# New Plant Seismic Issues Resolution Program

**Structural Tasks Working Meetings**

**Task S2.1 – Effect of Seismic Wave Incoherence on Foundation and Building Response**


by

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August 24, 2005

## Agenda

- Welcome – Introductions (Hardy)
- Summary of June Meeting Results/Actions for S2.1 – (Hardy)
- NRC June Meeting Feedback on S2.1 (Murphy)
- S2.1 Coherency Function Refinement– (Abrahamson)
- S2.1 Benchmark Problem Comparison – (Short & Ostadan)
- Results from Analysis Cases – (Short & Johnson)
- Bechtel Use of Coherency for DOE – (Ostadan)
- S2.1 Next Steps, Schedule and Milestones – (Johnson)

2

## Abrahamson Coherency Function

$$\gamma_{PW} = \left[1+\left(\frac{f\,Tanh(a_3\xi)}{a_1 f_c}\right)^{n1}\right]^{-1/2}\left[1+\left(\frac{f\,Tanh(a_3\xi)}{a_2 f_c}\right)^{n2}\right]^{-1/2}$$

$$\gamma = |\gamma_{PW}|\left[\cos(2\pi f\xi_R s) + i\sin(2\pi f\xi_R s)\right] = |\gamma_{PW}|e^{i2\pi f\xi_R s}$$

- **where $\gamma$ is the total coherency function and $\gamma_{PW}$ is the plane wave coherency function**
- **For horizontal ground motion : $a_1$=1.647; $a_2$=1.01; $a_3$=0.4; n1=7.02; n2=5.1-0.51ln($\xi$+10); s=0.00025 s/m (c=4000 m/s); $f_c$=-1.886+2.221ln(4000/($\xi$+1)+1.5)**
- **For vertical ground motion : $a_1$=3.15; $a_2$=1.0; $a_3$=0.4; n1=4.95; n2=1.685; s=0.00025 s/m (c=4000 m/s); $f_c$=exp(2.43-0.025 ln($\xi$+1)-0.048 (ln($\xi$+1))$^2$)**

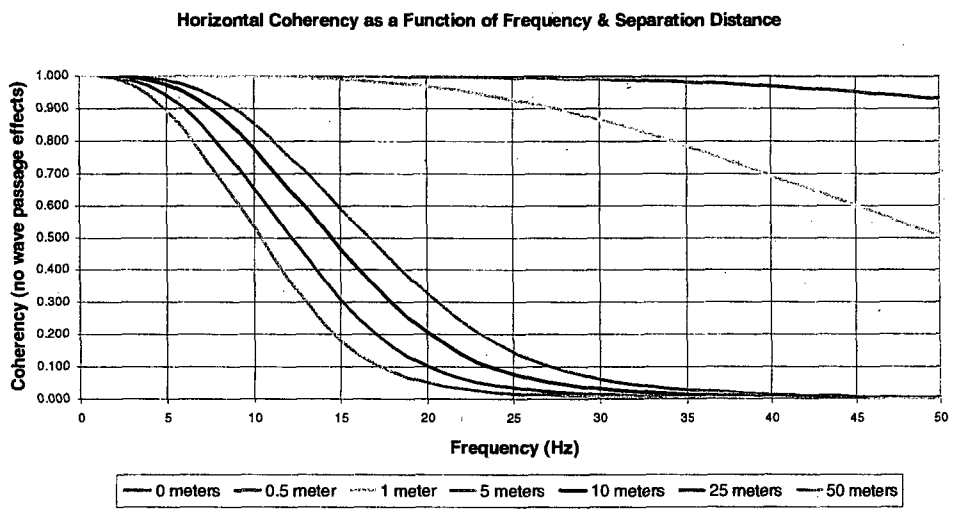
3

## Wave Passage Effects

- **The Abrahamson coherency function accounts for both wave passage effects and random spatial variation**
- **Horizontal Spatial Variation of Ground Motion**
  - **Wave passage effects**
    - Systematic spatial variation due to difference in arrival times of seismic waves across a foundation
  - **Random spatial variation**
    - Scattering of waves due to heterogeneous nature of the soil or rock at the locations of interest and along the propagation paths of the incident wave fields
- **For this project, only random spatial variation of ground motion will be considered**
  - **Random spatial variation results in large reductions in foundation motion**
  - **Wave passage effects produce minimal further reductions**
  - **Assigning an appropriate apparent wave velocity for wave passage effects may be controversial**

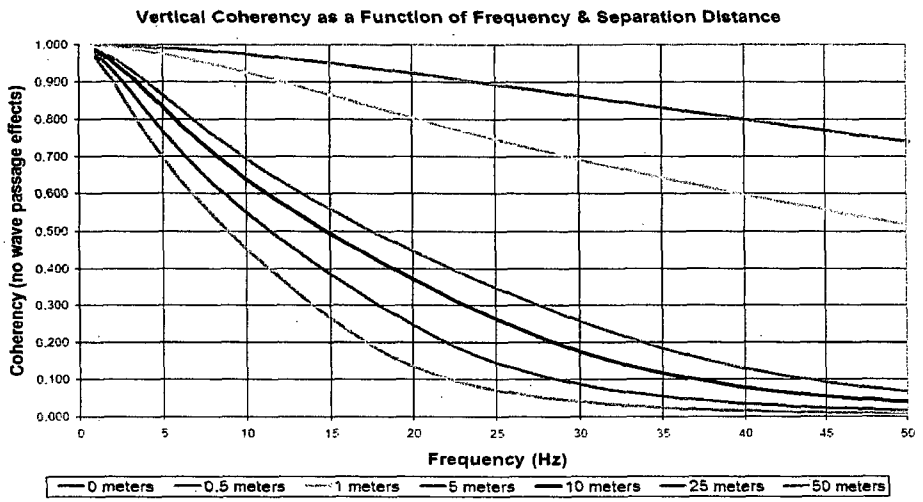
4

# Coherency for Horizontal Motion




5

# Coherency for Vertical Motion




6

## Coherency Function

- Median coherency function has been used for most analyses
- 84 percentile coherency function is now available for horizontal motion. A parametric case will be performed.

$$\gamma_{PW84}(f,\xi) = \tanh\left[\tanh^{-1}(\gamma_{PW}(f,\xi) + \sigma(f,\xi)\right]$$

- Where for frequencies greater than 20 Hz

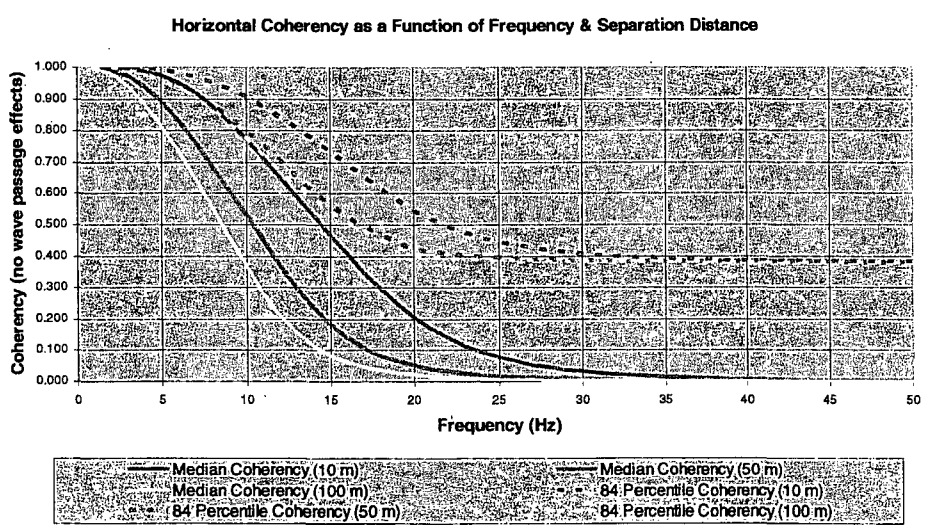
$$\sigma_H(f,\xi) = 0.4$$

- And for frequencies less than or equal to 20 Hz

$$\sigma_H(f,\xi) = 0.4 + (f-20)(-0.0065 - 1.9x10^{-6}\xi^2)$$

7

## Median & 84 Percentile Coherency for Horizontal Motion




8

## Technical Approach

- **Stochastic Approach**
  - Coherency transfer function developed for rigid massless, foundation & validated to be appropriate by evaluating structure response for a typical NPP structure
  - Random Vibration Theory (RVT) to convert response spectra to PSD and PSD to response spectra to determine spectra reductions
- **Coherency as a function of separation distance, frequency, apparent wave velocity, and direction of motion from Dr. Norm Abrahamson**
- **Coherency transfer function and spectra reductions generated for rigid, massless foundation using CLASSI**
  - Intent is to apply the coherency transfer function to Fourier amplitude spectra in the free-field -- the end result being an engineering modified motion accounting for incoherency effects and to be used in subsequent SSI analyses to generate structure response
- **Coherency transfer function and spectra reductions validated for complete SSI using CLASSI**

9

## Response Spectra & Power Spectral Density by Random Vibration Theory

- **Standard relationships of stationary random vibration theory are used to convert response spectra (RS) into power spectral density (PSD) functions and vice versa**
- **To calculate a PSD from a RS, an iterative process is used. A starting PSD uniform function (white noise) is used and iterations performed until the RS calculated from the new PSD matches the target RS**
- **To calculate a RS from a PSD, a direct integral relationship exists. Numerical integration is performed to calculate the moments of the PSD and the peak factors relating the standard deviation of the maximum response to the mean of the maximum peak response (RS)**
- **Der Kiureghian, A., "Structural Response to Stationary Excitation," Journal of the Engineering Mechanics Division, American Society of Civil Engineers, December 1980 is the basic reference followed.**

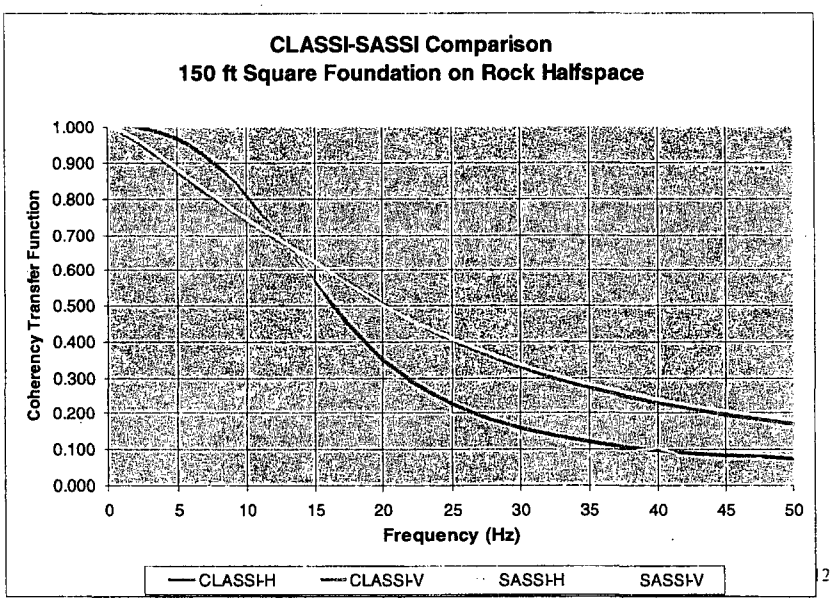
10

## Benchmark Problem Comparison

- The effect of incoherent ground motion has been evaluated by:
  - 2 different programs; CLASSI and SASSI
  - 2 different algorithms; CLASSI-stochastic method and SASSI eigen decomposition method
  - 2 different analytical approaches; RVT by CLASSI; time history by SASSI
- Determine motion of a rigid, massless foundation on a rock halfspace
  - 150 x 150 ft square foundation footprint
  - 6300 fps rock
- Excellent agreement is obtained for both coherency transfer functions and spectra reductions

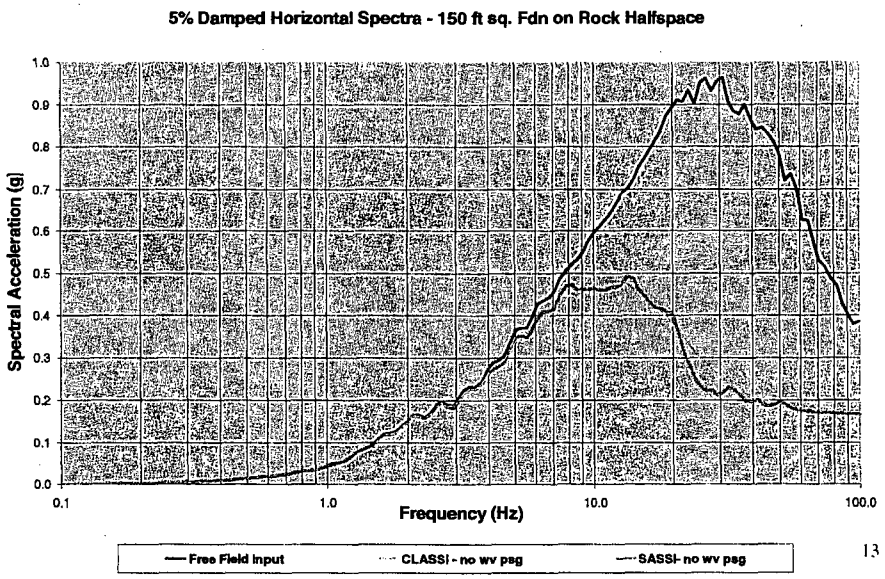
11

## Coherency Transfer Function Comparison



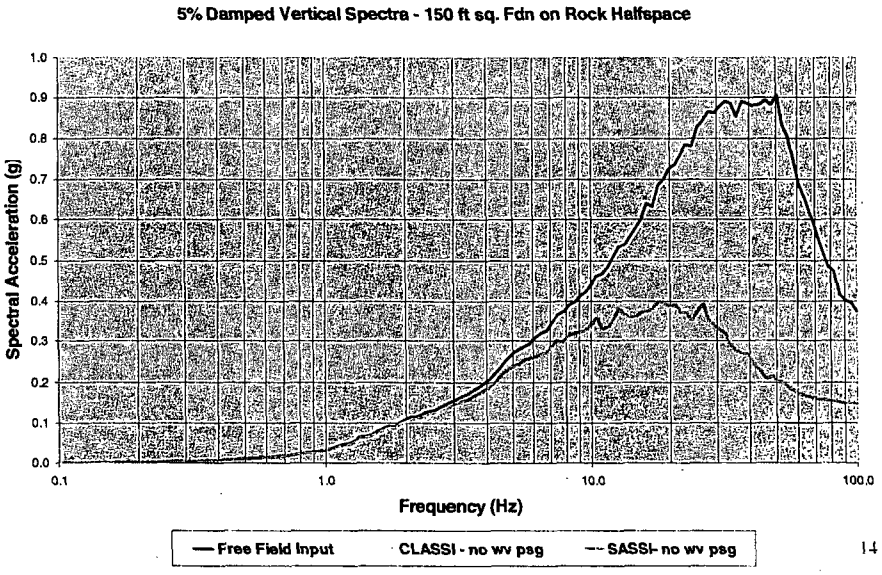

12

## Spectra Reduction Comparison-Horizontal




13

## Spectra Reduction Comparison-Vertical



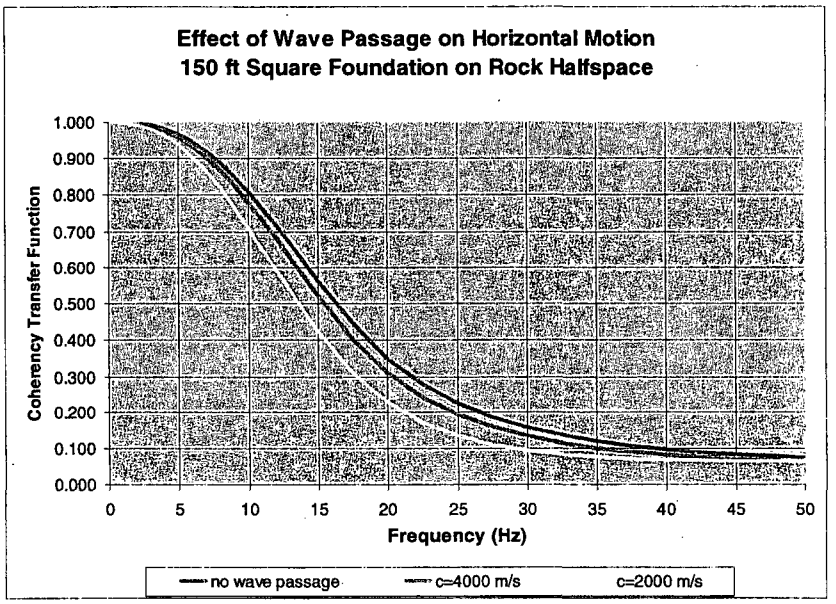

14

## Wave Passage Effects

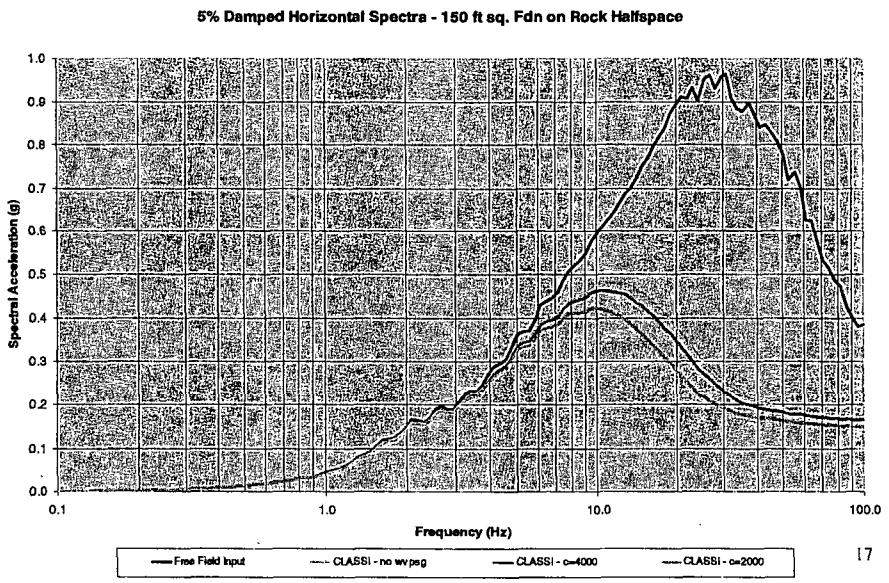
- The 150 foot square foundation on a rock halfspace was also evaluated including wave passage
  - Apparent wave velocity of 4000 m/s
    Slowness of 0.00025 s/m
  - Apparent wave velocity of 4000 m/s
    Slowness of 0.00025 s/m
  - No wave passage effects
    - Apparent wave velocity = infinity
      Slowness of 0 s/m

