Q5.1 - References

- Comment:
  - This report relies on previous work and references to academic work. It is not complete in itself, such that member of the public would be able to review the report and understand the theoretical bases for the approach proposed. Please complete or expand references.
- Response
  - Two reports on which the report is based have been provided
    - EPRI report on LSST array study including mathematical background
    - Unpublished report on site effects on coherency

Q5.2 - validation of foundation effects

- Comment:
  - It is very important that the proposed coherency model for calculating soil-structure interaction effects be validated against observed behavior of large light-weight foundations. Is validation available; please describe. If not available, please indicate an alternative.
- Response
  - The coherency models are for free-field motion. The effect on the foundation is part of the SSI task, not the coherency model.

Q5.3 - Effect of embedment

- Comment:
  - The formulation is completely based on instrumental recordings a surface on small pads that are more indicative of particle motion rather than scattered wave motion that could be experienced by nuclear power plant foundations located at depths of 50 to 60 ft. Seismic energy distribution at particle level and wave level can be significantly different. It would be necessary to demonstrate that the proposed coherency functions can be used for embedded foundations.

Q5.3 - Effect of embedment

- Response
  - The coherency functions are for free-field conditions. They do not include the effects of scattering from the foundation. The effects of foundation scattering are accounted for in the SSI calculations.
  - The coherency of the free-field motion at depth is compared to the surface coherency model in the response to Q5.4.

Q5.4 - Effect of embedment

- Comment
  - The dense array data are from surface recordings.
    - (a) Are there any recordings at depth?
    - (b) If so, how is the energy distribution of the motion at depth and at surface?
    - (c) How is the coherency between adjacent records at depth developed?

Q5.4 - (a) Are there any recordings at depth?

Response

Arrays with recordings at depth:

LSST (soil)

Depths: 6, 11, 17, 47

Horizontal separation: 45 m

Chiba (soil)

Depths: 5, 10, 20, 40

Horizontal separation: 5-156 m

EPRI Parkfield (rock)

Depth: 15 m

Horizontal separations: 25-43 m

Q5.4 - (b) how is the energy distribution of the motion at depth and at surface?

- Response
  - The amplitude of the energy distribution at depth will be different than at the surface due to the site response.
  - The coherency does not address the amplitude of the energy distribution. Instead, it addresses the phasing (timing) of the energy.

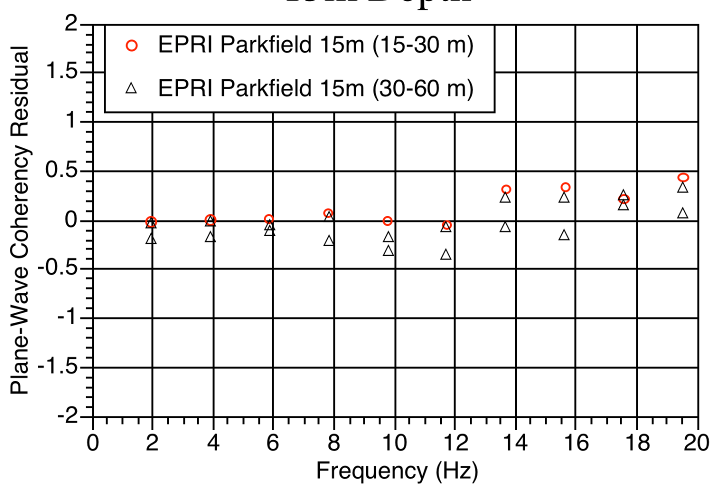
Q5.4 - (c) How is the coherency between adjacent records at depth developed?

- Response
  - The coherency at depth is computed between recordings located at the same depth.
  - Mathematically, it is computed in the same way as done for the surface recordings.

