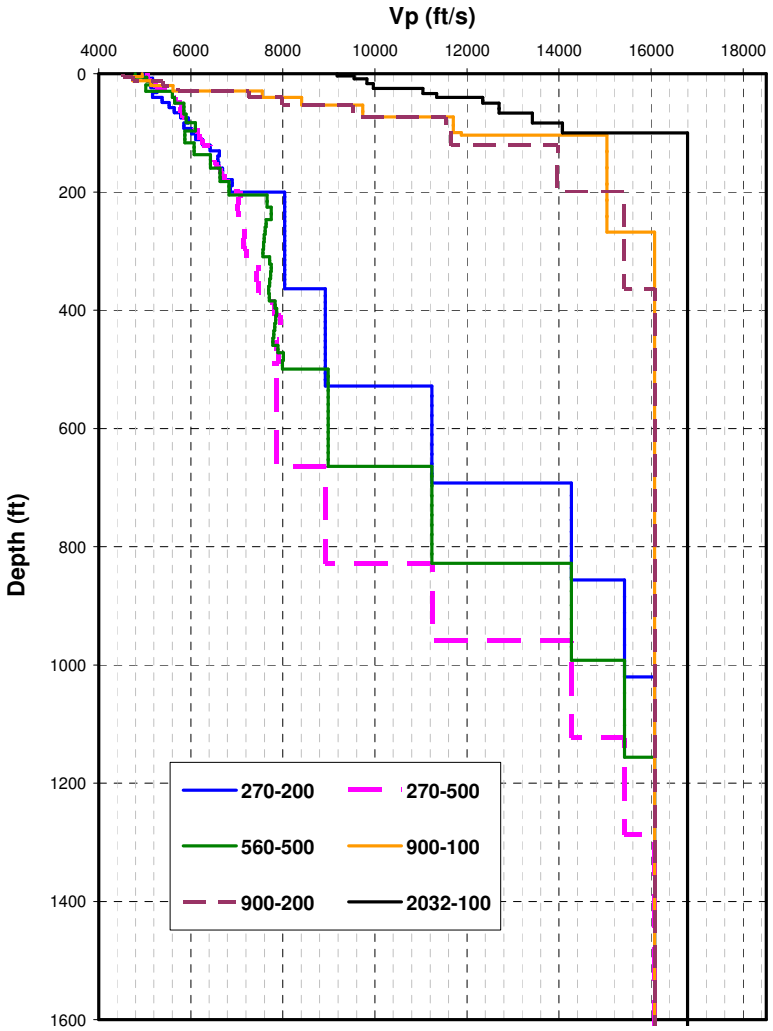


Preliminary Results

Resolution Proposal

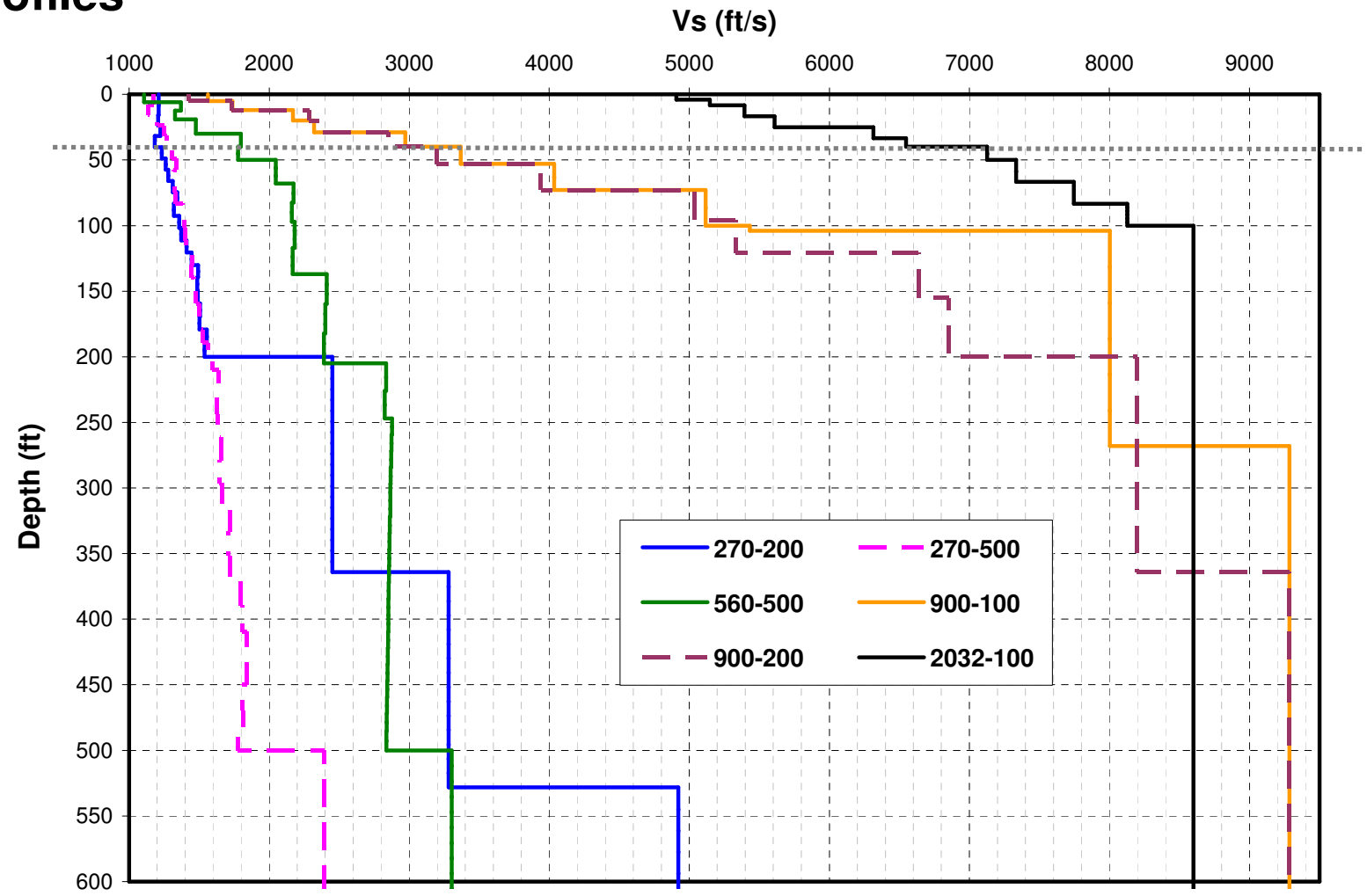
- Revised Profiles of Strain Compatible S and P Wave Velocities