15

## Wave Passage Effects – Horizontal Motion

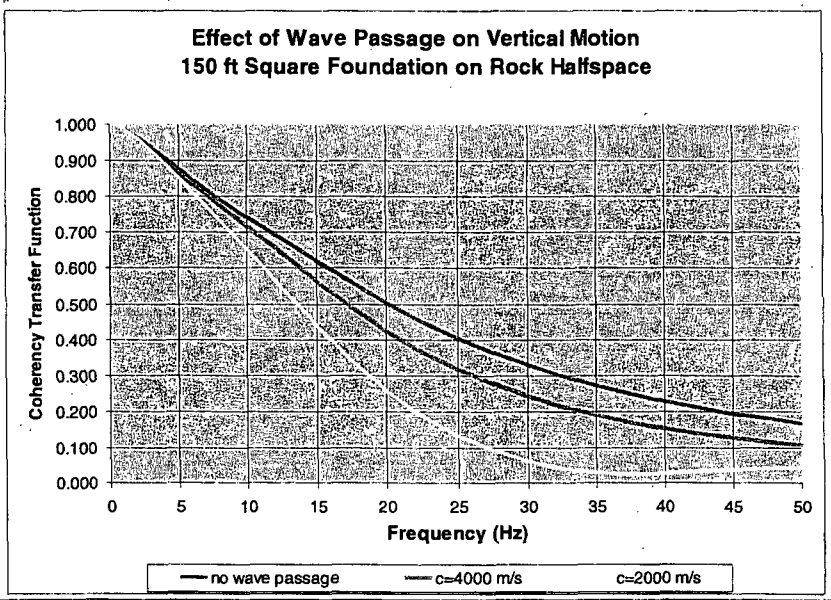


## Wave Passage Effects – Horizontal Motion



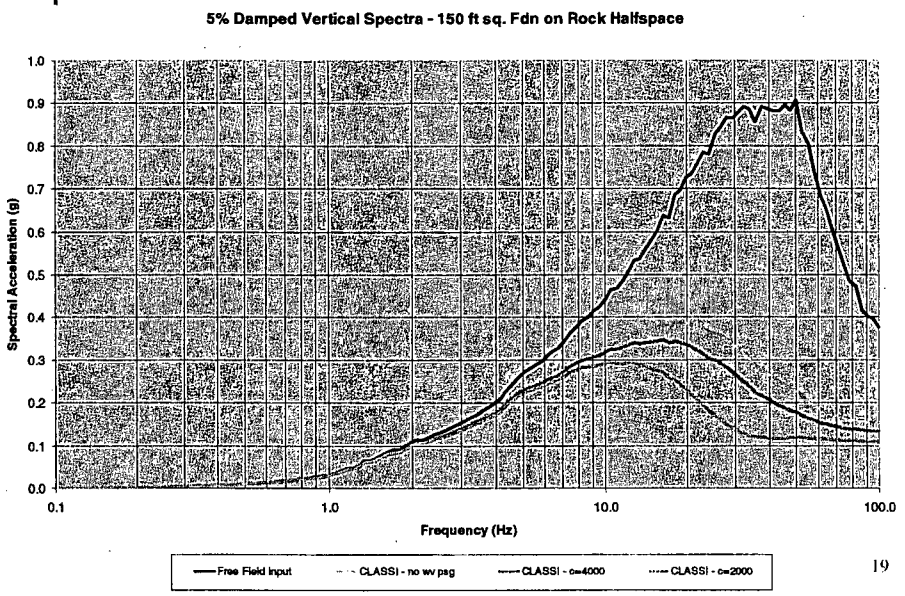

17

## Wave Passage Effects – Vertical Motion



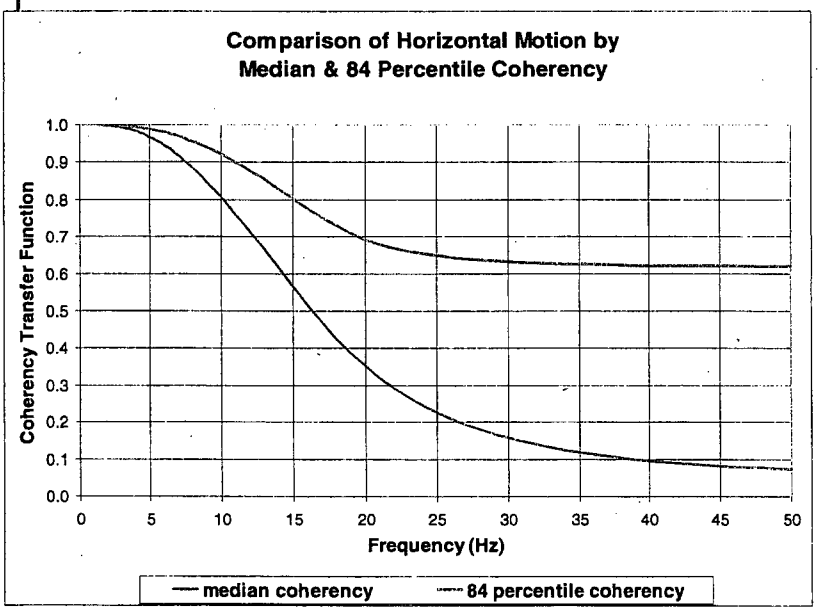

18

# Wave Passage Effects – Vertical Motion



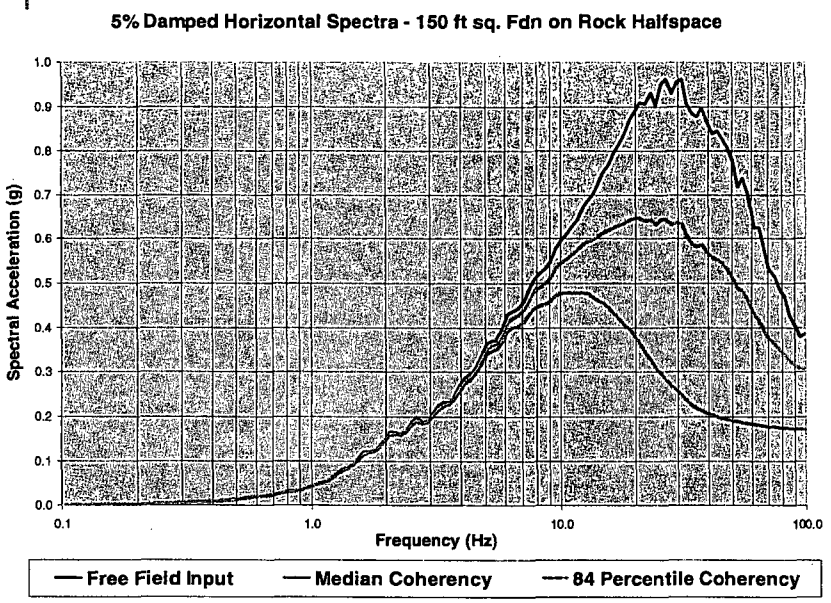

19

# Effect of Coherency Variability




20

## Effect of Coherency Variability (cont.)




21

## Effect of Coherency Variability (cont.) Spectra Reductions

| Frequency | ASCE 4 - 150 ft | Median Coherency | 84 Percentile Coherency |
|---|---|---|---|
| 5 | 1.00 | 0.93 | 0.97 |
| 10 | 0.90 | 0.80 | 0.92 |
| 15 | 0.86 | 0.61 | 0.82 |
| 20 | 0.82 | 0.43 | 0.73 |
| 25 | 0.80 | 0.31 | 0.68 |
| 30 | 0.80 | 0.27 | 0.67 |
| 40 | 0.80 | 0.24 | 0.66 |
| 50 | 0.80 | 0.25 | 0.66 |

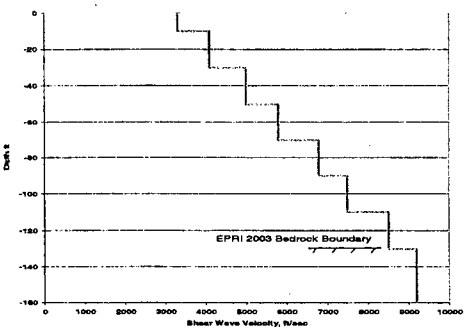
22

## S2.1 Analysis Cases

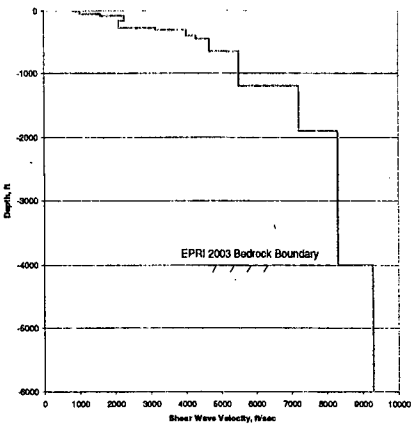
- Parameters
  - Rock Site Profile and High Frequency Spectra
  - Soil Site Profile and Lower Frequency Spectra
  - Foundation Shape, Constant Area
    - 150 foot square footprint
    - 100x225 ft rectangle footprint
  - Foundation Size
    - 75 foot square footprint
    - 150 foot square footprint
    - 300 foot square footprint
  - Coherency Transfer Function and Spectra Reduction
  - Median and 84 percentile Coherency