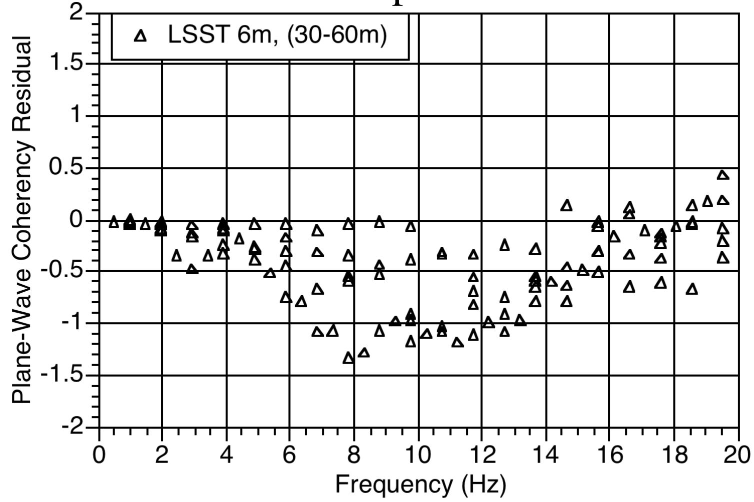
Q5.4 Coherency at Depth

- Compare computed coherency at depth with the model
- Compute residuals (positive residuals means under-prediction)
- Residual is averaged over each earthquake
- Only used data that was previously compiled
  - LSST - 5 eqk
  - Chiba - 3 eqk
  - EPRI Parkfield - 2 eqk
  - Other data from Chiba and LSST could be added
  - Data from other arrays could be added (Garni)

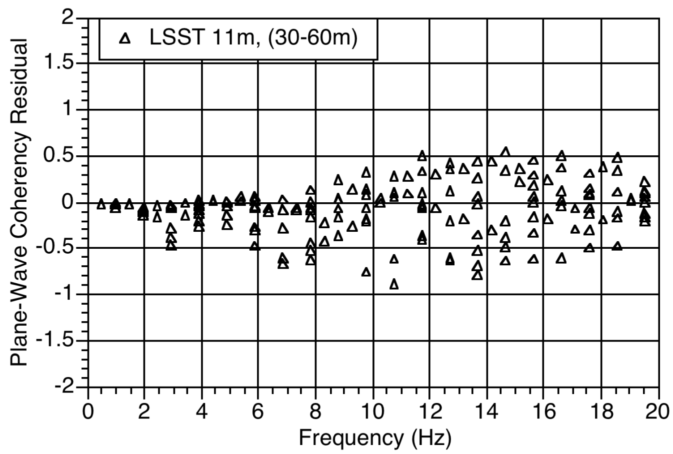
Q5.4 EPRI Parkfield Coherency Residual at 15m Depth



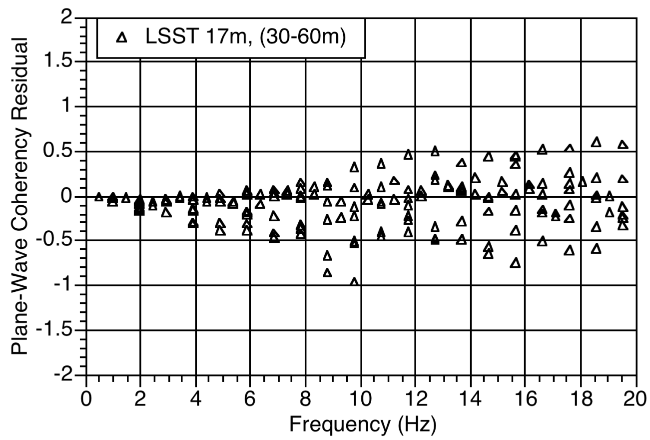
Q5.4 LSST Coherency Residual at 6m Depth



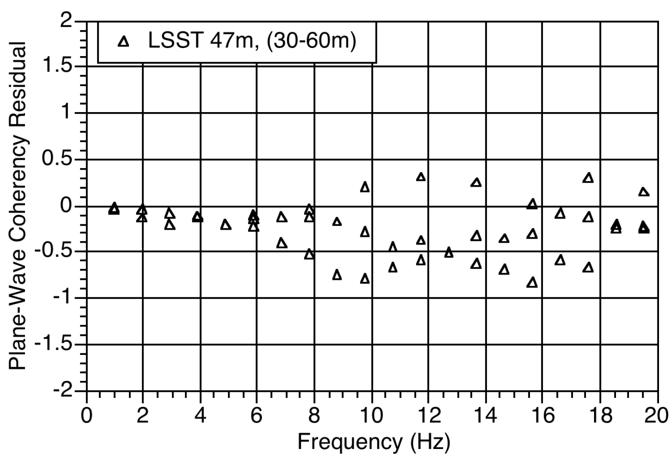
Q5.4 LSST Coherency Residual at 11m Depth