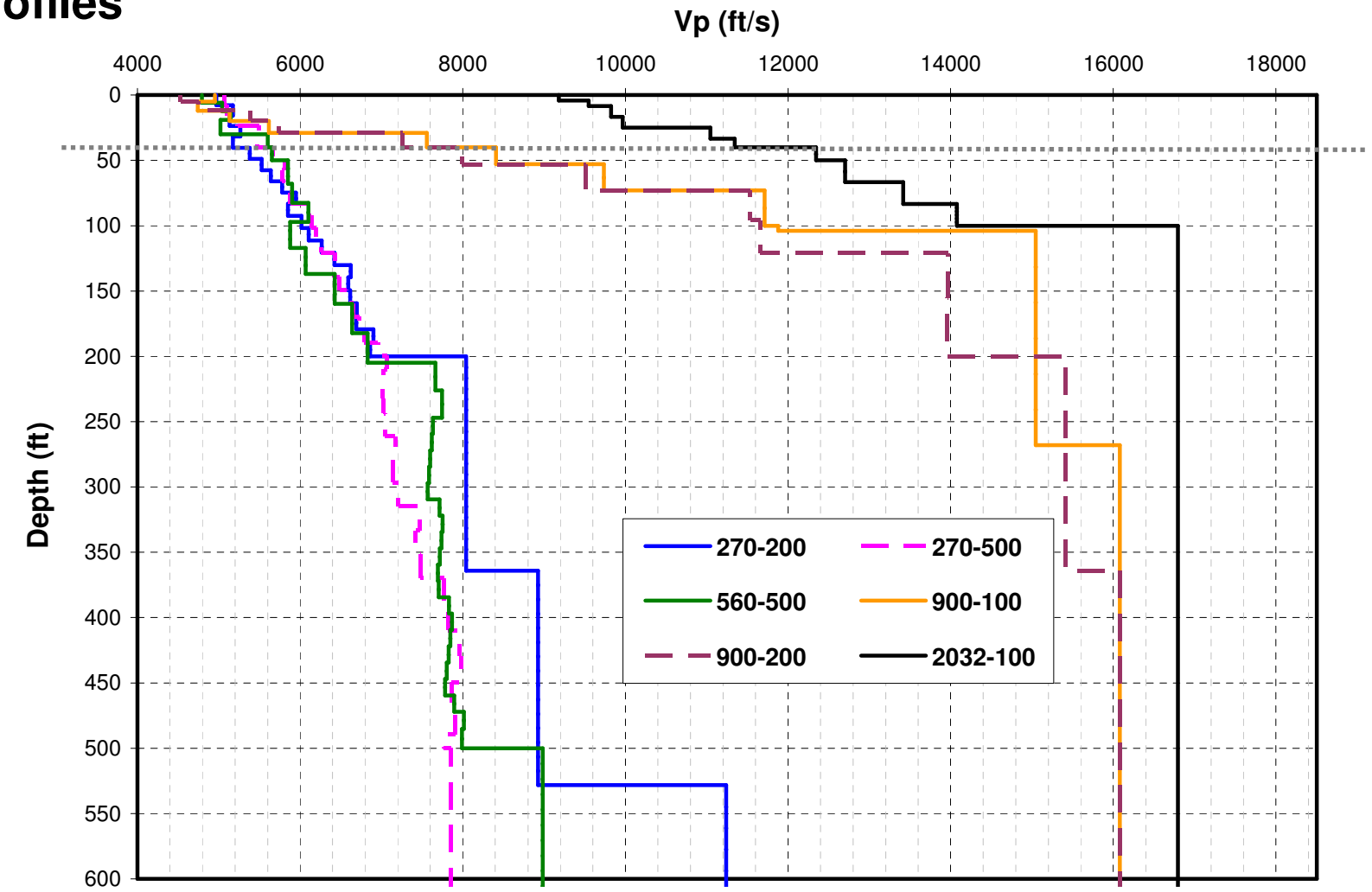
Resolution Proposal

- Top Soil Strain Compatible S-Wave Velocities of Revised Generic Profiles



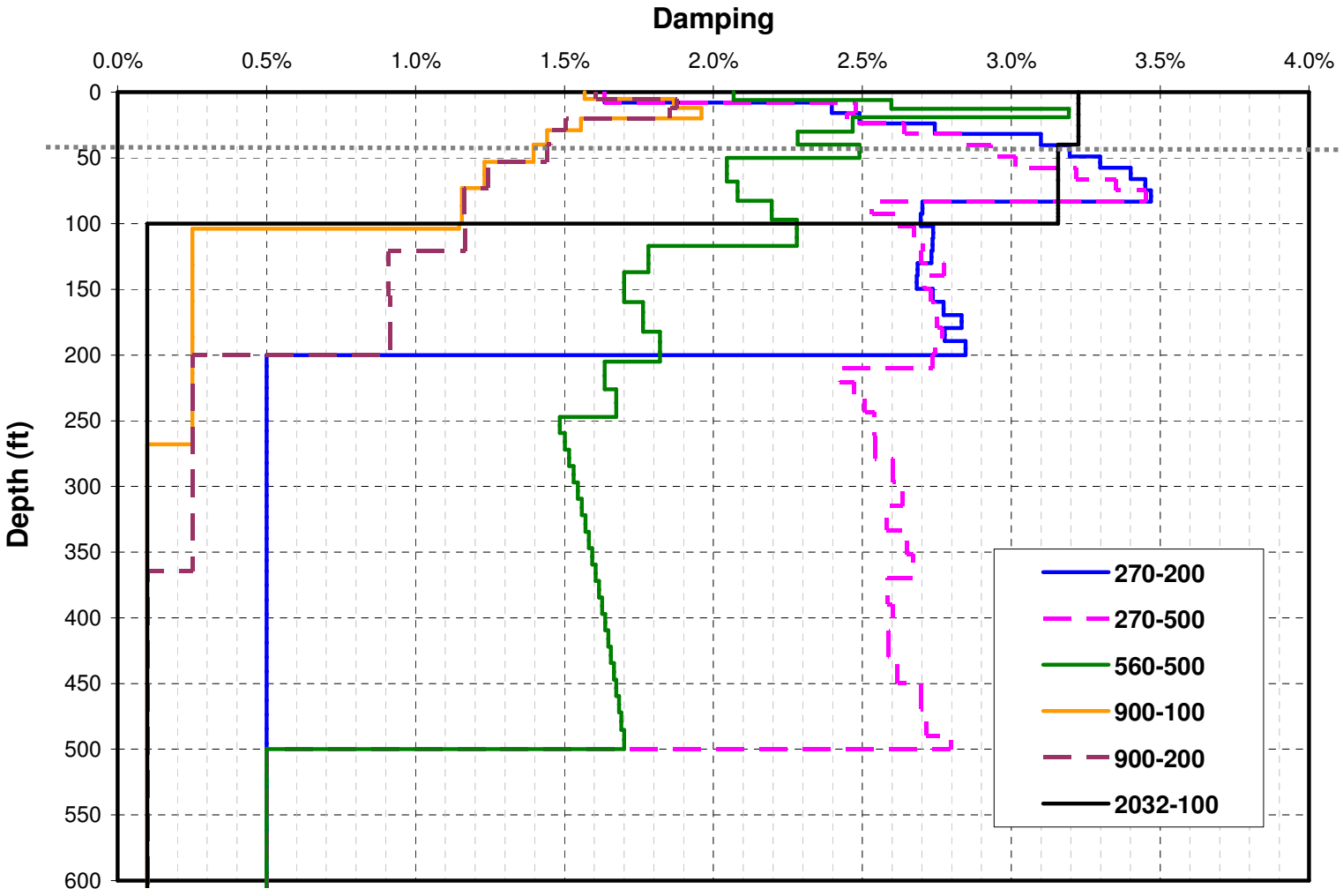
Resolution Proposal

- Top Soil Strain Compatible P-Wave Velocities of Revised Generic Profiles



Resolution Proposal

- Top Soil Strain Compatible Damping of Revised Soil Profiles



Deliverables

- Technical Reports
  - ✓ MUAP-10001 Rev. 4
  - ✓ MUAP-10006 Rev. 2
  - ✓ MUAP-11001 Rev. 2
  - ✓ MUAP-11002 Rev. 1
- DCD Mark-up