23

## S2.1 Soil Profiles



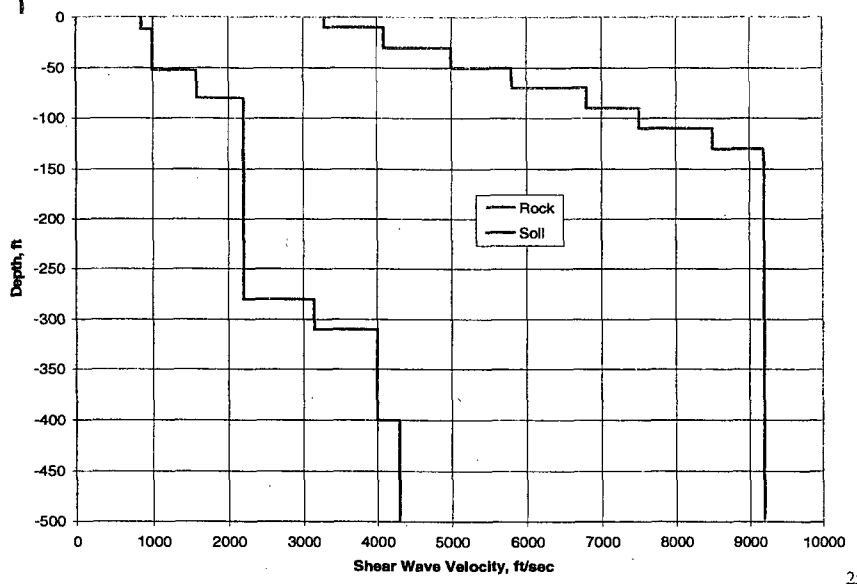

High Frequency Rock Site




Lower Frequency Soil Site

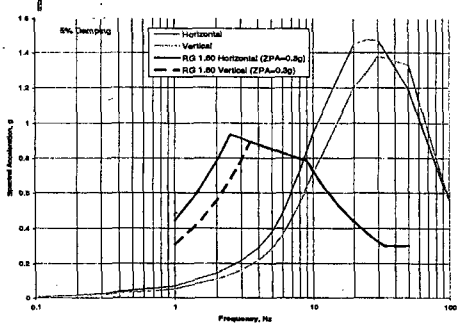
24

## Rock and Soil Profiles within 500 feet of Surface

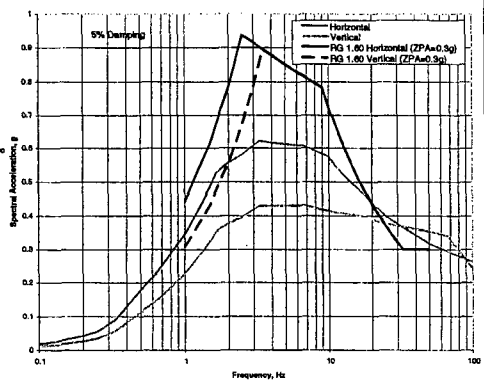



25

## S2.1 Ground Response Spectra



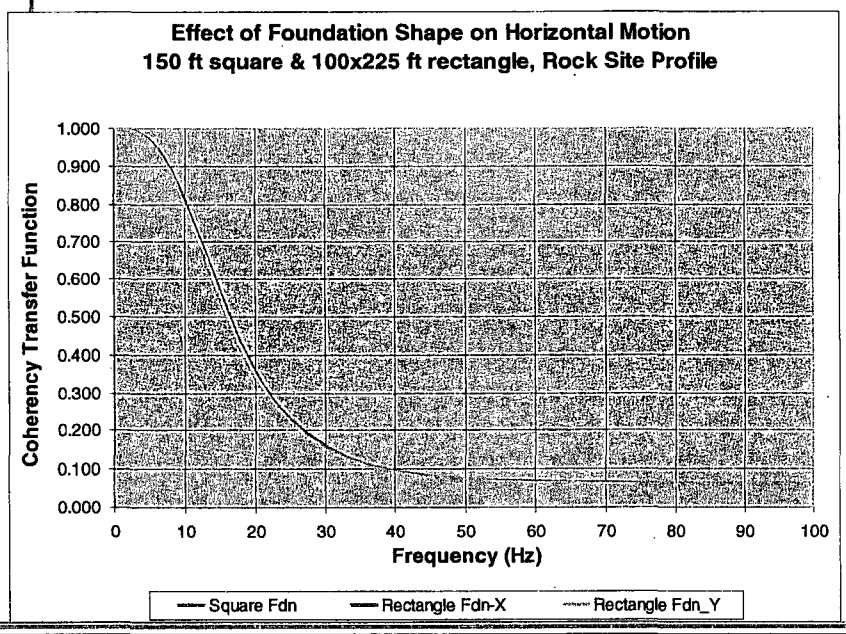

**Site specific response spectra for Rock Site**




**Site specific response spectra for Soil Site**

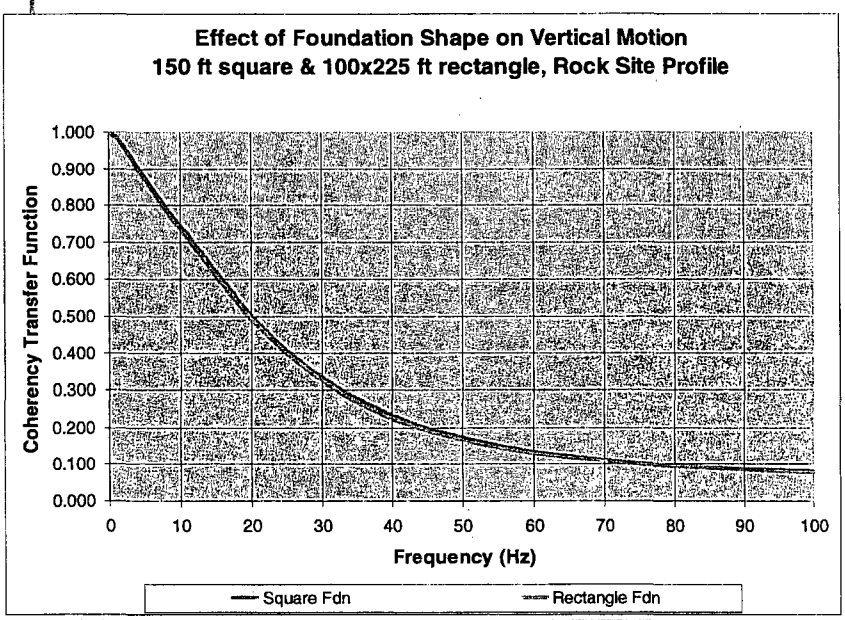
26

## S2.1 Results



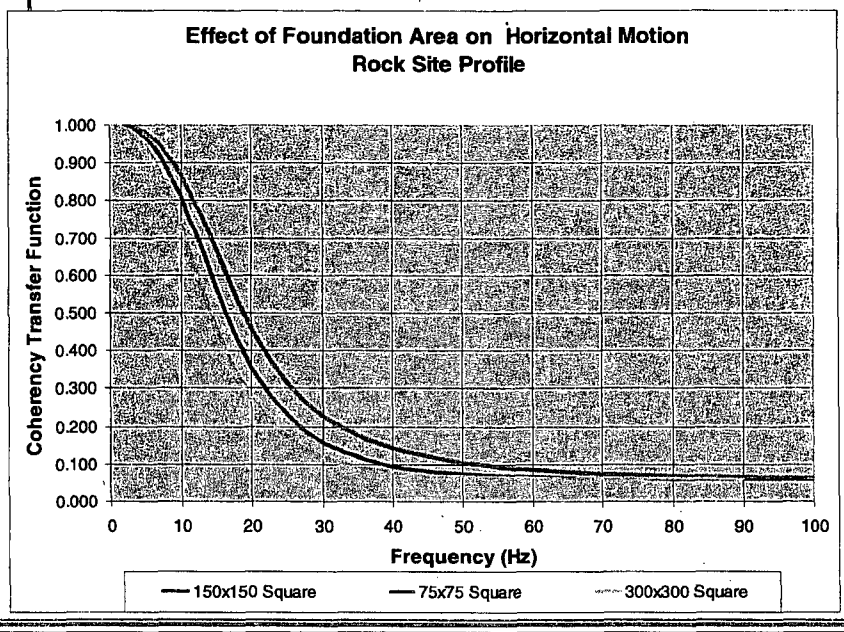

27

## S2.1 Results (cont.)



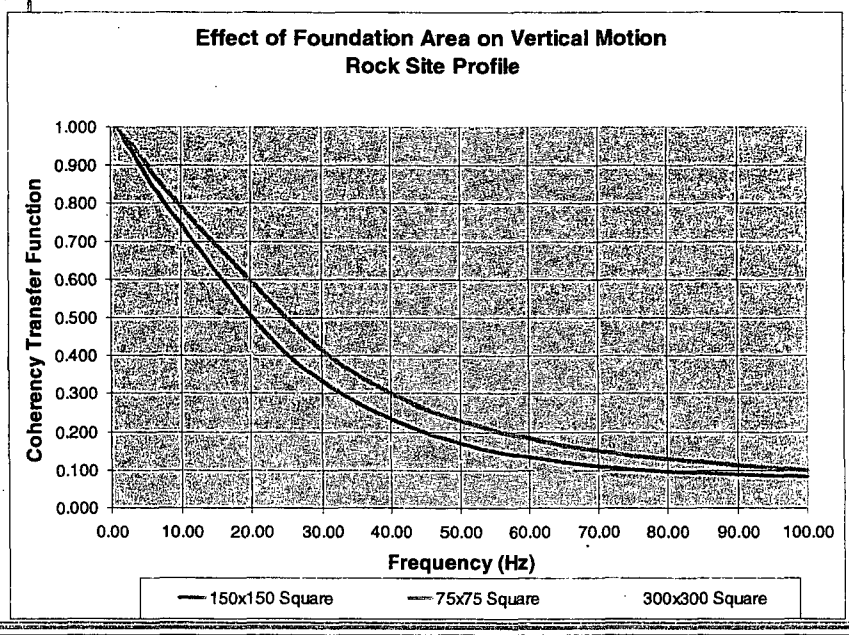

28

## S2.1 Results (cont.)




29

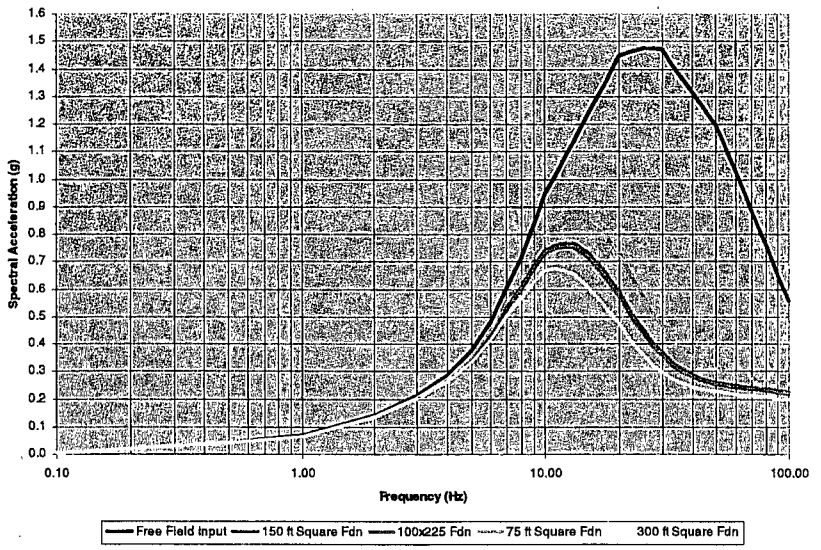
## S2.1 Results (cont.)




30

## S2.1 Results (cont.)

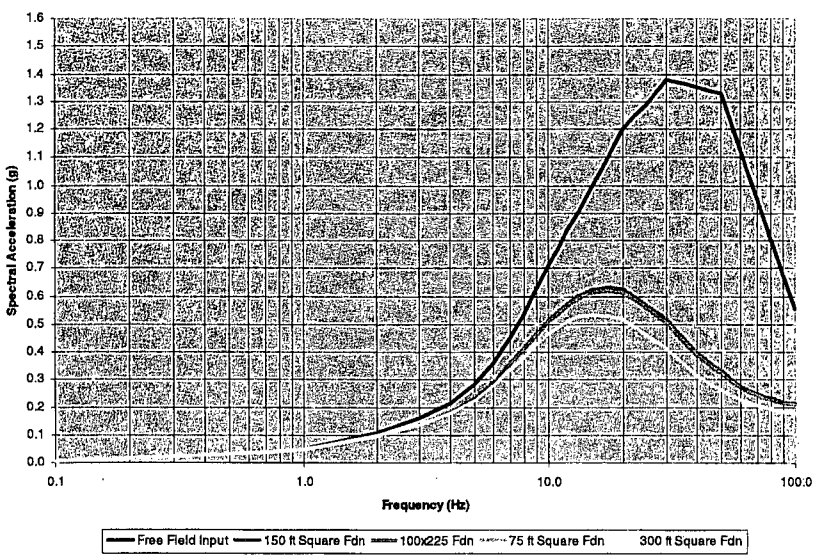
**Horizontal Spectra Reduction due to Incoherency, Rock Site Profile**




31

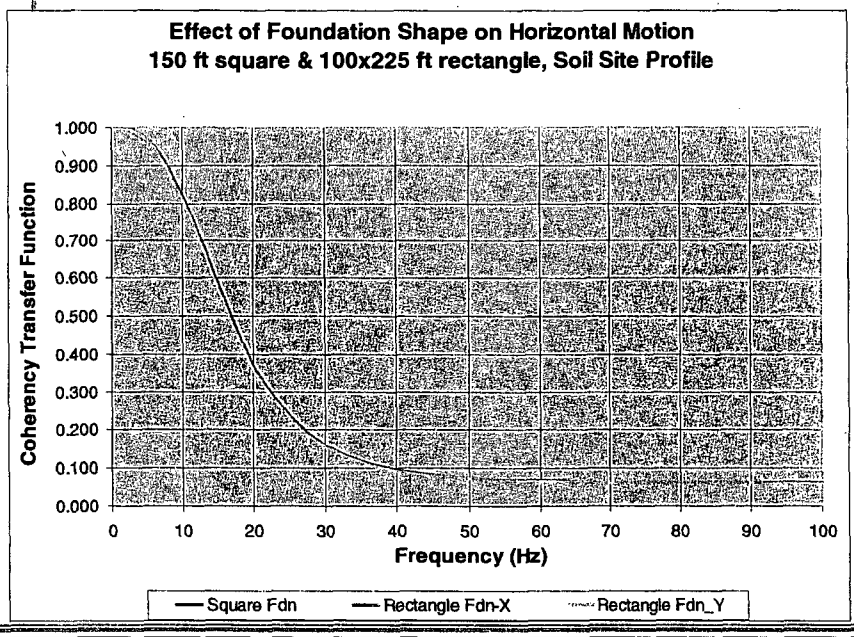
## S2.1 Results (cont.)

**Vertical Spectra Reduction due to Incoherency, Rock Site Profile**



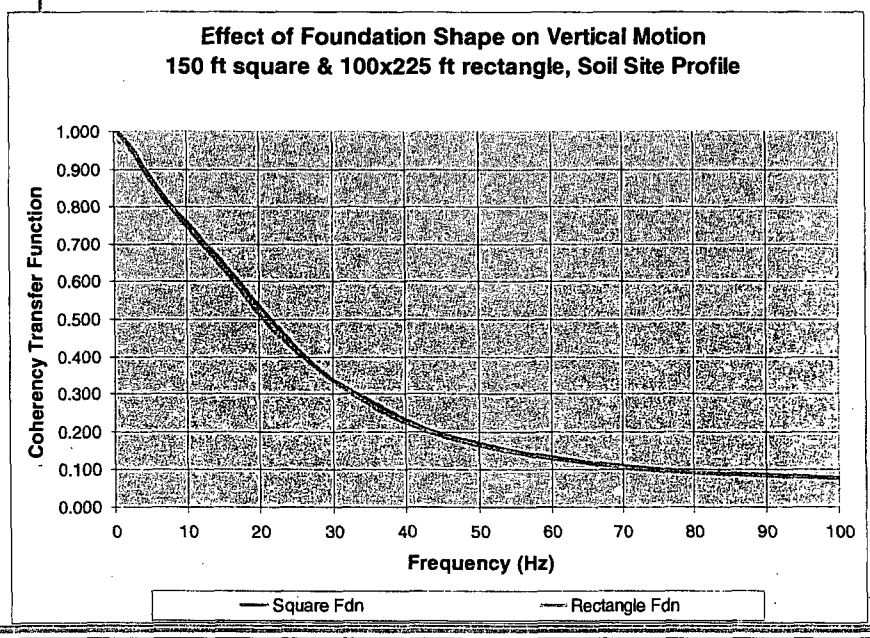

32

## S2.1 Results (cont.)



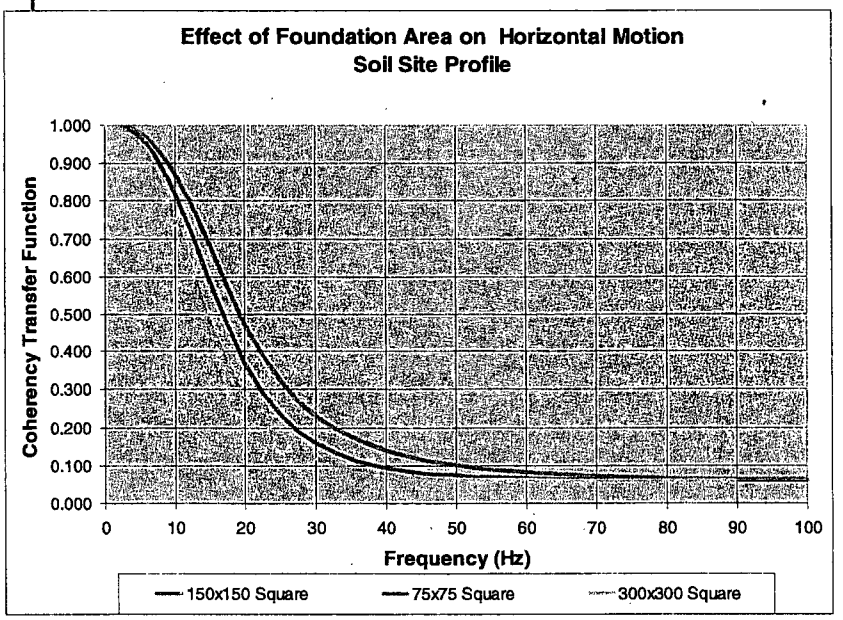

33

## S2.1 Results (cont.)



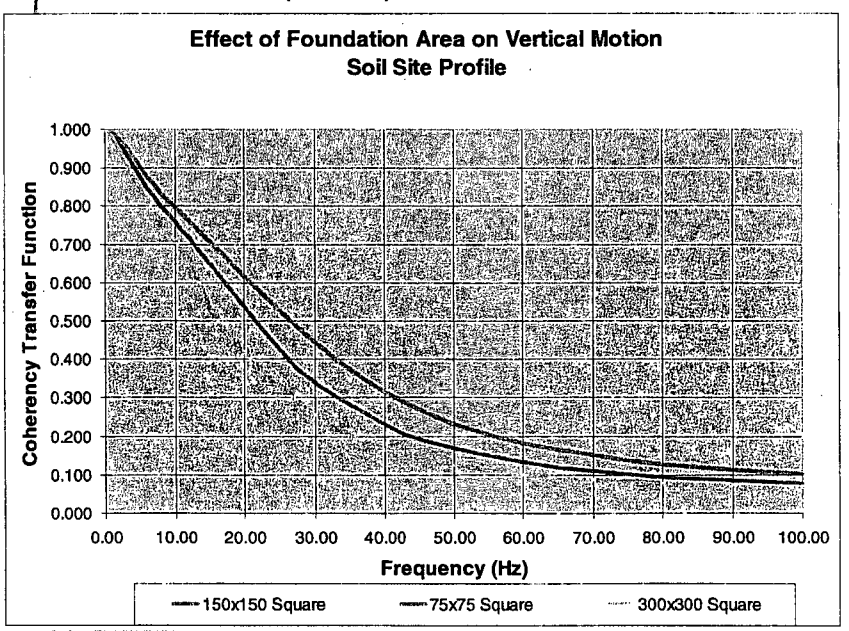

34

## S2.1 Results (cont.)



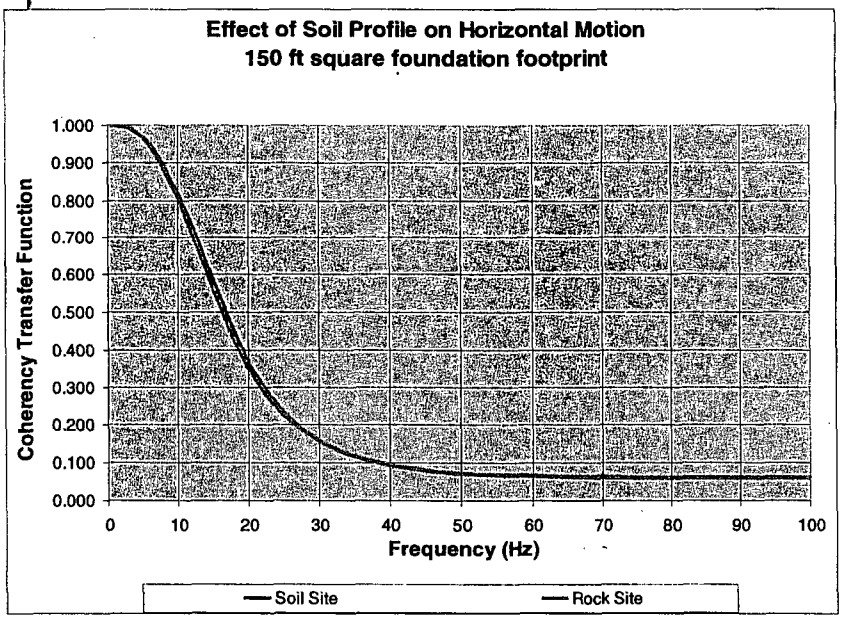

35

## S2.1 Results (cont.)



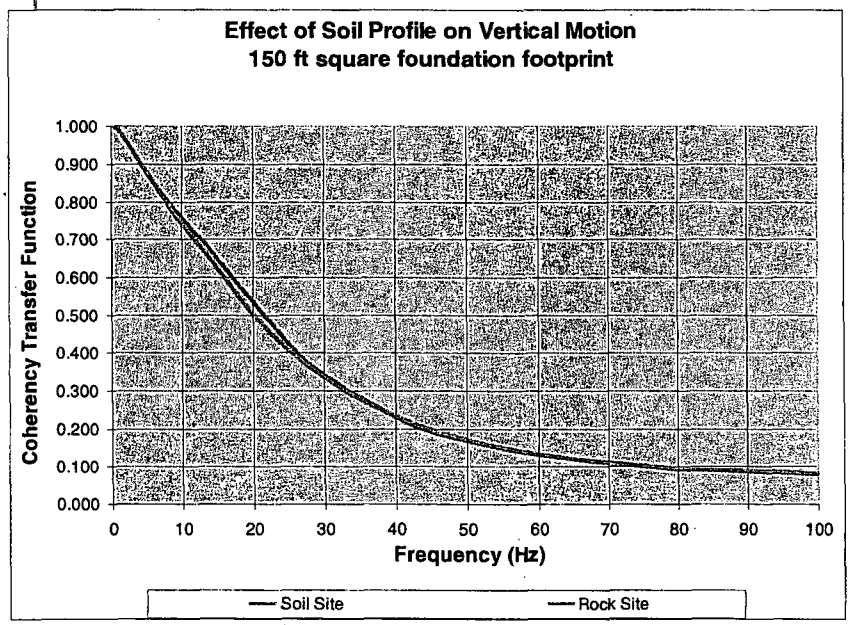

36

## S2.1 Results (cont.)




37

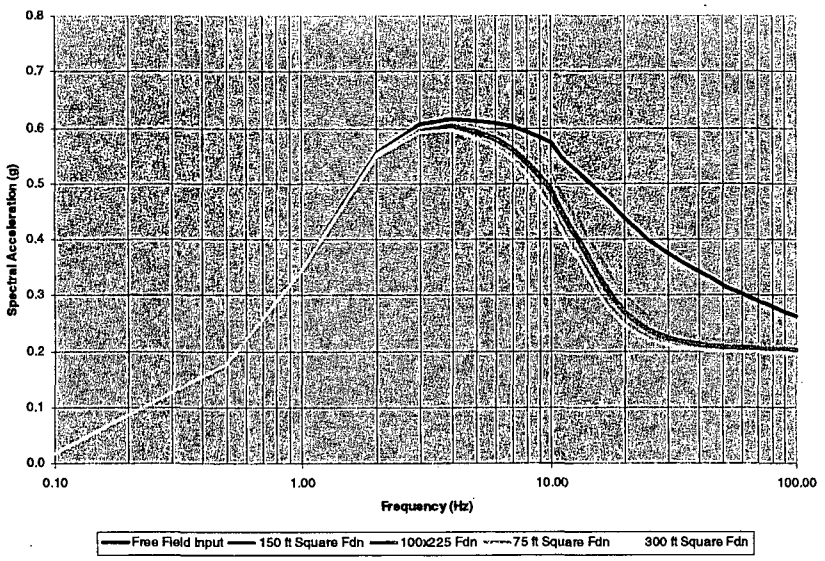
## S2.1 Results (cont.)