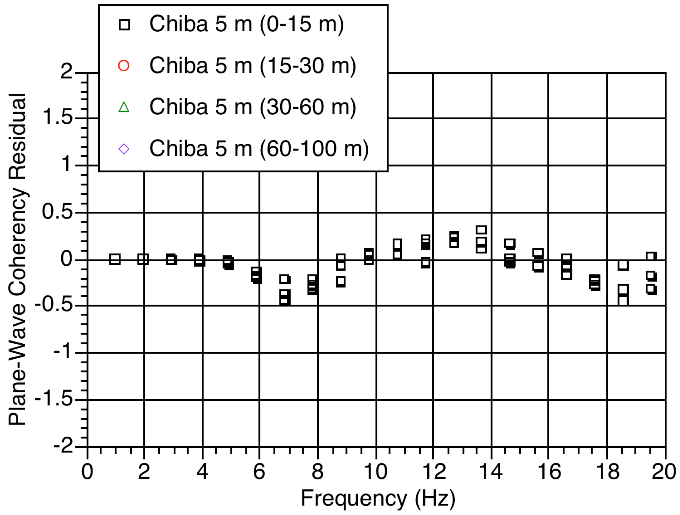
Q5.4 LSST Coherency Residual at 17m Depth



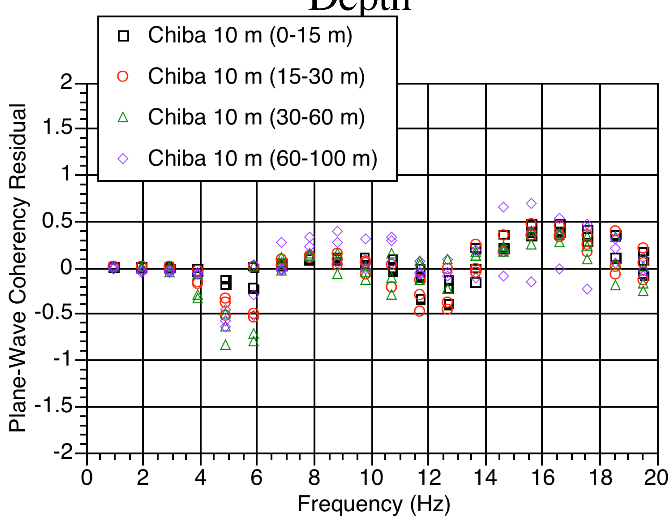
Q5.4 LSST Coherency Residual at 47m Depth



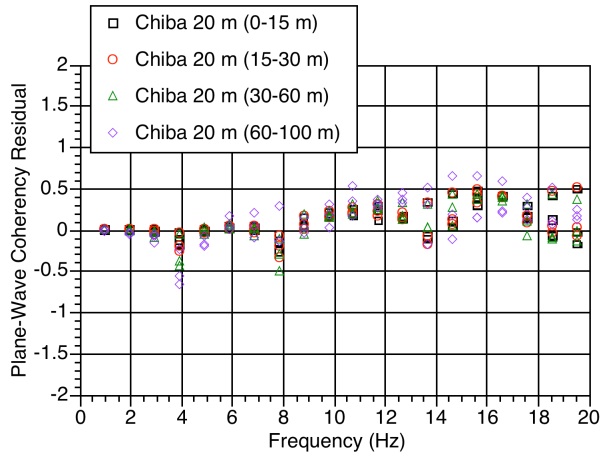
Q5.4 Chiba Coherency Residual at 5 m Depth