Summary

- The current standard design database of generic soil profiles is revised and total number of generic soil profiles is reduced from 8 to 6
- Revisions help address some of the NRC concerns noted in RAI's 821-5984 and 559-5133
- US-APWR DCD COL Item 3.7(25) requires site-specific SSI evaluation for every COL application to ensure safety of the plant for any specific site condition
- The revised generic profiles provide a sufficiently wide range of possible SSI responses to ensure wide applicability of US-APWR standard design

US-APWR

Modification to Time History Input

September 22, 2011

Mitsubishi Heavy Industries, Ltd.

Contents

- Issue Statement
- Current Status
- Resolution Proposal
- Deliverables
- Summary

Issue Statement

- March 2011 changes made in methodology for seismic analyses resulted in amplification of building base shear and overturning moment response due to the DCD Time History thus impacting sliding stability and soil bearing pressures
- US-APWR DCD Time Histories based on the Northridge earthquake do not provide as good a fit to the CSDRS as the Time Histories developed from the Nahanni earthquake

Current Status

- Existing time history seeds are time histories from the BAL (Mt. Baldy) recording of the January 24, 1994 Northridge Earthquake

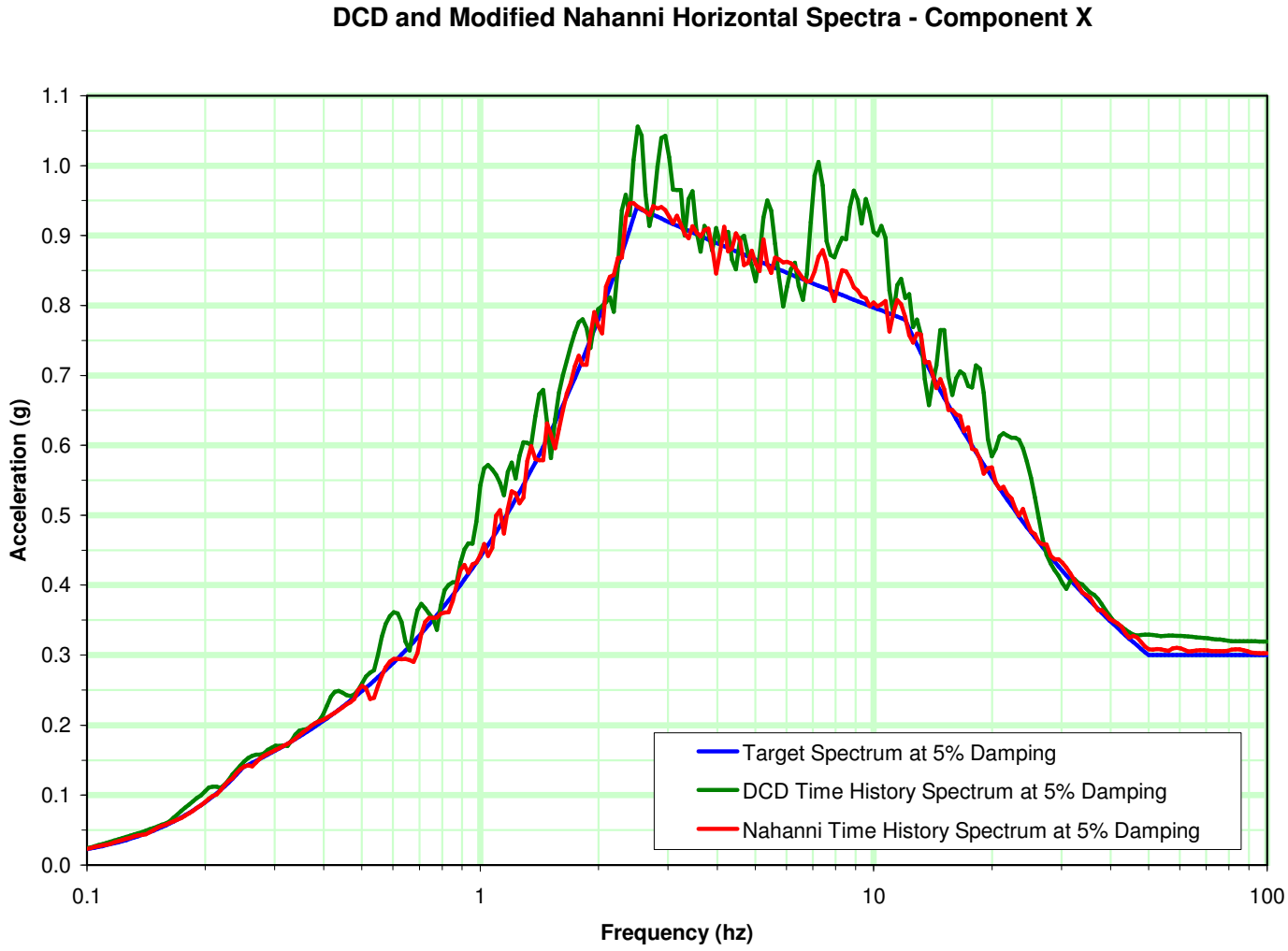
Resolution Proposal

- Replace the current seed records with the December 23, 1985 Nahanni Canada earthquake recorded at Site 3
- Develop three time histories from these seed records to match the CSDRS in accordance with NUREG 0800, Section 3.7.1, March 2007
- Use NUREG 0800 methodology compliant with Subsection 3.7.1.II.1B, Option 1, Approach 2.
- Analysis methodology is unchanged
- Nahanni Epicenter is > 600 miles from the fault line between the North American Plate and the Pacific Plate

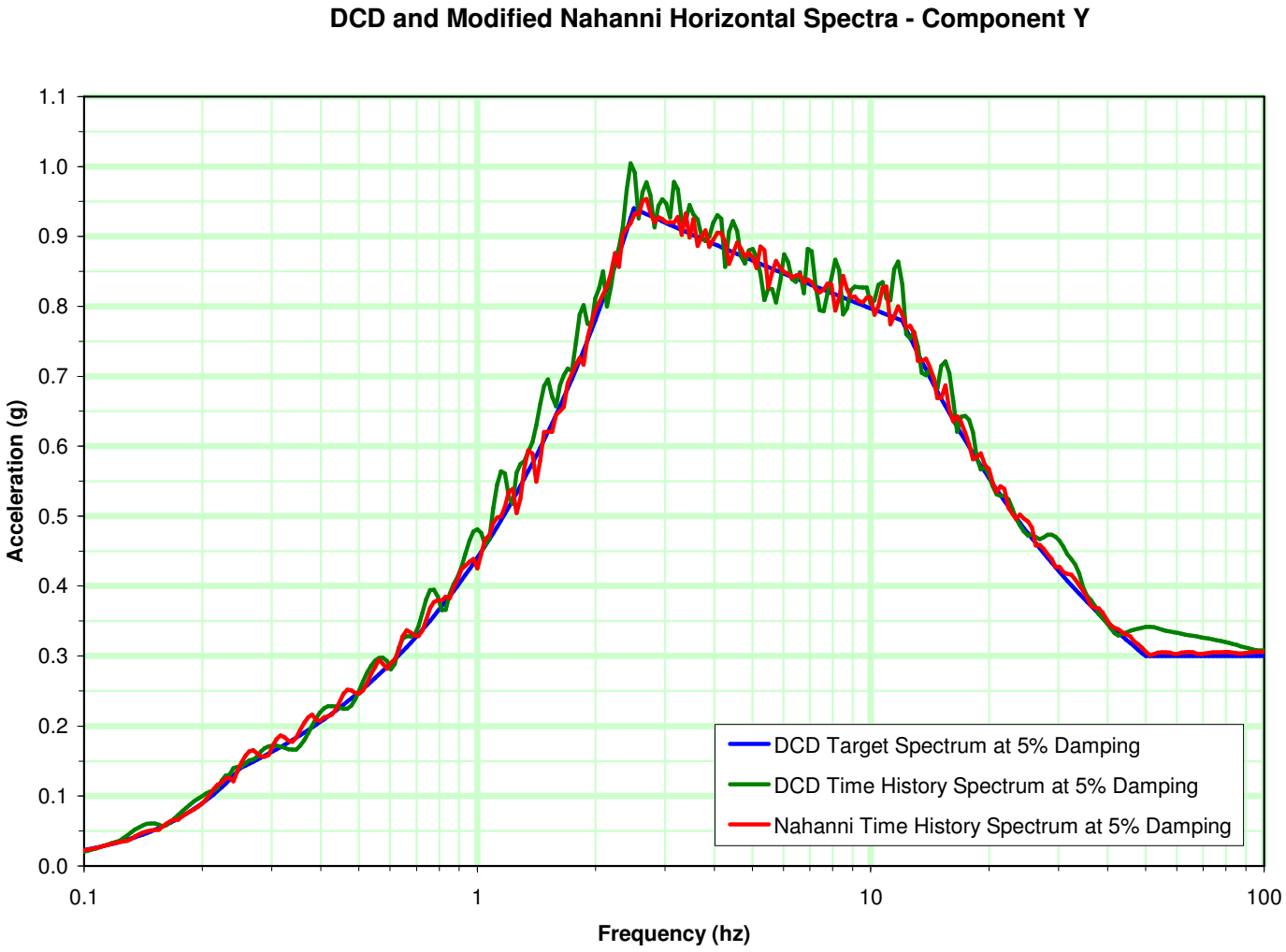
Resolution Proposal

- The revised time histories resolve challenges associated with contact area ratio and subsequent bearing pressures
- The revised time histories help resolve sliding stability challenges