38

## S2.1 Results (cont.)

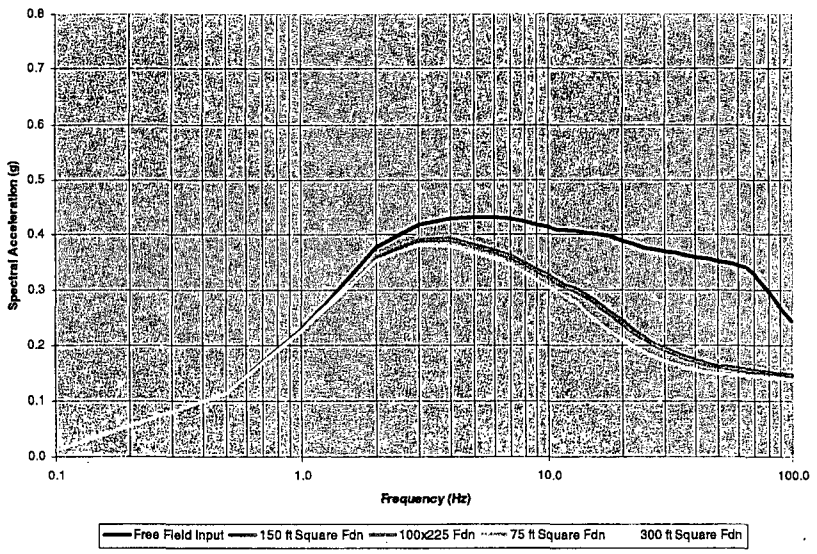
**Horizontal Spectra Reduction due to Incoherency, Soil Site Profile**




39

## S2.1 Results (cont.)

**Vertical Spectra Reduction due to Incoherency, Soil Site Profile**




40

## Spectra Reductions for Horizontal Motion

| | ASCE 4 | | Rock-H | | | Soil-H | | |
|---|---|---|---|---|---|---|---|---|
| Frequency | 150 | 300 | 75 | 150 | 300 | 75 | 150 | 300 |
| 5.00 | 1.00 | 1.00 | 0.95 | 0.93 | 0.89 | 0.98 | 0.97 | 0.95 |
| 10.00 | 0.90 | 0.80 | 0.84 | 0.78 | 0.71 | 0.90 | 0.85 | 0.79 |
| 15.00 | 0.86 | 0.71 | 0.68 | 0.59 | 0.49 | 0.78 | 0.71 | 0.63 |
| 20.00 | 0.82 | 0.65 | 0.50 | 0.41 | 0.33 | 0.68 | 0.62 | 0.56 |
| 25.00 | 0.80 | 0.60 | 0.38 | 0.30 | 0.24 | 0.64 | 0.60 | 0.55 |
| 30.00 | 0.80 | 0.60 | 0.32 | 0.25 | 0.20 | 0.64 | 0.60 | 0.56 |
| 40.00 | 0.80 | 0.60 | 0.27 | 0.22 | 0.19 | 0.65 | 0.62 | 0.59 |
| 50.00 | 0.80 | 0.60 | 0.26 | 0.22 | 0.19 | 0.68 | 0.66 | 0.63 |

41

## Spectra Reductions for Vertical Motion

| | ASCE 4 | | Rock-V | | | Soil-V | | |
|---|---|---|---|---|---|---|---|---|
| Frequency | 150 | 300 | 75 | 150 | 300 | 75 | 150 | 300 |
| 5.00 | 1.00 | 1.00 | 0.88 | 0.85 | 0.80 | 0.91 | 0.89 | 0.86 |
| 10.00 | 0.90 | 0.80 | 0.78 | 0.73 | 0.66 | 0.83 | 0.79 | 0.74 |
| 15.00 | 0.86 | 0.71 | 0.69 | 0.62 | 0.54 | 0.76 | 0.71 | 0.62 |
| 20.00 | 0.82 | 0.65 | 0.61 | 0.52 | 0.43 | 0.69 | 0.63 | 0.54 |
| 25.00 | 0.80 | 0.60 | 0.53 | 0.44 | 0.36 | 0.64 | 0.57 | 0.50 |
| 30.00 | 0.80 | 0.60 | 0.46 | 0.38 | 0.30 | 0.59 | 0.52 | 0.46 |
| 40.00 | 0.80 | 0.60 | 0.36 | 0.29 | 0.23 | 0.53 | 0.48 | 0.43 |
| 50.00 | 0.80 | 0.60 | 0.31 | 0.25 | 0.20 | 0.50 | 0.46 | 0.42 |

42

## Bechtel Use of Coherency for DOE

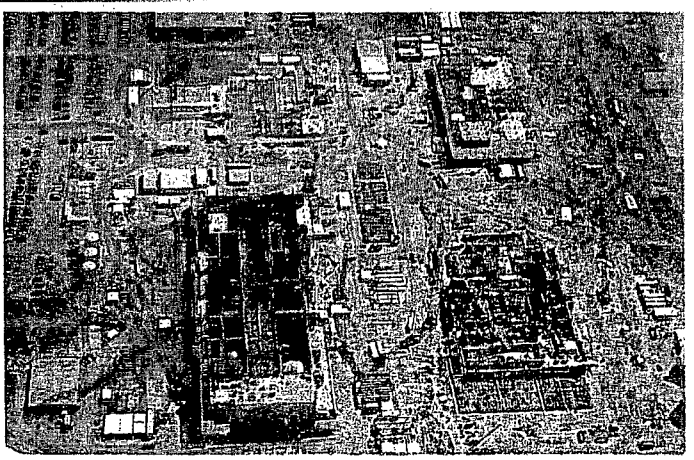
- Application to WTP PC3 Structure
- DOE/DNFSB Meeting of July 22, 2005
  - Attendees
  - Agenda
  - Current Status
  - Parametric Study

- SMiRT18th Paper Presented in August 2005, Beijing
- Yucca Mountain Surface Facility

43

## Bechtel Use of Coherency for DOE

WTP Site 4/19/2005



3 44

## High Level Waste Building – Layout Description

- **Four Story Building**
  - Basemat Below Grade (-21'-0")
  - 4 Stories (0'-0", 14'-0", 37'-0", 58'-0")
  - Roof Truss (86'-0" Bottom of truss)
- **Dimensions of the Building**
  - 281' Wide x 448' Long
  - 120' Tall (Bottom of Mat @ -21' to Roof Peak)

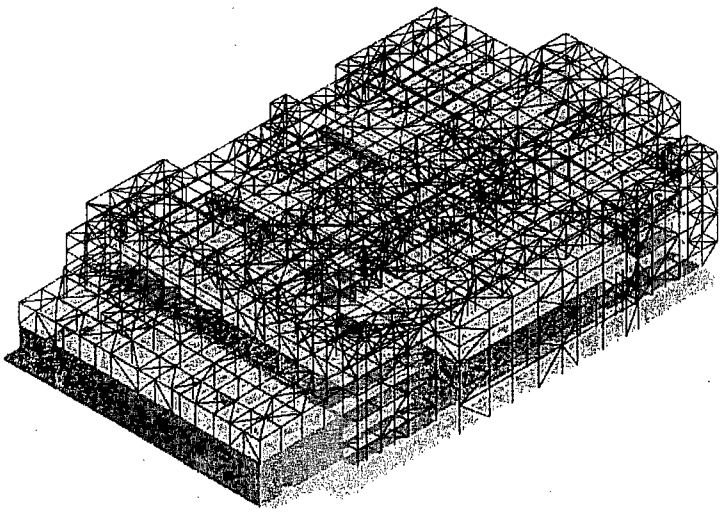
45

## High Level Waste Building – Layout Description

- **Concrete**
  - Mat Foundation - 6 ft thick
    - 256' x 326'
    - Basemat at TOC Elev. –21', Except –31' at Handling Tunnel Area & Elevator Pits
  - Walls to Elevation 58'
    - As Required for Shielding (3' to 4' thick typ.)
    - Utilized as Shear Walls
  - Floor Diaphragms
    - Elevations 0', 14', 37', 58'

46

## High Level Waste Building – Dynamic Model



HLW Building (Rev 0D)

47

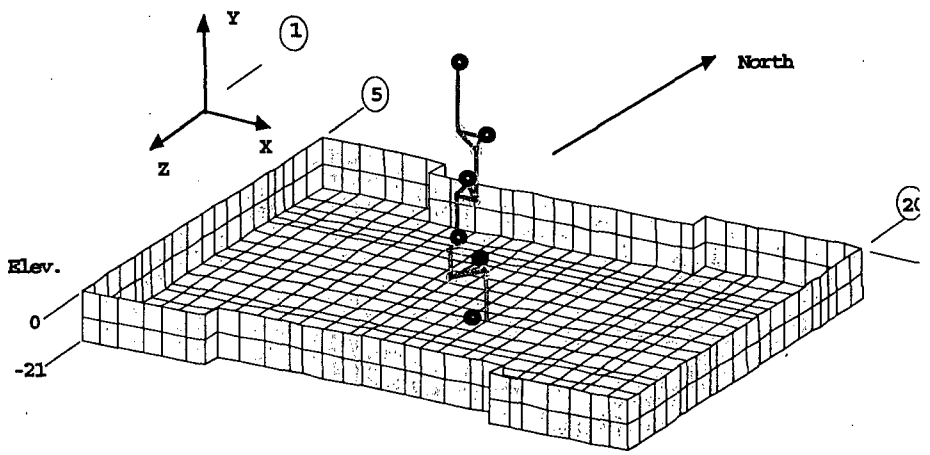
## High Level Waste Building – Dynamic Model

**Fixed Base Fundamental Frequencies (Hz)**

| Description | Rev 0C | Rev 0D | |
|---|---|---|---|
| | | Uncracked | Cracked |
| Stack N-S | 2.16 | 2.27 | 2.25 |
| Stack E-W | 2.47 | 2.63 | 2.62 |
| Steel Superstructure N-S | 4.86 | 5.40 | 5.36 |
| Steel Superstructure E-W | 5.43 | 5.64 | 5.59 |
| Concrete Walls N-S | 10.71 | 11.02 | 10.82 |
| Concrete Walls E-W | 8.66 | 8.91 | 8.74 |

48

## Ground Motion Coherency Task – WTP Study Case

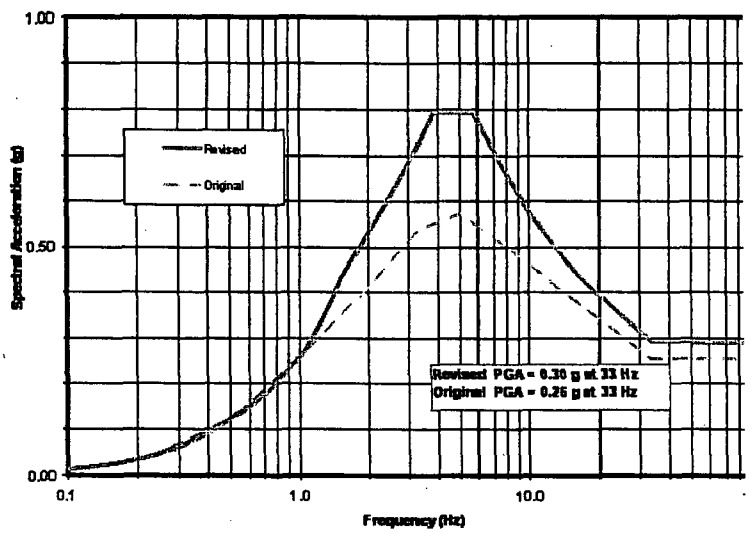



SASSI Beam Stick Model of the HLW Building

49

## Changes in Analysis Approach (SADC, Rev. 1) – Design Motion

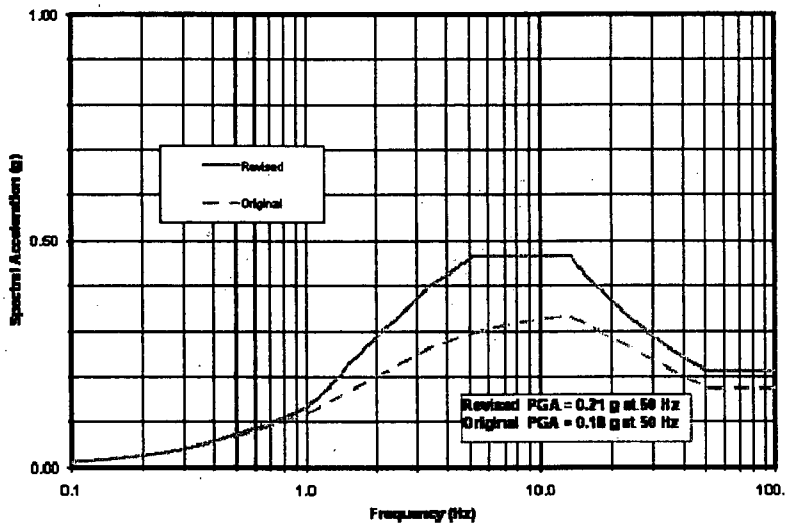
**RPP-WTP Original and Revised DBE Horizontal Response Spectra (5% Damping)**




50

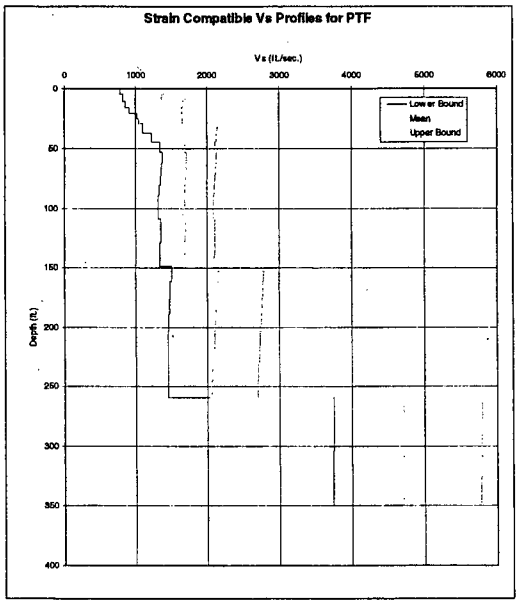
## Changes in Analysis Approach (SADC, Rev. 1) – Design Motion

**RPP-WTP Original and Revised DBE Vertical Response Spectra (5% Damping)**




51

## Soil Profile




52

## Ground Motion Coherency Task – WTP Study Case

- SSI analysis was performed with the hybrid stick/finite element model of HLW building (Rev 0B) for the upper bound soil case
- Two cases were analyzed:
  1. surface foundation,
  2. embedded foundation
- For each case the results of fully coherent wave are compared with those obtained from NA model

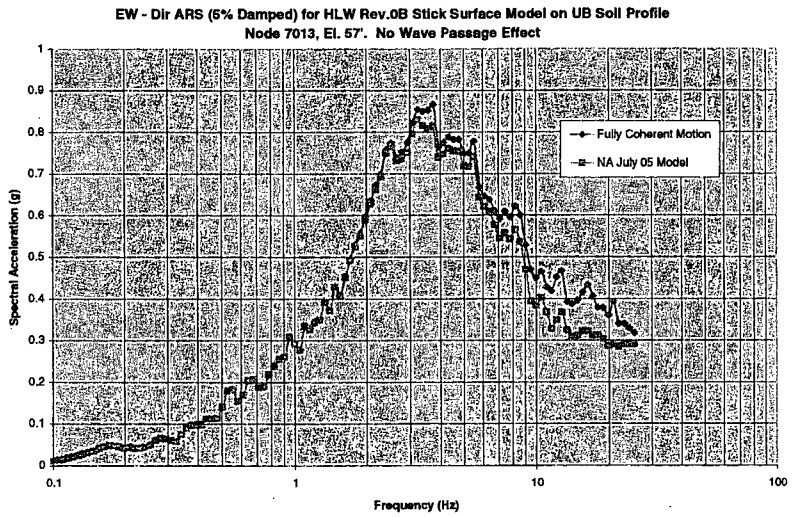
53

## Ground Motion Coherency Task – WTP Study Case

**Surface Foundation**

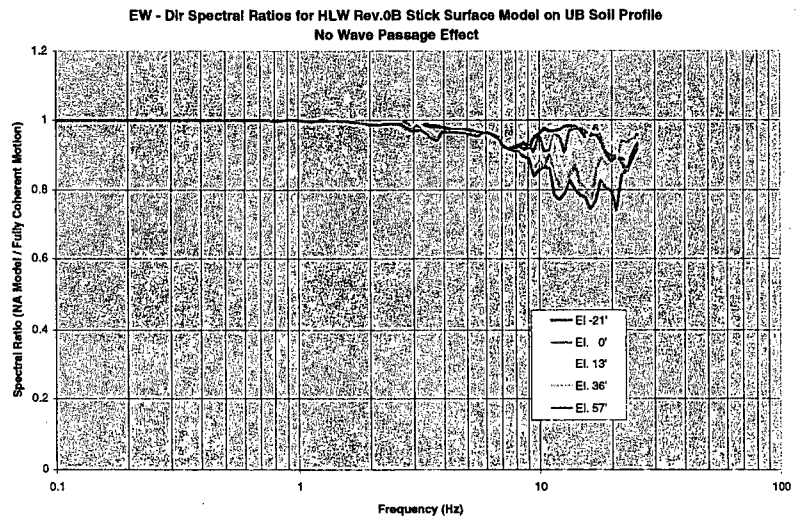
54

# Ground Motion Coherency Task – WTP Study Case




55

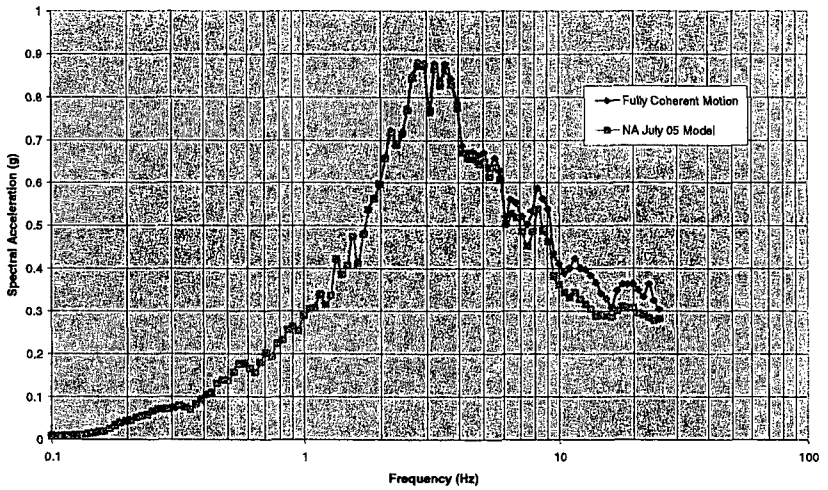
# Ground Motion Coherency Task – WTP Study Case