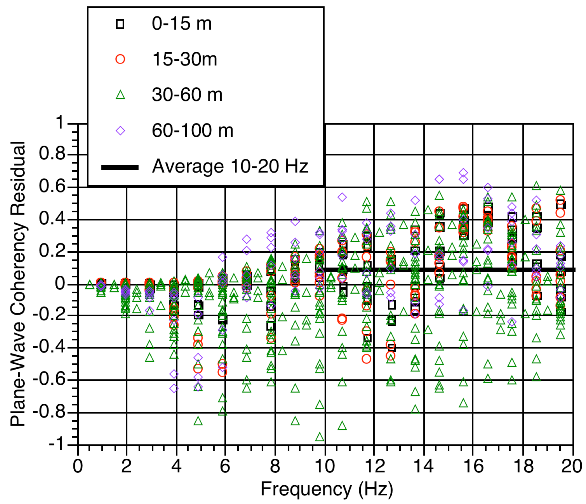
Q5.4 Chiba Coherency Residual at 10 m Depth



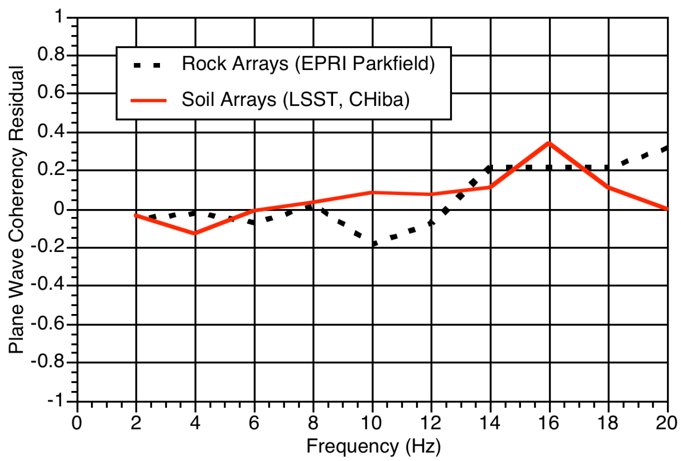
Q5.4 Chiba Coherency Residual at 20 m Depth



Q5.4 Coherency Residual at 10-20 m Depth



Q5.4 Coherency Residual at 10-20 m Depth



Q5.5 - Theory & terms

- <u>Comment:</u>
  - The underlying theory and assumptions involved in the use of the proposed approach need to be clearly stated. Terms such as tapered time series are used without explaining what the tapering function is.
- <u>Response</u>
  - The report has been modified to describe these terms. Theory is described in the references (Q5.1)

Q5.6

- Comment:
  – The report starts off with assertions that SMART-1 and LSST array data provide well calibrated empirical models without providing the basis for the statement. What is the basis for this assertion?
- Response
  – The text on page 1-1 has been modified to provide the basis for the statement.

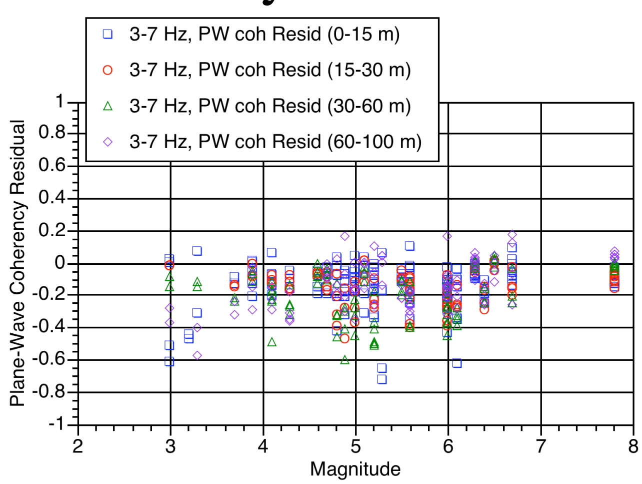
Q5.7 - Eqk Parameter Dependence

- Comment:
  – It is recognized in the report that topography influences amplification of ground motion at higher elevations. The extent to which magnitude, depth, local geology and directivity of ground motion propagation influence coherency of vibratory ground motions recorded within distances comparable to the foundation dimensions of a nuclear plant structures is not clear. Please document the cases.