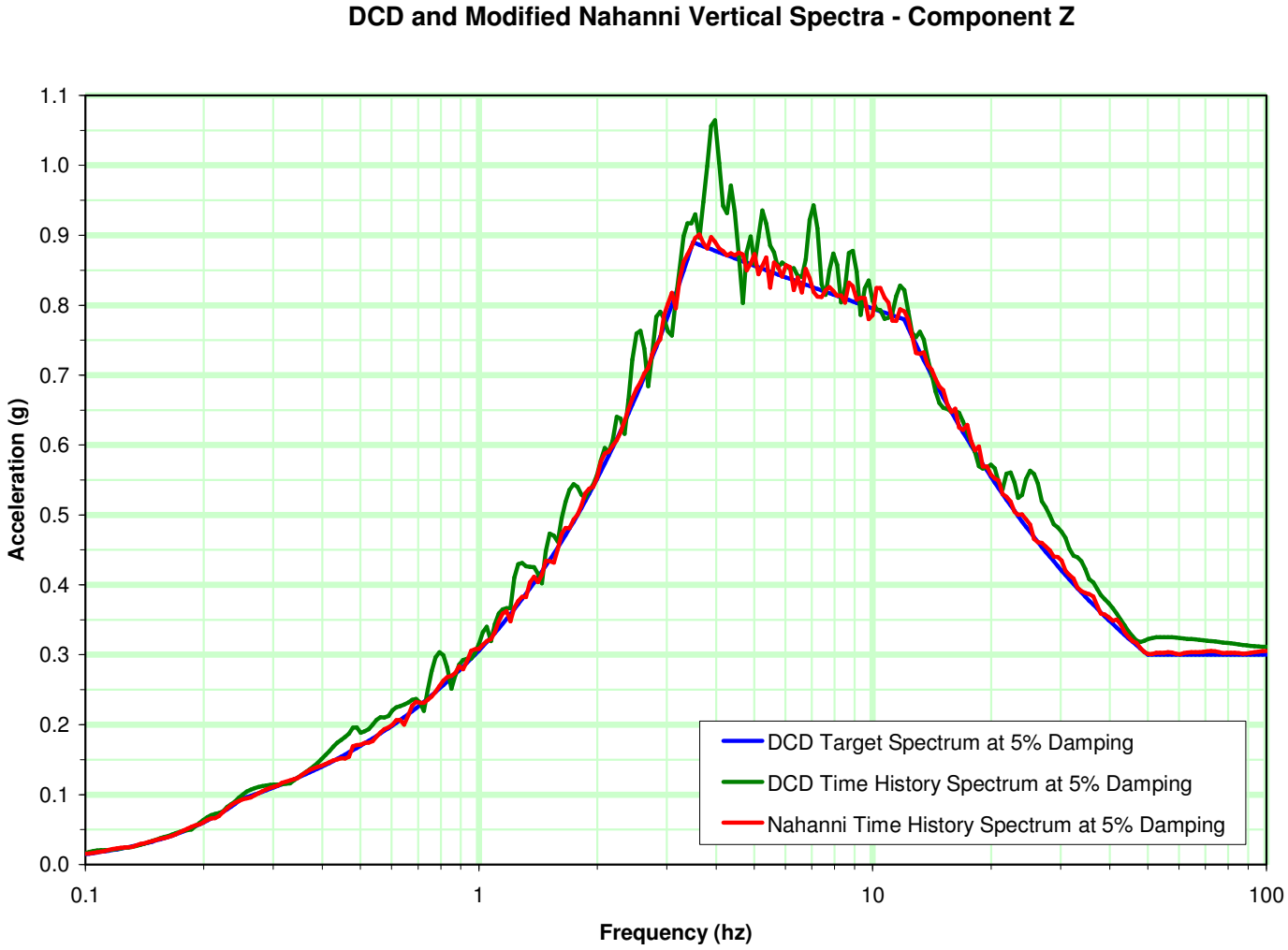
Resolution Proposal



Resolution Proposal



Resolution Proposal



Resolution Proposal

NUREG 0800 3.7.1.II.1B, Option 1, Approach 2 Requirements for Nahanni Revised Time Histories

Requirement	X	Y	Z
Nyquist Frequency is 100 Hz. Time step is 0.005 seconds			
Damping is 5%. Frequency scale is 0.10 to100.0 Hz			
Average all points	1.009	1.015	1.009
Total Duration (GE 20 Sec.)	20.000	20.000	20.000
Rise Time: Arias' Intensity (GE 1 Sec)	2.845	2.729	3.026
Strong Motion: Arias' 5% to 75% (GE 7 S.)	7.795	8.286	7.165
Decay Time: Arias' 75% to 100% (GE 5 S.)	9.360	8.985	9.809