56

## Ground Motion Coherency Task – WTP Study Case

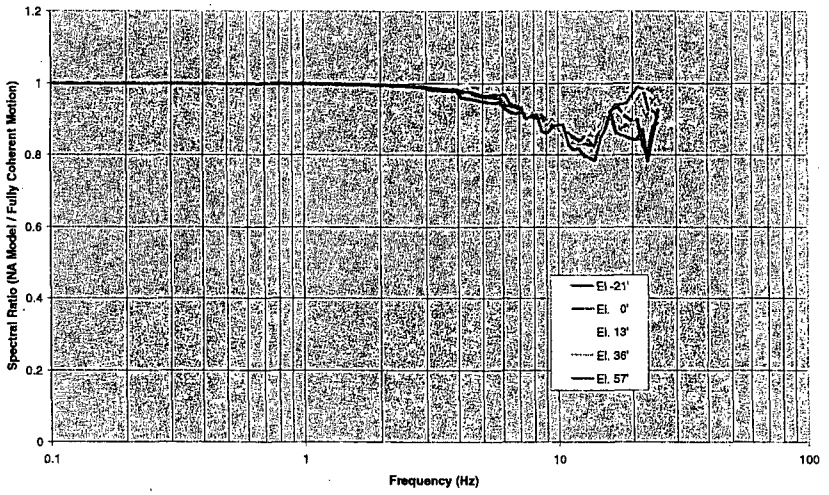
**NS - Dir ARS (5% Damped) for HLW Rev.0B Stick Surface Model on UB Soil Profile**
**Node 7013, El. 57'. No Wave Passage Effect**




57

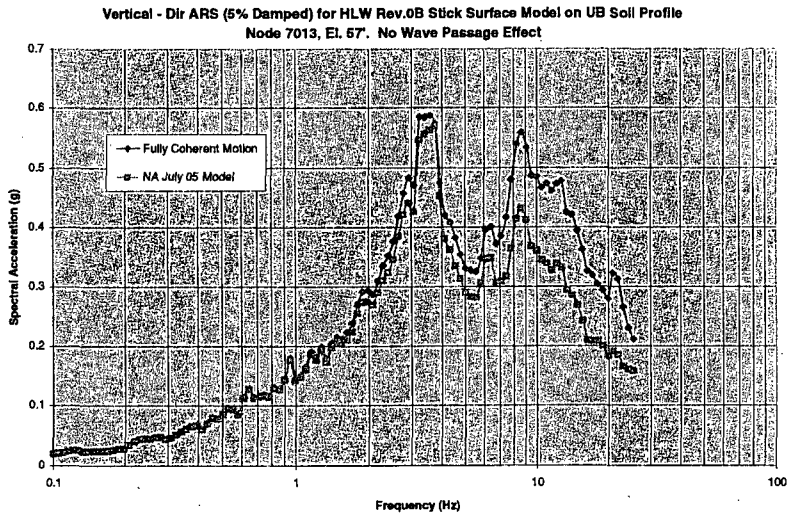
## Ground Motion Coherency Task – WTP Study Case

**NS - Dir Spectral Ratios for HLW Rev.0B Stick Surface Model on UB Soil Profile**
**No Wave Passage Effect**



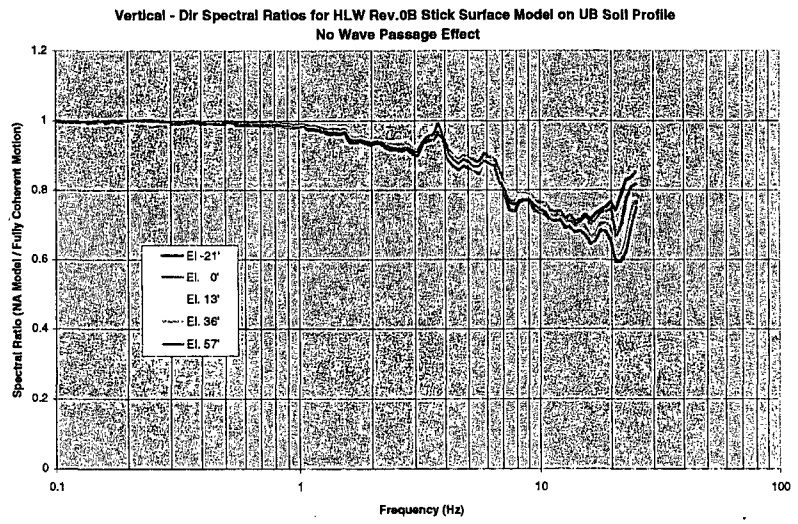

58

# Ground Motion Coherency Task – WTP Study Case




59

# Ground Motion Coherency Task – WTP Study Case



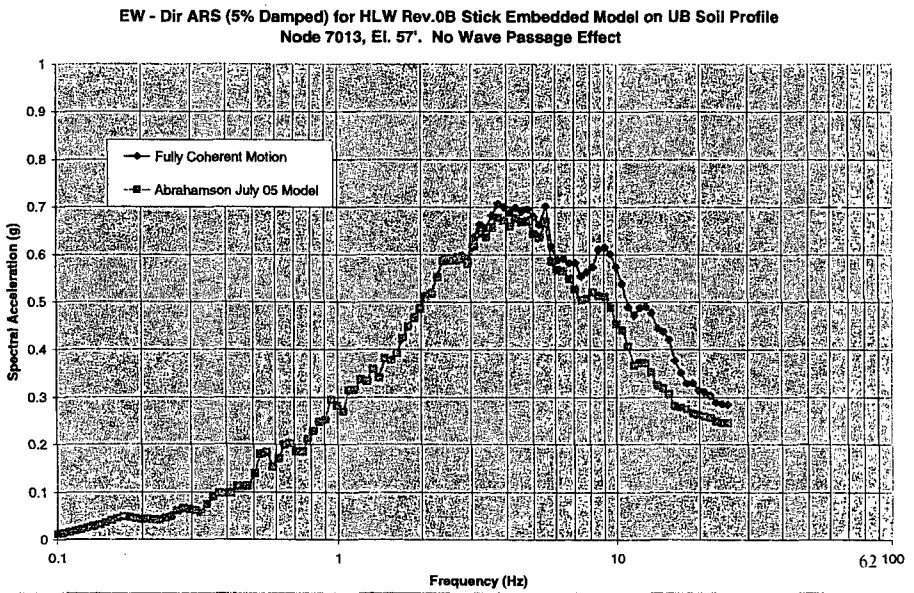

60

## Ground Motion Coherency Task – WTP Study Case

**Embedded Foundation**

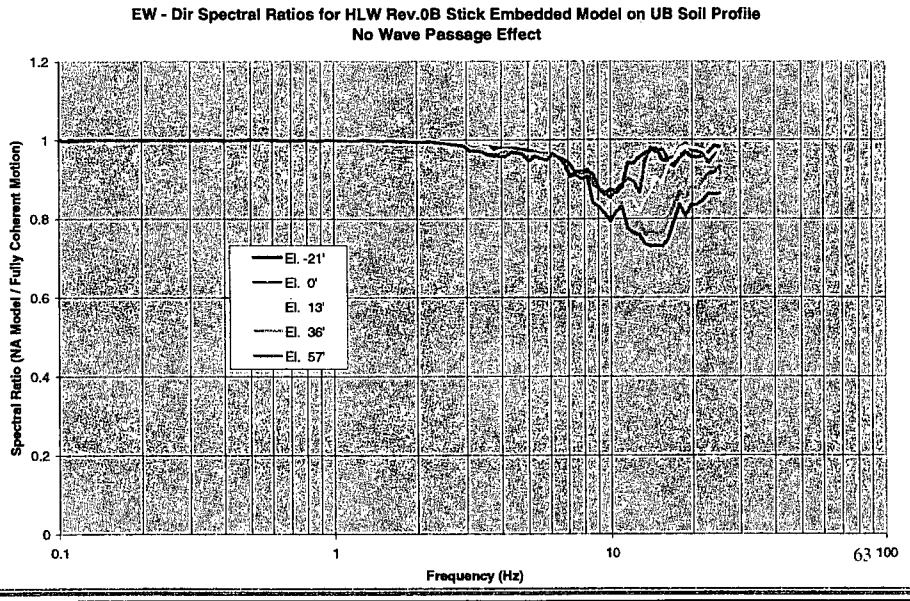
61

## Ground Motion Coherency Task – WTP Study Case



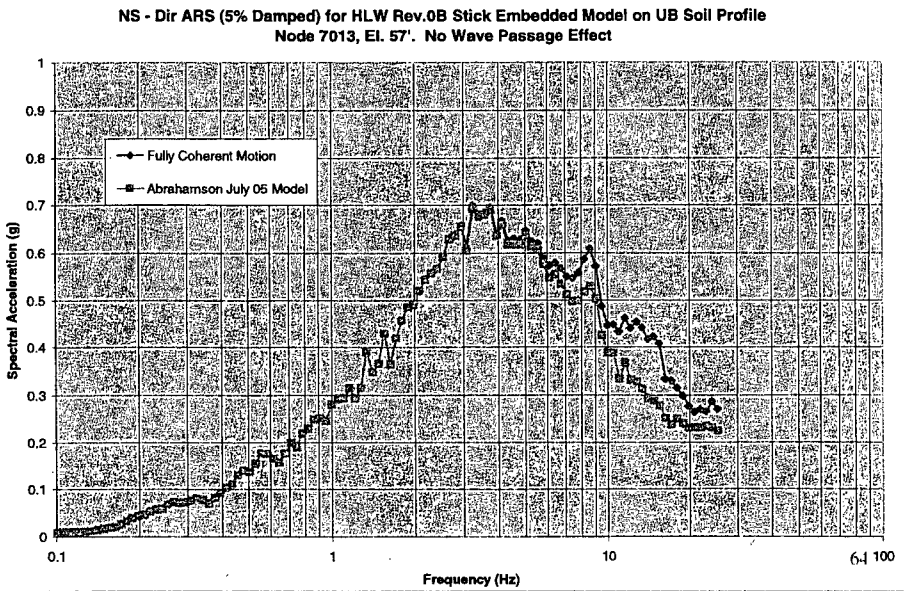

62

## Ground Motion Coherency Task – WTP Study Case




63

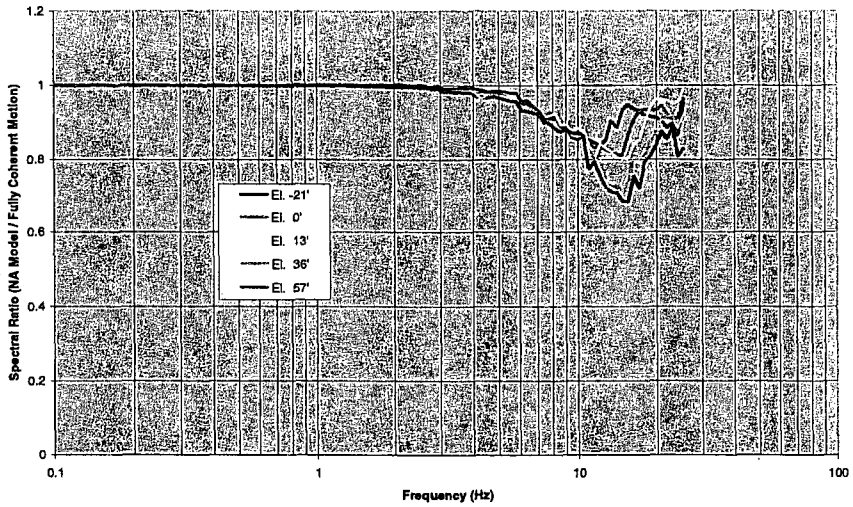
## Ground Motion Coherency Task – WTP Study Case




64

# Ground Motion Coherency Task – WTP Study Case

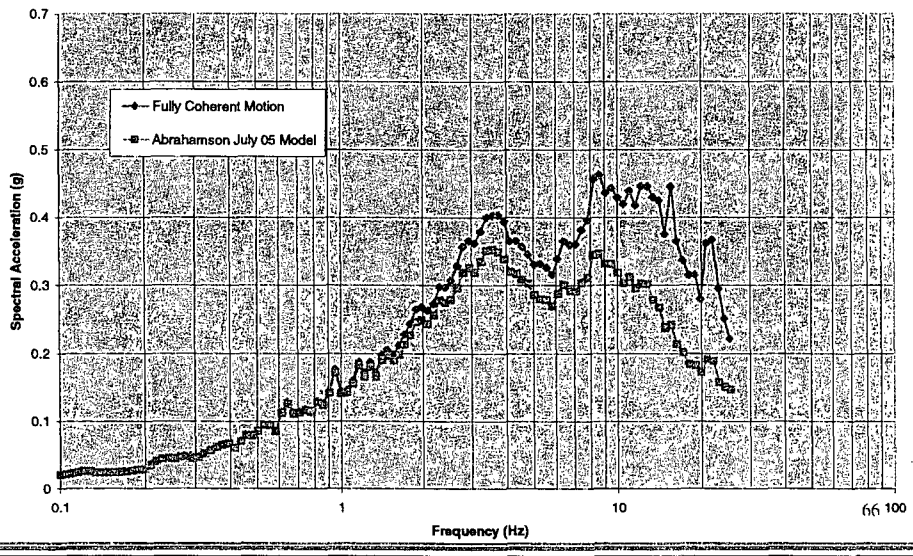
**NS - Dir Spectral Ratios for HLW Rev.0B Stick Embedded Model on UB Soil Profile**
**No Wave Passage Effect**




65

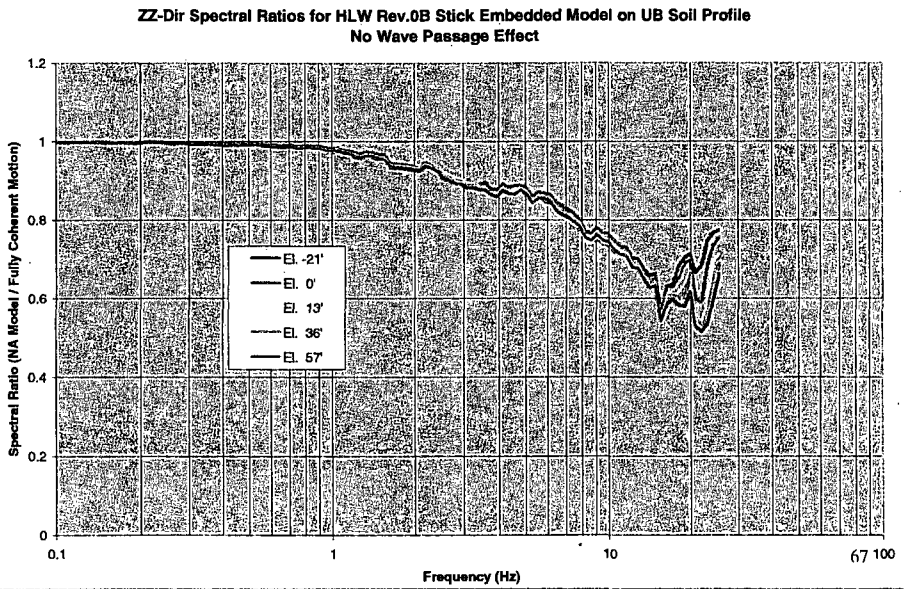
# Ground Motion Coherency Task – WTP Study Case

**Vertical - Dir ARS (5% Damped) for HLW Rev.0B Stick Embedded Model on UB Soil Profile**
**Node 7013, El. 57'. No Wave Passage Effect**




66

## Ground Motion Coherency Task – WTP Study Case




## Ground Motion Coherency Task – WTP Application

- The implementation of the model in SASSI is completed
- Additional set of SSI analysis will be performed using Abrahamson coherent model in August-October
- The results of SSI coherency analysis will be used in the design of SSCs

68

## Ground Motion Coherency Task – WTP Application

- SMiRT18th Paper Presented in August 2005, Beijing
  - (F Ostadan, N Deng, R Kennedy)
- Yucca Mountain Surface Facility
  - Three very large concrete shear wall structures, effectively surface foundations
  - High ground motion
  - Plan to use the incoherency effects (2005-2006) program

69

## S2.1 Next Steps, Schedule and Milestones

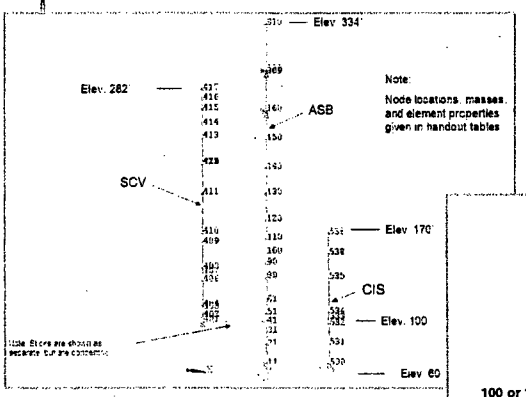
70

## S2.1 Additional Analysis Cases

- **SSI inertial interaction foundation & structure response**
  - 1 site condition/ground motion (rock profile, high frequency spectra)
  - 1 foundation footprint (150 foot square)
  - 1 structural model (AP1000 3-stick model)
  - 3 directions - H1; H2; V
  - 2 coherency functions; NAA, coherent motion
- **Parametric Studies**
  - Embedment; foundation flexibility performed in SASSI by Bechtel and compare coherency transfer functions and spectral reductions with those of the CLASSI surface rigid case