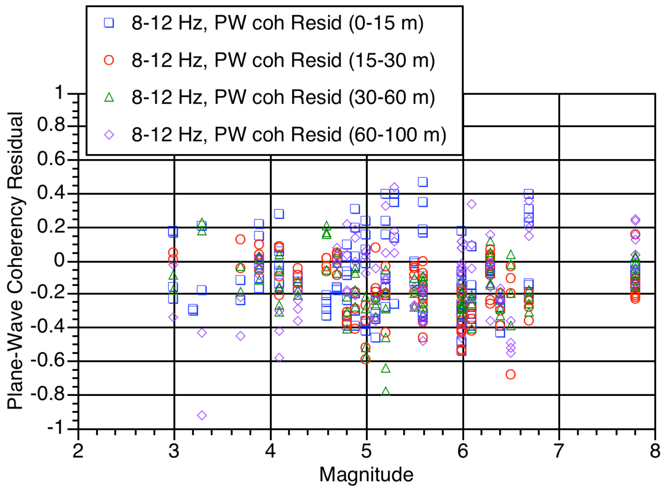
Q5.7 - Eqk Parameter Dependence

- Response
  - Earthquake magnitude, focal depth, local geology, and directivity affect the amplitude of the ground motion but coherency is influenced by complex wave propagation due to scattering in the site region.
  - Residuals
    - Original Figures 3-4, 3-5 with respect to old model
      - Residuals corrected in Report
    - Magnitude, distance dependence checked with residuals
    - Directivity dependence cannot be checked with this data

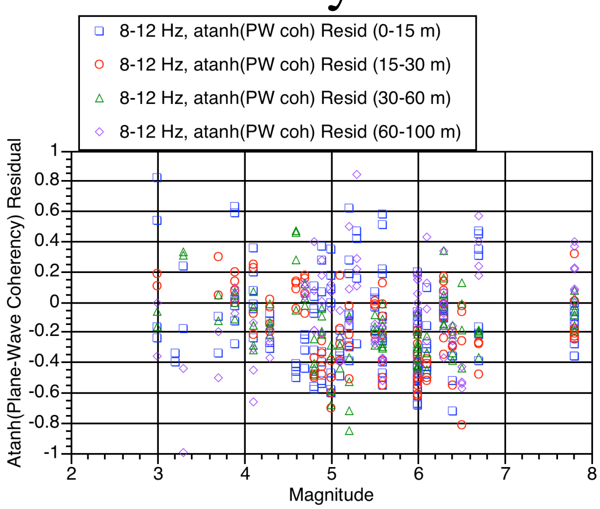
Q5.7 Mag dependence Coherency Residual 3-7 Hz



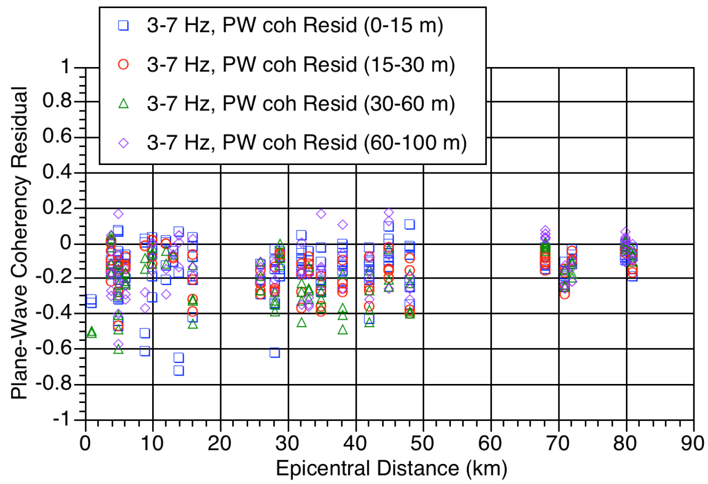
Q5.7 Mag dependence
Coherency Residual 8-12 Hz