Resolution Proposal

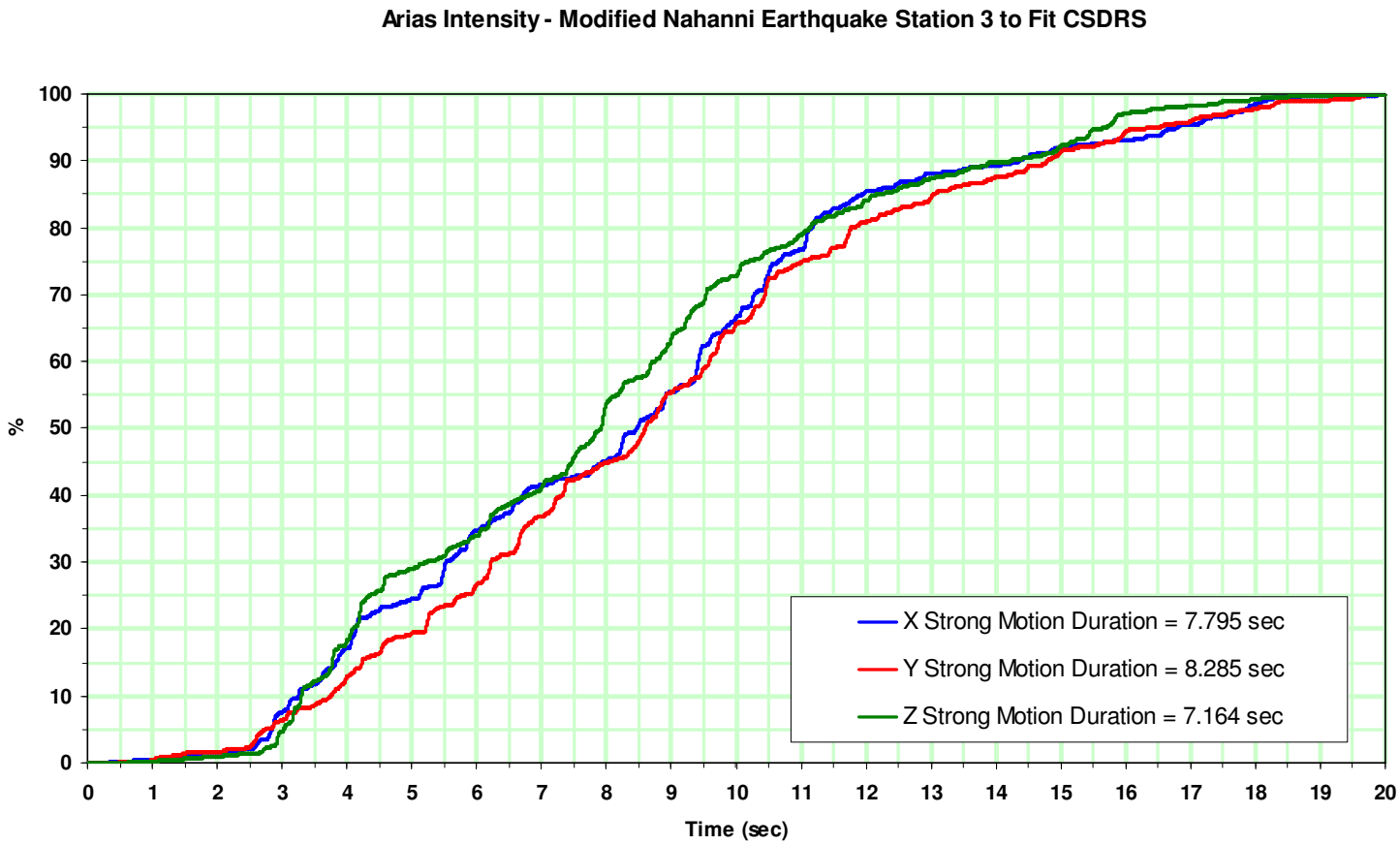
NUREG 0800 3.7.1.II.1B, Option 1, Approach 2 Requirements for Nahanni Revised Time Histories

Requirement	X	Y	Z
Statistical Independence (ABS < 0.16)	-0.0327		
	0.1390		0.1390
		0.1170	
Number of points with acc. ratio > 1.3 (if 0 OK)	0	0	0
Number of points with acc. ratio < 0.9 (if 0 OK)	0	0	0
Number of windows wider than 9 points below target spectra (if 0 OK)	0	0	0

The revised time histories comply with all the NUREG 0800 3.7.1.II.1B, Option 1, Approach 2 requirements

Resolution Proposal

Arias Intensity plots showing % Intensity Vs Time



Plot demonstrates reasonable intensity input with time.

Deliverables

- Technical Reports
  - ✓ MUAP-10001 Rev. 4
  - ✓ MUAP-10006 Rev. 2
  - ✓ MUAP-11001 Rev. 2
  - ✓ MUAP-11002 Rev. 1
  - ✓ MUAP-11011 Rev. 1
- DCD Mark-up

Summary

- MHI will document methodology and results for revised time histories in the October revision of Technical Reports
- DCD will be updated to include the revised time histories in MUAP-10001 Rev. 4

Luminant MITSUBISHI HEAVY INDUSTRIES, LTD. Dominion US-APWR

US-APWR

Modifications to Standard Plant: Gap Between Structures and Foundation Enhancements

September 22, 2011

Mitsubishi Heavy Industries, Ltd.