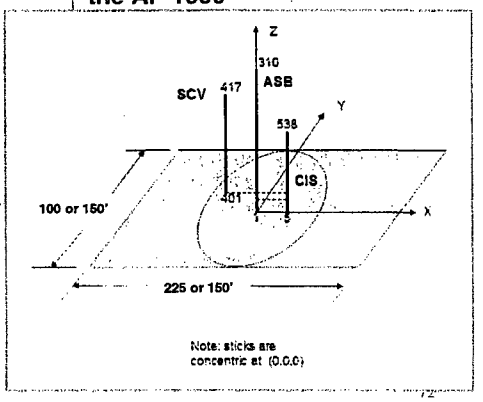
71

## S2.1 Structural Model




**The main containment/auxiliary building stick model for the AP 1000 design will be used.**

**This model includes the following three sticks representing concentric parts of the AP 1000**



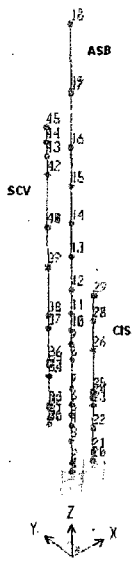

**Coupled Auxiliary & Shield Building (ASB)**

**Steel Containment Vessel (SCV)**

**Containment Internal Structure (CIS)**

72

## Stick Model Configuration




**ASB: Auxiliary/Shield Building**

**CIS: Containment Internal Structure**

**SCV: Steel Containment Vessel**

73

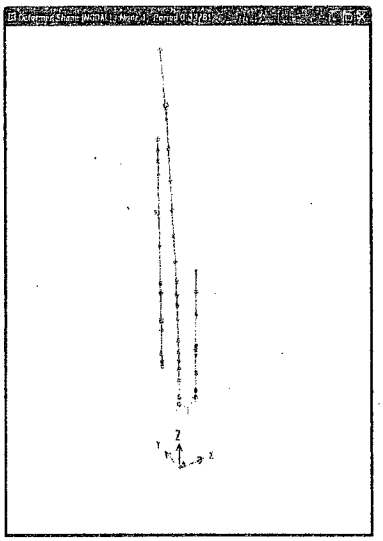
## Significant Modes – Mass Participation

| Mode | Freq (Hz) | Mass Participation Ratio X | Y | Z | Description |
|---|---|---|---|---|---|
| 1 | 3.00 | 0.000 | 0.215 | 0.000 | ASB Y-direction mode |
| 2 | 3.21 | 0.199 | 0.000 | 0.000 | ASB X-direction mode |
| 5 | 5.46 | 0.031 | 0.000 | 0.000 | SCV X-direction mode |
| 6 | 6.14 | 0.000 | 0.053 | 0.000 | SCV Y-direction mode |
| 11 | 9.47 | 0.000 | 0.216 | 0.000 | ASB Y-direction mode.<br>CIS Y-direction mode |
| 13 | 9.85 | 0.000 | 0.000 | 0.253 | ASB Z-direction mode |
| 14 | 9.89 | 0.163 | 0.000 | 0.000 | ASB X-direction mode.<br>CIS X-direction mode.<br>SCV X-direction mode |
| 16 | 12.04 | 0.000 | 0.041 | 0.000 | CIS Y-direction mode |
| 17 | 13.29 | 0.068 | 0.000 | 0.000 | CIS X-direction mode |

74

## Mode Shapes

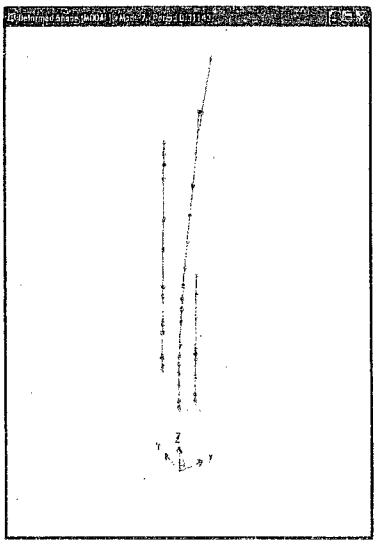
- Mode 1
- f = 3.00 Hz
- ASB Y-direction mode



75

## Mode Shapes

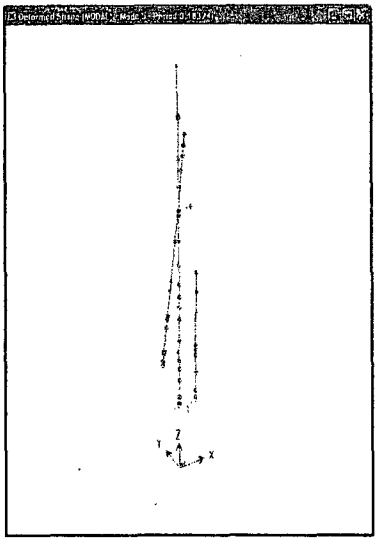
- Mode 2
- f = 3.21 Hz
- ASB X-direction mode



76

## Mode Shapes

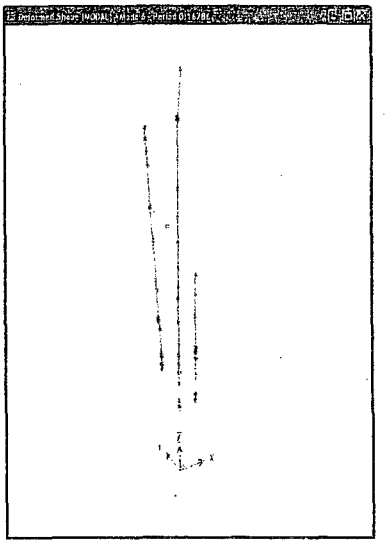
- Mode 5
- f = 5.46 Hz
- SCV X-direction mode



77

## Mode Shapes

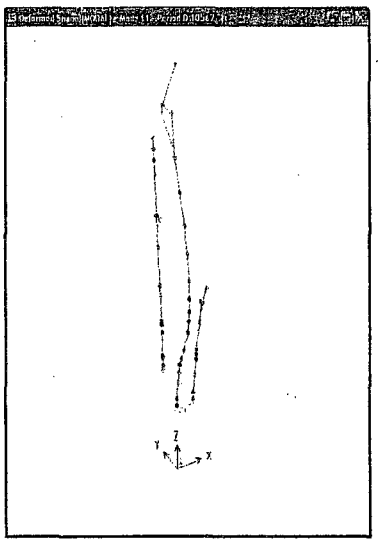
- Mode 6
- f = 6.14 Hz
- SCV Y-direction mode



78

## Mode Shapes

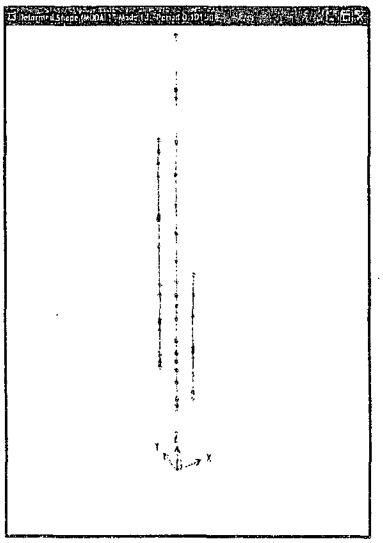
- Mode 11
- f = 9.47 Hz
- ASB Y-direction mode, CIS Y-direction mode



79

## Mode Shape

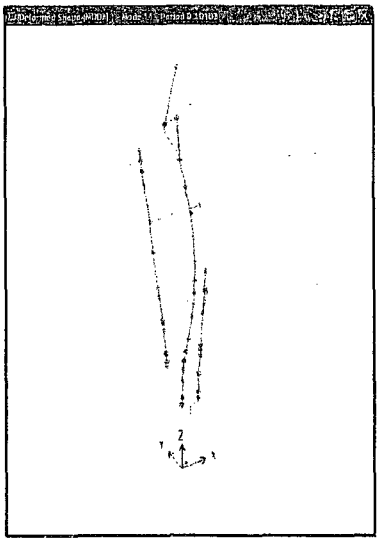
- Mode 13
- f = 9.85 Hz
- ASB Z-direction mode



80

## Mode Shapes

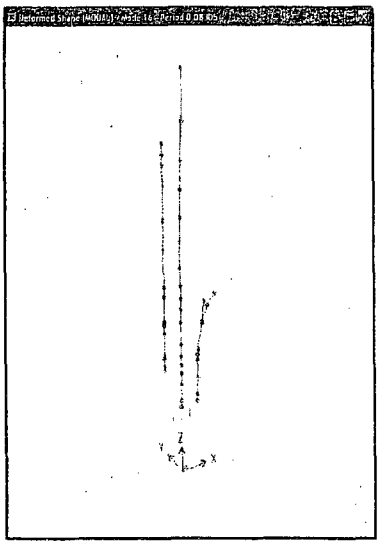
- Mode 14
- f = 9.89 Hz
- ASB X-direction mode, CIS X-direction mode, SCV X-direction mode



81

## Mode Shape

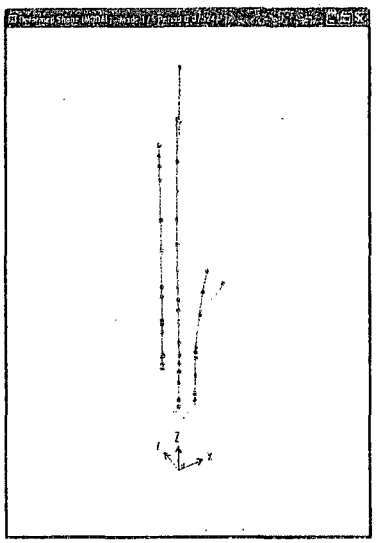
- Mode 16
- f = 12.04 Hz
- CIS X-direction mode



82

## Mode Shape

- Mode 17
- f = 13.29 Hz
- CIS X-direction mode



83

## Analysis Case Summary

- **Scattered incoherent rigid massless foundation input – 36 cases**
  - **3 site conditions/ground motion**
  - **4 foundation footprints**
  - **3 directions – H1; H2 (rectangular fdn); V**
  - **2 coherency functions; NAA, coherent**
  - **Develop Coherency Transfer Functions (CTFs)**
- **SSI inertial interaction foundation & structure response – 9 cases**
  - **1 site condition/ground motion**
  - **1 foundation footprint**
  - **1 structural model**
  - **3 directions - H1; H2; V**
  - **2 coherency functions; NAA, coherent w/CTFs**
- **Parametric Studies – 5 cases**
  - **Another apparent wave velocity (2 km/s) for one case**
  - **84% coherency function for one case**
- **Benchmark with SASSI (surface rigid) NAA coherency function – 2 cases**
- **Embedment; foundation flexibility performed in SASSI by Bechtel and compare CTFs with those of CLASSI surface rigid**

84

## Foundation Footprints

- A square and a rectangular foundation footprint will be considered
  - Rectangular foundation 225 feet by 100 feet
  - Square foundation 150 feet by 150 feet
  - Representative of potential advanced reactor designs (AP 1000 and ESBWR)
  - Footprints are of equal area such that they will demonstrate the influence of foundation shape
  - 150 foot square foundation will be used for comparisons with the SASSI approach by Bechtel
- Additional Foundation Footprints
  - 75 feet by 75 feet
  - 300 feet by 300 feet

85

## Analysis Cases

| Response Locations | H1 | H2 | V | Site/fnd | Total |
|---|---|---|---|---|---|
| Rigid, massless Fdn - NAA | 8 | 2 | 8 | 2/4 | 18 |
| Rigid, massless Fdn Spectra - CTF | 8 | 2 | 8 | 2/4 | 18 |
| Fdn/Structure after SSI – Coherent | 1 | 1 | 1 | 1/1 | 3 |
| Fdn/Structure after SSI – NAA | 1 | 1 | 1 | 1/1 | 3 |
| Fdn/Structure after SSI - CTF | 1 | 1 | 1 | 1/1 | 3 |
| 2 km/s & 4 km/s apparent wave velocity | 2 | 0 | 2 | 1/1 | 4 |
| 84% NEP coherency function | 1 | 0 | 0 | 1/1 | 1 |
| SASSI benchmark – rigid, massless fdn | 1 | 0 | 1 | 1/1 | 2 |

86

## Status/Schedule of S2.1 Tasks

- **Define cases to be analyzed (4/21/2005)**
  - Site conditions
  - Foundation characteristics
  - Structural characteristics
- **Ground motion input (5/3/2005)**
  - Response spectra
  - Coherency functions
    - **Complete except uncertainty bands (7/05)**
    - **Uncertainty bands (8/19/05)**
  - PSD by random vibration theory (7/31/05)
- **Programming CLASSI**
  - **Rigid massless foundation (6/15/05)**
  - **Structure response by Random Vibration Theory (In process)**
- **Coherency Transfer Function**
  - Rigid-Massless Foundation Rock (6/17/2005)
  - Rigid Massless Foundation Soil (7/22/2005)
  - Coherency Transfer Function SSI Validation (9/1/2005)

87

## Status/Schedule of S2.1 Tasks (cont.)

- **Sensitivity studies (6/17/2005 plus)**
  - 4 & 2 km/s apparent wave velocity (6/17/05)
  - Foundation shape (6/17/05)
  - Foundation size (6/17/05 & 8/19/05)
  - 84 % coherency function (8/19/05)
- **Development of CTFs/evaluation of spectra reductions (8/19/05)**
- **Sensitivity Studies in August/September**
- **Final Report in November**

88

# Update of Coherency Studies

Norm Abrahamson

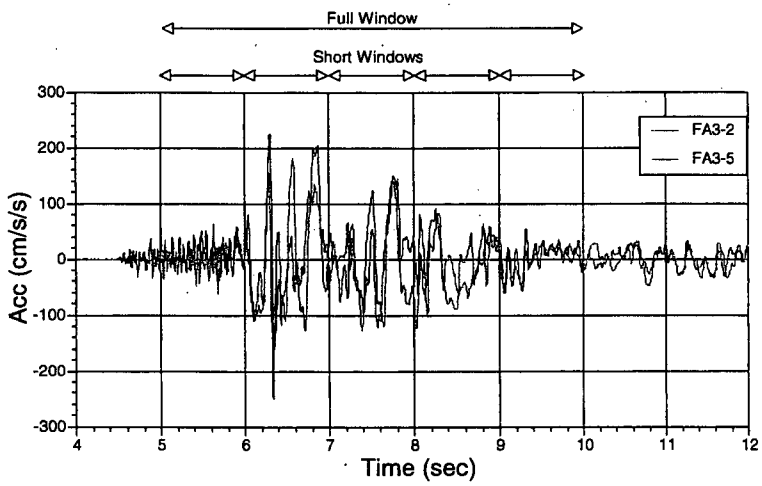
August 24, 2005

## Coherency Studies

- Effect of Short Time Windows
- 84th Percentile Coherency
- Empirical Observations of Incoherency Effect
  - Records from DCPP

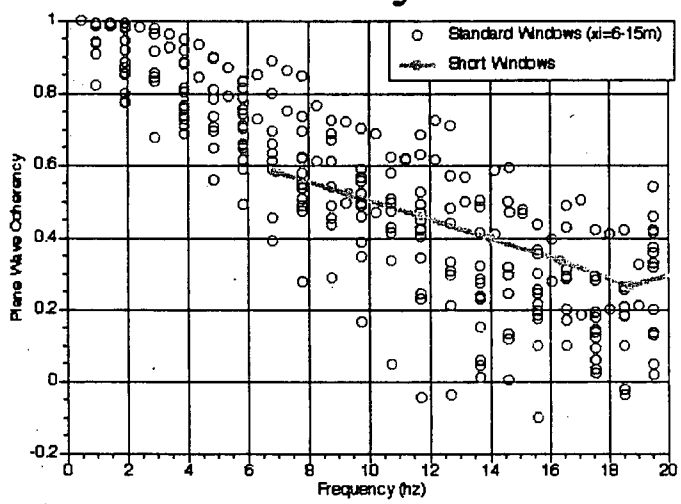
# Compare Coherency

## Short vs Long Time Windows

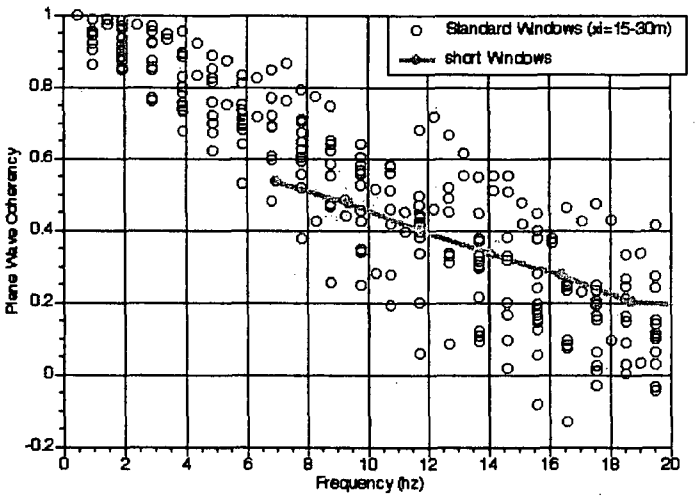



# Effect of Short Windows

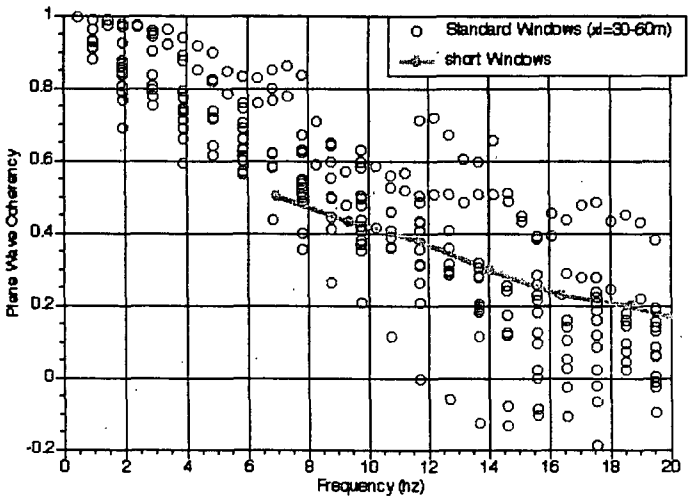
## LSST Data: $\xi$=6-15m



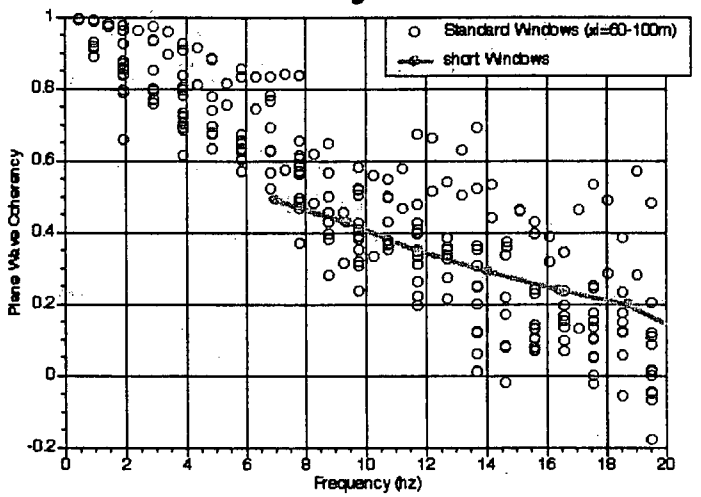
# Effect of Short Windows
# LSST Data: $\xi$=15-30m