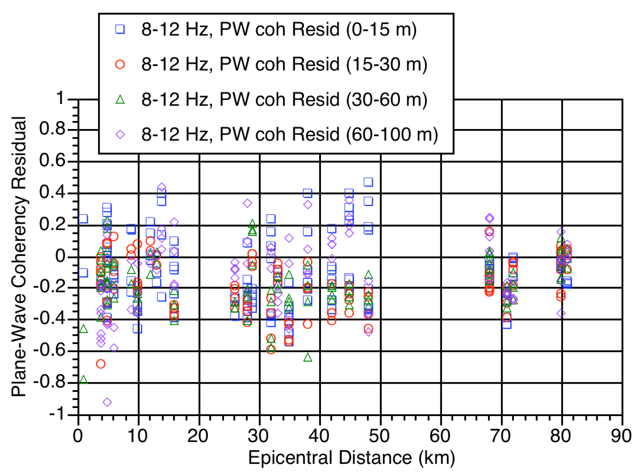
Q5.7 Mag dependence
atanh Coherency Residual 8-12 Hz



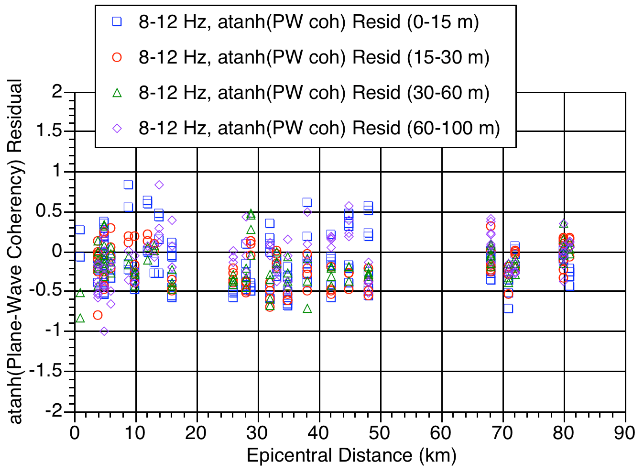
Q5.7 Eqk Dist dependence Coherency Residual 3-7 Hz



Q5.7 Eqk Dist dependence Coherency Residual 8-12 Hz



Q5.7 Eqk Dist dependence atanh Coherency Residual 8-12 Hz



Q5.8 - physical nature of coherency

- <u>Comment:</u>
  - Assumptions related to the physical nature of the coherency of propagated motion should be clearly stated at first, the parameters that strongly influence the observed coherency should be identified, then the results of sensitivity studies undertaken to mitigate the effects of sparsity of data, and uncertainty of the nature of future ground motion should be presented.

Q5.8 - physical nature of coherency

- Response:
  - Physical models have not been able to reproduce coherency at short separation distances
  - Use empirical models rather than physical models
  - Key parameters are separation distance and frequency (not just number of wavelengths)

Q5.9 - Definitions & sensitivities

- Comment:
  - Terms such as data taper, lagged coherency, and number of time samples should be defined and the sensitivity of predicted coherency of the ground motion to these parameters should be presented.
- Response:
  - Terms have been defined in section 1
  - Main sensitivity is to number of frequencies smoothed
    - This is shown in EPRI (1992) report (Q5.1)
  - Variability of coherency between stations, earthquakes, is much larger than the effect of the analysis parameters (e.g. window length, pre-whitening)

Q5.10 - Wave-types

- Comment:
  - Soil-structure interaction (SSI) effect is modeled upon a basic assumption of vertically propagating shear waves. Please discuss the influences of the type of seismic waves incident upon the site on predicted coherency model.
- Response:
  - Analysis has been for the S-wave window.
    - Horizontal: S-waves
    - Vertical: Includes both P and S-waves
  - Using the P-wave window would likely lead to higher coherency, but the amplitude is expected to be lower.
    - Coherency model for P-wave window has not been addressed