Contents

- Issue Statement
- Current Status
- Resolution Proposal
- Deliverables
- Summary

Issue Statement

- Results of analyses indicate the current gap between standard plant structures of 4” is insufficient, which could impact the structural integrity of adjacent Seismic Category I structures

- Stability evaluations based on current design inputs indicate that maintaining a margin of 1.1 against sliding presents a challenge for Standard Plant Structures

Current Status

- The calculated gap closure is based on:
  - ✓ Seismic SSI Displacements
  - ✓ Settlement/Tilt
  - ✓ Sliding Displacement (Shear Key Engagement)
- The total gap closure is determined by an absolute summation of displacements
- Investigations are ongoing to confirm the following do not impact the required gap:
  - ✓ SSSI
  - ✓ Embedment
  - ✓ Overturning/Uplift

Current Status – Seismic SSI

- SSI displacements based on
  - ✓ Displacements are relative to center of basemat
  - ✓ Envelope of maximum displacements across interfacing wall
- Current SSI displacement values are based on analysis performed for previous soil cases and input motion
  - ✓ For R/B, PS/B, and A/B, displacements relative to basemat center are approximated by reducing the maximum displacement-relative-to-free-field at critical areas by 90% of the maximum displacement-relative-to-free-field of the basemat
  - ✓ For T/B, maximum displacements relative to free field are conservatively considered

Current Status – Settlement

- Settlement analysis was performed for softest soil condition (270-500) to determine reasonable relative tilt between structures during operation
  - ✓ 0.014% or 1/7,143 for a sand site
  - ✓ 0.068% or 1/1,471 for a remediated clay site
- Maximum allowable R/B tilt of 1/2,000 per DCD
- A maximum relative tilt between structures of 1/1,000 is considered.
  - ✓ Maximum relative tilt is multiplied by the height from basemat to maximum height of structure to determine tilt displacement

Current Status – Sliding

- A limit equilibrium analysis determined that shear keys may be required to ensure stability for all structures
- A required shear key depth of 15 ft is selected based on initial evaluations for purposes of the current gap closure estimate
- Sliding displacement conservatively considered as 1% of the required depth of the shear key for stability

Current Status – Displacement Results

		Displacement			
		Seismic SSI	Settlement/Tilt	Sliding	Total
R/B - A/B Elev. Below 101'	R/B West Wall Col. Line AR – JR	1.259	1.647	1.8	7.470
	A/B East Wall	0.964		1.8	
R/B - PS/B West Elev. Below 49'	R/B West Wall Col. Line JR - LR	0.693	1.023	1.8	5.675
	PS/B East Wall	0.359		1.8	
R/B - PS/B East Elev. Below 49'	R/B East Wall Col. Line JR - LR	0.711	1.023	1.8	5.693
	PS/B East Wall	0.359		1.8	
R/B - T/B Elev. Below 3'-7"	R/B South Wall	0.376	0.478	1.8	4.754
	T/B North Wall	0.300		1.8	
R/B - T/B Elev. Below 61' (25" gap)	R/B South Wall	0.788	1.167	1.8	7.875
	T/B North Wall	2.32		1.8	
PS/B - A/B Elev. Below 49'	PS/B North Wall	0.638	1.023	1.8	5.767
	A/B South Wall	0.506		1.8	

Resolution Proposal

- The gap between all standard plant structures will increase to 16 inches, which provides:
  - ✓ Allowance for gap closure
  - ✓ Allowance for construction tolerances and settlement
  - ✓ Additional margin for safety

- Refine seismic displacement values considering:
  - ✓ Plant configuration with 16” gaps
  - ✓ Modified soil cases
  - ✓ Modified time history input
  - ✓ Details of required shear keys

Resolution Proposal

- SSI displacement determined as absolute summation of maximum displacement-relative-to-basemat of interfacing walls
- Rotation/tilt displacement considered as maximum allowable rotation/tilt allowed by DCD
  - ✓ DCD requirements to be updated
- Sliding displacement conservatively considered as 1% of the required depth of the shear key for stability

Deliverables

- Technical Reports
  - ✓ MUAP-10001 Rev. 4
  - ✓ MUAP-10006 Rev. 2
  - ✓ MUAP-11001 Rev. 2
  - ✓ MUAP-11002 Rev. 1
  - ✓ UAP-SGI-08001 Rev. 4
  - ✓ UAP-SGI-08002 Rev. 3
- DCD Mark-up

Summary

- The gap will increase to 16 inches between standard plant structures, allowing margin for construction tolerances and margin of safety

- Gap closure requirements based on current results
  - ✓7.5 in. (R/B – A/B)