# Effect of Short Windows
# LSST Data: $\xi$=30-60m



# Effect of Short Windows
# LSST Data: $\xi$=60-100m



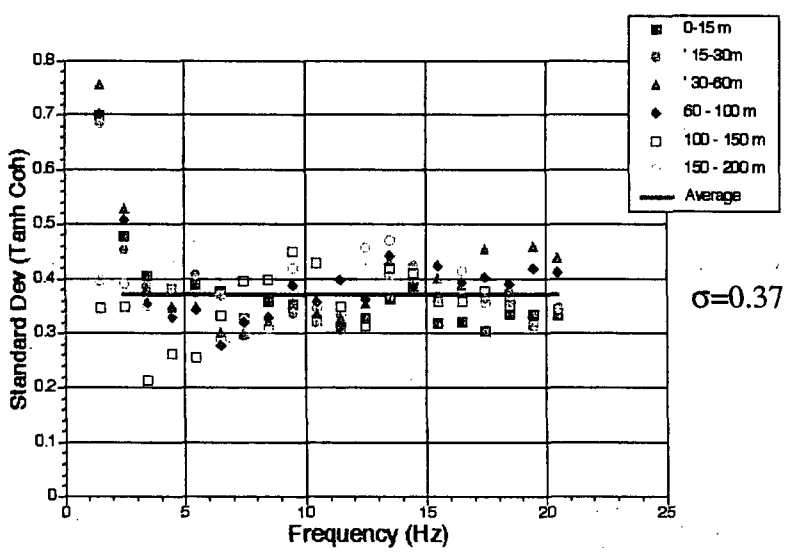

# Conclusions - Window Length

- Plane-wave coherency is not affected by window length for f< 15 Hz.
- For 15-20 Hz, small increase in coherency (e.g. 0.1 units) for shorter time window

# 84th Percentile Coherency

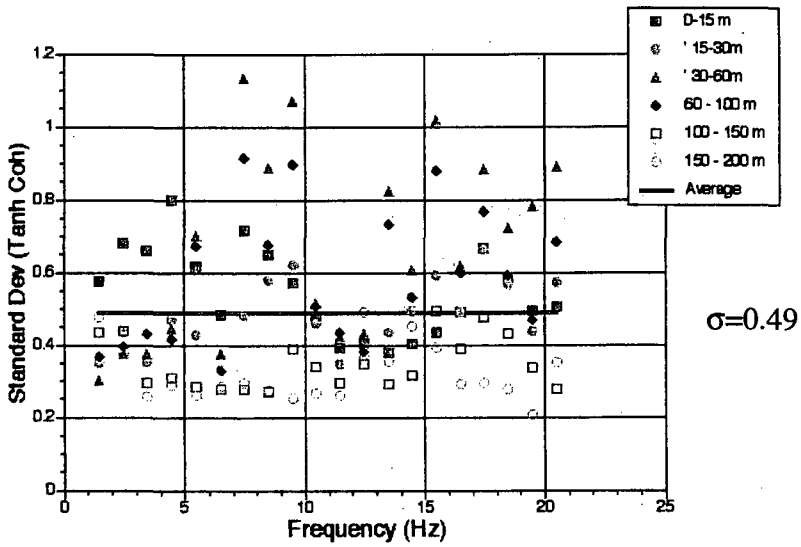
- ATANH(Coh) is approximately normally distributed
- Find the standard deviation of ATANH($Coh_{pw}$)

# Horizontal Component




$\sigma$=0.37

# Vertical Component




$\sigma$=0.49

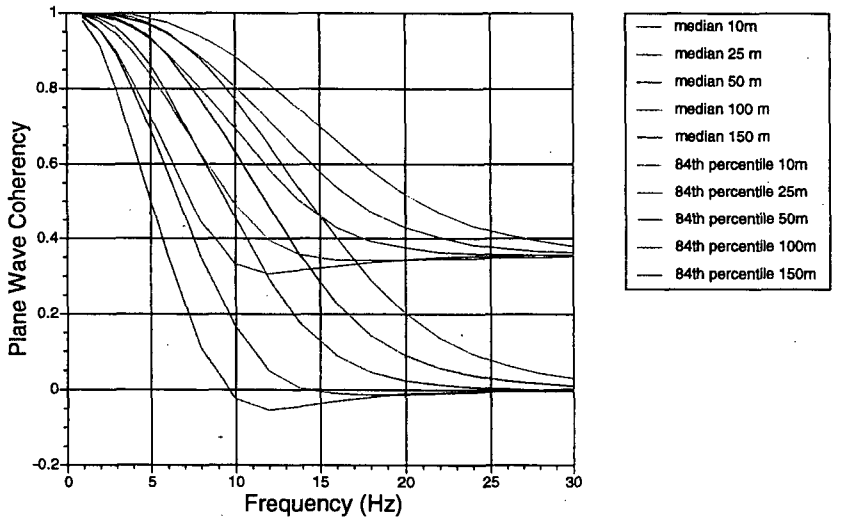
# 84th Percentile Coherency

$$\gamma_{pw84}(f,\xi)=\tanh\left[\tanh^{-1}\left(\gamma_{pw}(f,\xi)\right)+\sigma\right]$$

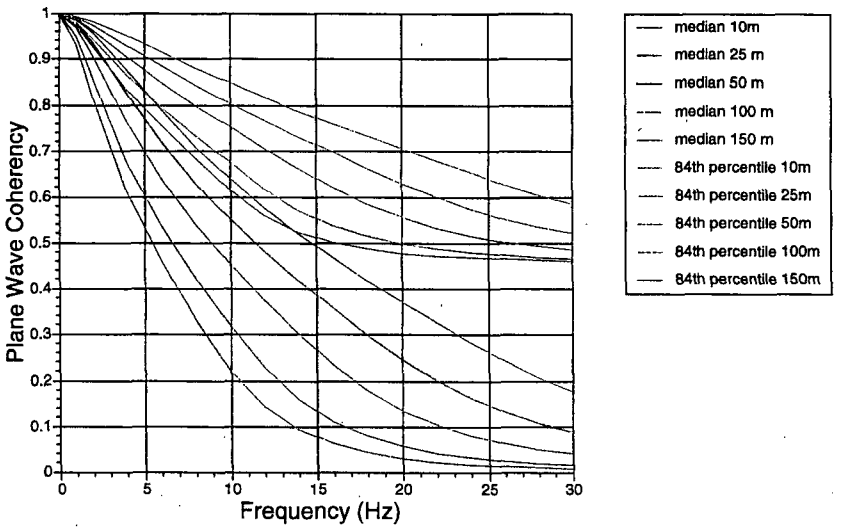
$\sigma_H = 0.37$

$\sigma_Z = 0.49$

# Horizontal Coherency



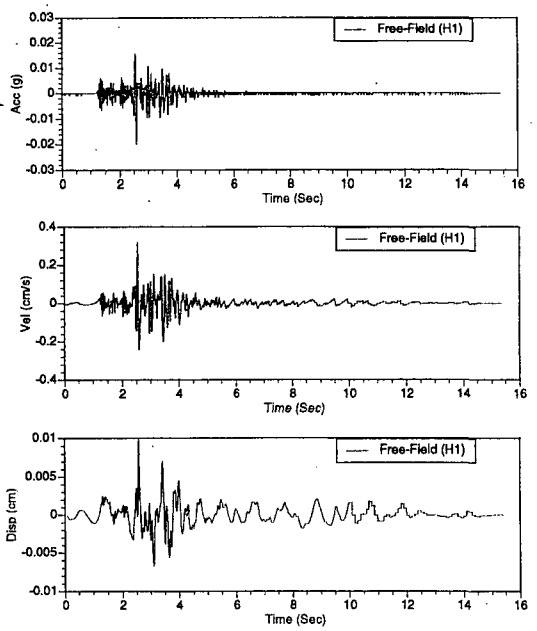

# Vertical Coherency



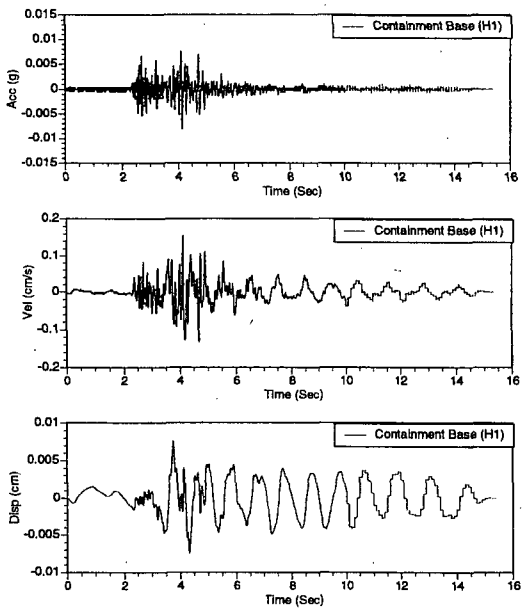
# Empirical Check of Effect

- DCPP recordings (Basemat and Free-field)
  - 2003 Deer Canyon (M3.4, $D_{rup}$=8 km)
  - 2003 San Simeon (M6.5, $D_{rup}$=35 km)
  - 2003 Parkfield (M6.0, $D_{rup}$=85 km)

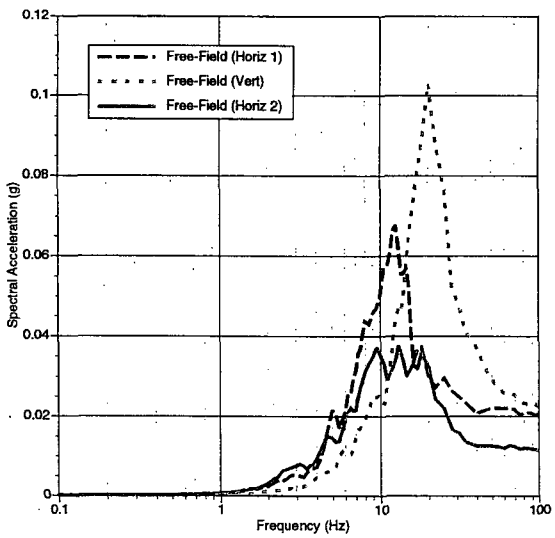
Deer Canyon Free-Field



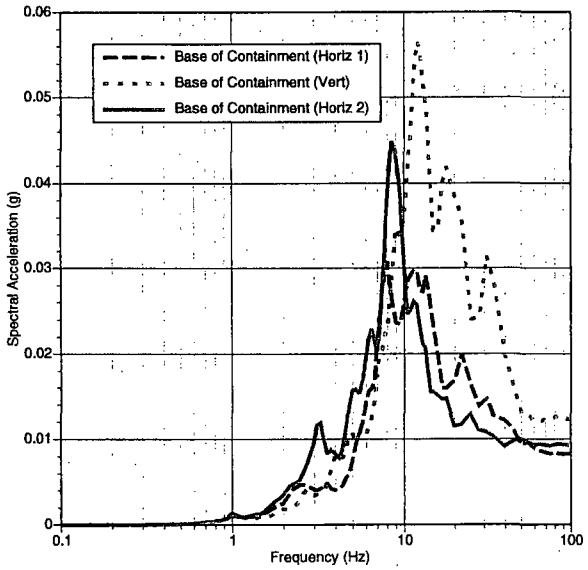
# Deer Canyon Containment Basemat



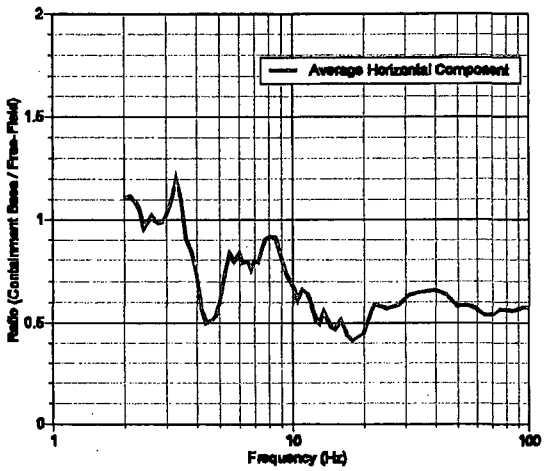

# Deer Canyon Free Field



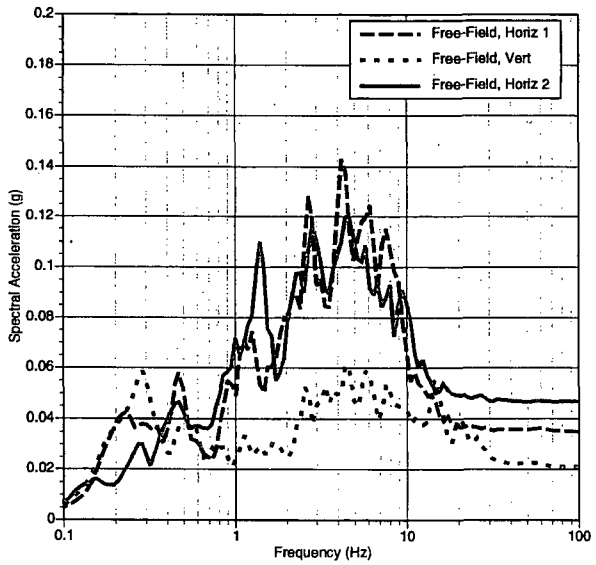
# Deer Canyon Containment Basemat



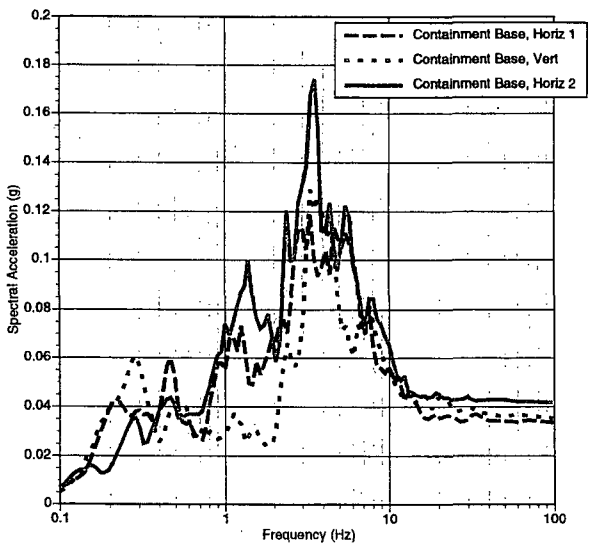

# Deer Canyon Basemat/FF



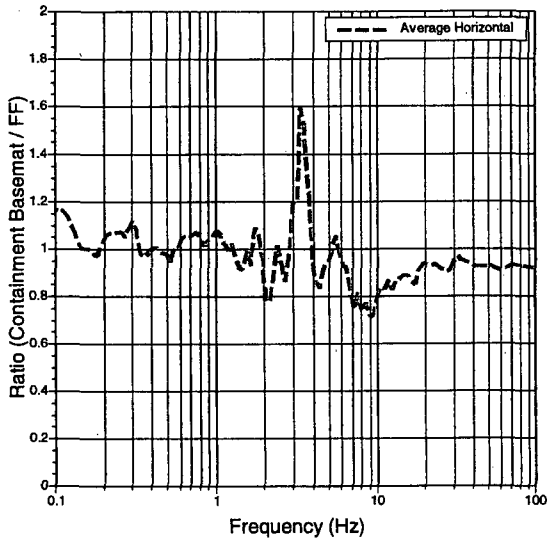
# San Simeon Free-Field



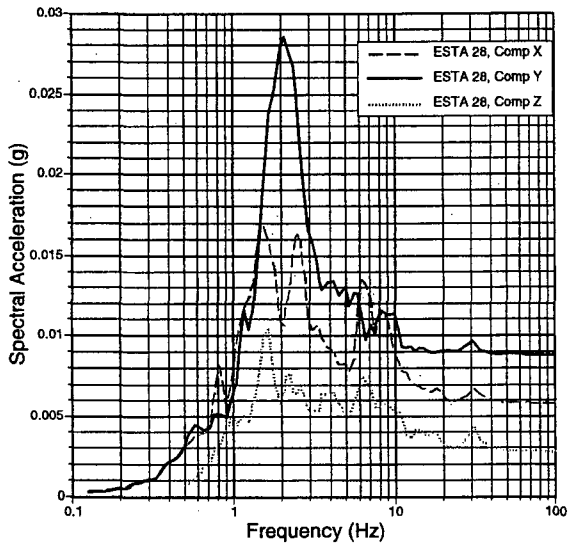

# San Simeon Containment Basemat



# San Simeon Basemat/FF




# Parkfield Free-Field



## Empirical Check

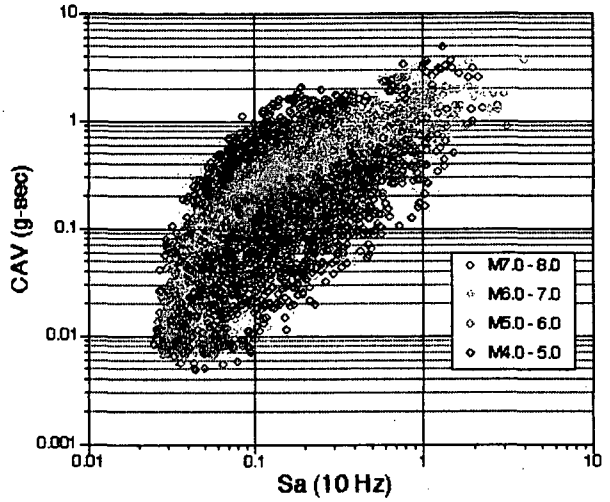
- DCPP seismic recordings can be used to test the coherency model
  - Deer Canyon has the strongest high frequency content (10-20 Hz)

# Update on CAV Model for CAV Filtered Hazard Curves

Norm Abrahamson

August 24, 2005

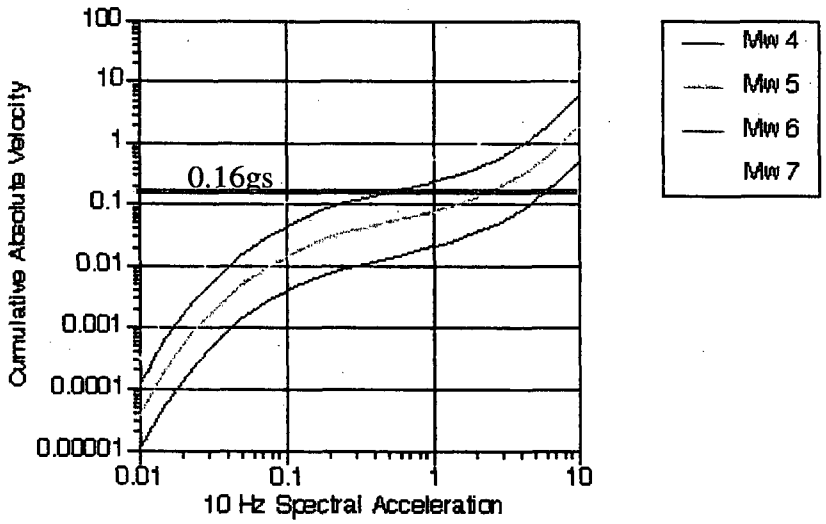
# CAV from WUS Earthquakes




# Preliminary Model (June 23)

- CAV depends on
  - Magnitude
  - Distance (weak)
  - Spectral acceleration
  - Site Condition (Vs30)

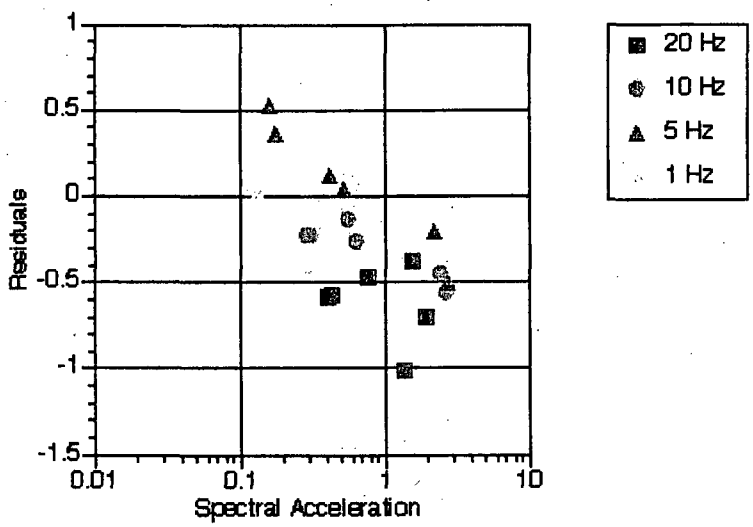
## Median CAV model (June 23)
## Rrup = 15km and Vs30 = 2800 m/s



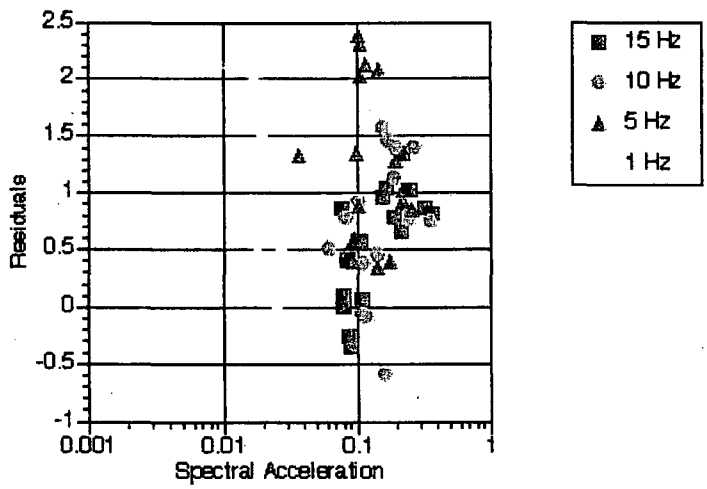

## Test of the June 23 WUS CAV Model for EUS Earthquake

- Saguenay
  - M5.9
  - Distances ~60-200 km
- Nahanni
  - M6.8
  - Distances 8-16 km
  - Located in NW Territories but considered to be representative of EUS high frequency content

# CAV Residuals for Nahanni




# CAV Residuals for Saguenay (June 23 model)



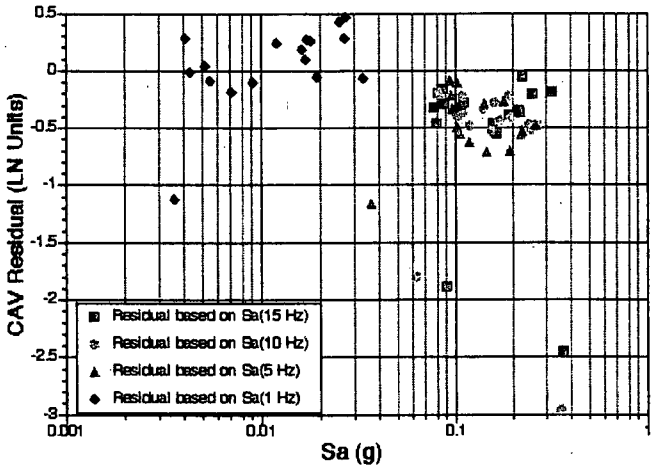
## Need Revised CAV Model for EUS Earthquakes

- Preliminary model significantly underpredicts CAV for Saguenay
- Need to consider additional parameters
  - Duration
  - RMS acceleration

## Revised CAV Model

- Additional Parameters
  - Duration above 0.025g
  - RMS acceleration
- Removed Parameters
  - Distance
- Kept Parameters
  - Magnitude
  - Spectral acceleration
  - Site Condition (Vs30)

# Saguenay Residuals Using Updated Model




# How to Define Additional Parameters

- Duration and RMS acceleration not directly available from hazard analysis
  - Develop empirical models for Duration and RMS from WUS earthquakes
  - Use seismological models to estimate changes to these models for EUS
    - This will be based on the same point source stochastic model this is the basis for the most attenuation relations used in the EUS

# CAV Study

- Add additional EUS ground motions for evaluation of model
  - Current model overpredicts CAV from Saguenay
- Final revision of model
- Complete report by end of September

# New Plant Seismic Issues Resolution Program

**Summary of June Working Meetings on Tasks G1.2 & S2.1**

by
Greg Hardy ARES

August 24, 2005

ARES CORPORATION Applied Research & Engineering Sciences — EPRI

## August 24th G1.2 and S2.1 Meeting Agenda

- **Welcome – Introductions (Hardy)**
- **Summary of June Meeting Results/Actions for G1.2 and S2.1 – (Hardy)**
- **NRC June Meeting Feedback on G1.2 and S2.1 (Murphy)**
- **G1.2 Current Project Activities – (Abrahamson)**
- **S2.1 Coherency Function Refinement– (Abrahamson)**
- **S2.1 Benchmark Problem Comparison – (Short/Ostadan)**
- **Results from Analysis Cases – (Short/Johnson)**
- **Bechtel Use of Coherency for DOE – (Ostadan)**
- **S2.1 Next Steps, Schedule and Milestones – (Johnson)**

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## ESP Task Overall Schedule (Tasks S2.1, S2.2 & G1.2)

**Status**

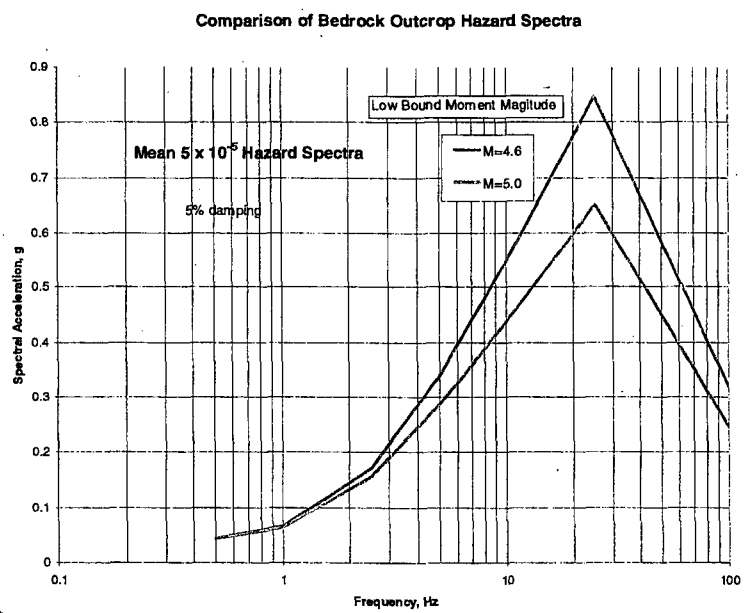
- **NRC/TRAG Technical Meetings in So Cal June 22/23**
- **Next G1.2 meeting in October – add to agenda of August meeting on S Tasks (Carl Stepp to attend)**
- **NRC/TRAG Technical Working Meeting at ARES So Cal Office August**
  - **Tuesday, August 23 = S2.2 Status**
  - **Wednesday, August 24 = S2.1 and G1.2 Status**
- **Full NEI/NRC Meeting in October in Washington DC**
- **Draft Reports November 2005**



## Task G1.2 - Lower Bound Magnitude

*Task Motivation and Scope*

- **Choice of lower bound magnitude (LBM) has major impact on computed hazard levels, especially for higher frequencies**
- **Task will study**
  - New observations of damage to industrial facilities and nuclear plant assessments to support a revised LBM
  - New data on Cumulative Absolute Velocity (CAV) to provide the basis for the LBM distribution
- **A realistic LBM distribution would reduce hazard consistent with realistic damage potential of small earthquakes**

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## CAV Approach for G1.2

- **Task 1 - Initial Trial Application**
  - Compute the 10 Hz and 20 Hz hazard curves for the North Anna site using the USGS source model and the Toro et al (1997) attenuation relation
  - Re-compute the hazard using the WUS Probability (CAV>0.16g-sec) model
  - Assess the impact of this approach
- **Task 2 - Document WUS Probability (CAV>0.16g-sec) Model**
  - Prepare documentation of the development of the Probability (CAV>0.16g-sec) model for PGA and spectral frequencies of 20 Hz, 10 Hz, and 5 Hz, 2.5 Hz, and 1 Hz

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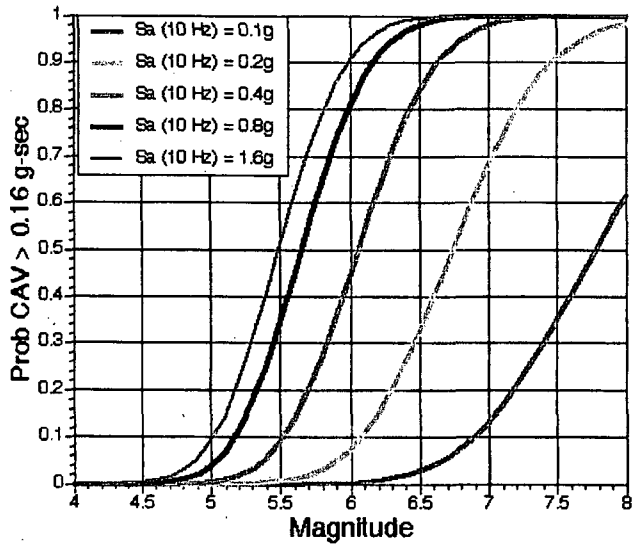
## Probability of CAV Exceeding 0.16-g sec

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## CAV Approach for G1.2

- **Task 3 - Develop new Probability (CAV>0.16g-sec) model for EUS ground motions**
  - Ground motion models for the EUS are primarily based on the point source stochastic model
  - CAV can also be computed from the point source stochastic model
  - Develop/Calculate Probability (CAV>0.16g-sec) as a function of magnitude and spectral acceleration for the EUS
  - Consistent with the attenuation relations used in the hazard analysis

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## CAV Approach for G1.2

- **Task 4 - Compare EUS Probability (CAV>0.16g-sec) model with empirical data from the EUS**
  - Small number of strong motion recordings from EUS
  - Collect available EUS data
  - Calculate CAV values from this EUS data
  - Compare to the model from previous task as a check on the model



## CAV Approach for G1.2

- **Task 5 - Trial Application**
  - Use the EUS Probability (CAV>0.16g-sec) model
  - Compute UHS spectra at 2 Example Sites in EUS
- **Task 6 - Documentation**
  - EPRI Report documenting results of task
- **Potential Phase 2**
  - Create new UHS spectra for 28 CEUS Sites

## Lower Bound Magnitude Task G1.2: Actions from June Meeting

- **Complete EUS CAV Model (Duration and RMS Parameters)**
- **Compare EUS Probability (CAV>0.16g-sec) model with empirical data from the EUS**
- **Demonstrate Effect of CAV filtering process on example UHS**



## Motivation for S2.1 Task

- **Background**
  - Observations have shown that effective input motion to structures accounts for the averaging or integrating effects of the foundation especially for structures with large, relatively rigid foundations such as those at NPPs.
  - Phenomenon was recognized early, but the lack of extensive recorded data prevented the incorporation of the effect into the dynamic analysis of NPP structures.
- **Prior High Frequency Response Considerations Used Early (limited) Incoherence Data**
- **New research effort required to properly address incoherency**
  - Generate new coherency function based on all current applicable data
  - Objective of this study is to systematically study the ground motion incoherency effects on structures/foundations similar to those being considered for Advanced Reactor designs

## Motivation for S2.1 Task (Cont)

- **Significant New Data Exists:**
  - **EPRI TR-100463, "*Spatial Variation of Earthquake Ground Motion for Application to Soil-Structure Interaction*", 1992, presented coherency functions based on LLST array (Taiwan) data for fifteen earthquake events**
  - **Arrays used for coherency model also include all available and appropriate data, e.g. :**
    - **EPRI Parkfield**
    - **Chiba, Japan**
    - **Coalinga**
    - **UCSC ZIYA**
    - **Pinyon Flat**



## Diablo Canyon Incoherency Application

- **Ground motion incoherency was considered using CLASSI for the Diablo Canyon Long Term Seismic Program (1988)**
- **Site-specific spatial incoherence functions were developed at Diablo Canyon**
  - Developed from small earthquake recordings, dynamite explosions in boreholes, and air gun shots fired at sea
- **The results of analyses performed show that the spatial incoherence of ground motion generally results in reductions in the soil/structure interaction responses**
- **The NRC addressed the LTSP SSI including incoherency in Safety Evaluation Report, NUREG-0675, Supplement No. 34**
  - "The SSI analysis provides acceptable plant seismic responses"
  - NRC audit by Costantino and Veletsos
- **LTSP re-analyses using CLASSI & coherency models from the Lotung array developed by Abrahamson (1991)**
  - Greater effects of incoherency from Lotung than from Diablo Canyon site-specific measurements

## S2.1 Task Objectives

- **Develop a state-of-the-art representation of the coherency function based on the most applicable data available (Dr. Norm Abrahamson)**
- **Develop a coherency transfer function to be applied to the seismologically defined seismic ground motion to account for the effects of incoherence on NPP structures/foundations as a function of foundation size, site conditions, and other relevant parameters (ARES)**
- **The modified Fourier amplitude spectra and the original Fourier phase spectra will be used to develop new input ground motion time histories that account for incoherency**
- **Validate incoherence response transfer functions and their implementation via a Benchmark Problem:**
  - CLASSI (ARES)
  - SASSI (Bechtel)



## Conclusions/Decisions from Past Meetings

- **Coherency functions are appropriate for all frequencies (including above 20 Hz)**
- **The slowness (s) of 0.00025 sec/m is conservative with respect to translation input but may tend to increase torsion/rocking input. A parametric case using s of 0.0005 sec/m will be performed to assess the effects of torsion/rocking input.**
- **For the purposes of this Task S2.1 study, Dr. Norm Abrahamson concluded:**
  - Coherency does not vary as a function of site conditions
  - Coherency does not vary as a function of earthquake magnitude (for magnitudes of interest, greater than 4.5 to 5).
  - Each component of earthquake input can be treated as uncorrelated.
- **Mean input ground motion is the goal and mean coherency will be used. A parametric case study will be run with an 84% NEP coherency function.**

# Task S2.1 Actions from June 23 Meeting

- **Coherency Function**
  - Action to study the data in shorter time windows to determine whether coherency exists for higher frequencies
  - Decision on whether the median, mean, 84% or other coherency curve is appropriate (Norm to provide curves)
  - Verify that topographical data has been excluded from our data set
  - Consider using infinite wave speed case following completion of case studies of 2000, 4000 m/s
  - Deer Canyon Records at Diablo considered for future task
- **Verification Example (rigid 150' sq foundation)**
  - Finalization of both CLASSI and SASSI results for latest coherency function
  - Issue memo summarizing the results to TRAG and NRC (conference call if necessary)
- **Revise/Simplify the Table of Analysis Cases – Insert SASSI runs also**
  - **Steve/Jim/Farhang/Orhan to discuss Bechtel runs**
- **Complete Remaining Analysis Cases following Agreement of Benchmark Verification Example**