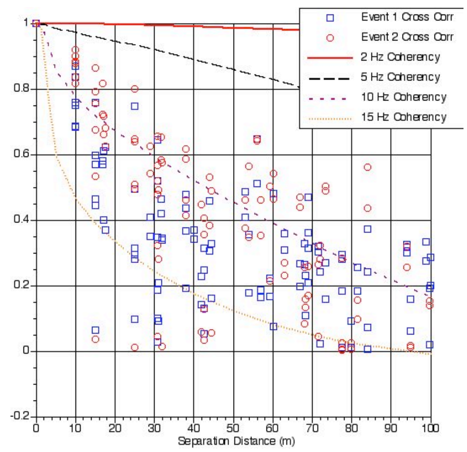
Q5.11 - Cross-Correlation and Effect of Rigid Foundation

- Comment:
  - (a) Based on the Figure 3-1, it appears that coherency falls off sharply above about 15 Hz. Please present the correlation coefficients between adjacent recordings from the data base used to derive the curves in Figure 3-1.
  - (b) It is not clear that the behavior of a rigid foundation (most nuclear plant structures with their layout of intersecting shear walls make the entire foundation very rigid compared to the compliant subsurface material) would not modify differently than those coherency coefficients recorded by a dense array of instruments on pads of very small footprints.

Q5.11 - (a) Cross-correlation

- Response:
  - Cross-correlation function from band-pass filtered recordings is the Fourier Transform of the coherency smoothed over same freq band
  - Unfiltered Cross-correlation will be similar to the coherency at the frequency of the main power in the spectrum

EPRI Parkfield (rock)



Q5.11 (b) Effect of Foundation

- Coherency model is for free-field
- Does not account for foundation
- Foundation effects are considered in the SSI

Q5.12 - Effect on Soil Non-linearity

- Comment:
  - The strain dependent soil properties used in the SSI calculations are derived from an assumption of vertically propagating motion that is coherent from point to point on the foundation attachment locations. Please develop and provide guidance on modeling of soil properties when calculating SSI effects.
- Response:
  - Coherency affects phase, not the amplitude of the ground motion
  - With same amplitude, the soil-nonlinearity should be the same.

Q5.13 - References

- Comment:
  - Report references proprietary EPRI report and Caltrans Report. Make these available
- Response:
  - EPRI report discussed in Q5.1
  - Caltrans appendix given in revised report

Q5.14 Typo

- Comment:
  - p 2-2, third paragraph: "As a result, the plane-wave coherency is smaller than the unlagged coherency", "Unlagged" should be changed to "lagged"
- Response:
  - Corrected

Q5.15 - Data Sets Used

- Comment:
  - It is unclear which data sets were used in the evaluation of the plane-wave coherency model in Eqs. 3 …
    - (a) Were Pinyon flat and Stanford excluded from the coherency evaluation due to timing problems?
    - (b) Was each event or was the ensemble of all events at an array considered as an individual sample in the evaluation of the coherency model?
    - (c) Number of events used for each event is no consistent between Tables 3-1 and 3-2.

Q5.15 - (a) Data Sets Used

(a) Were Pinyon flat and Stanford excluded from the coherency evaluation due to timing problems?

- Response:
  Pinyon Flat and Stanford arrays were used to constrain the lagged coherency, but not the plane-wave factor. The final plane-wave coherency was fit to the product of these terms, but in arithmetic units, not atanh(coh) units.

Q5.15 - (b) Data Sets Used

(b) Was each event or was the ensemble of all events at an array considered as an individual sample in the evaluation of the coherency model?

- Response:
  - Each event was considered as an individual sample so arrays with more events are given greater weight in the mean residual.

Q5.15 - (c) Data Sets Used

(c) Number of events used for each event is no consistent between Tables 3-1 and 3-2.

- Response:
  - The number of events listed in Tables 3-2 and 3-3 have been corrected and now are consistent.
  - For the EPRI LSST array, events 13 and 15 were excluded because there was no magnitude estimate, so in all 13 events from the LSST arrays were used.
  - For the Coalinga array, 2 events (126H43 and 126S31) had very low coherency values are low frequencies. These to events were excluded leaving 4 Coalinga events (see Abrahamson, 1994)

Q5.16 - Separation Distance Dependence

Comment:

Can a single expression for the coherency reasonably represent the different exponential decay observed at long and short separation distances?

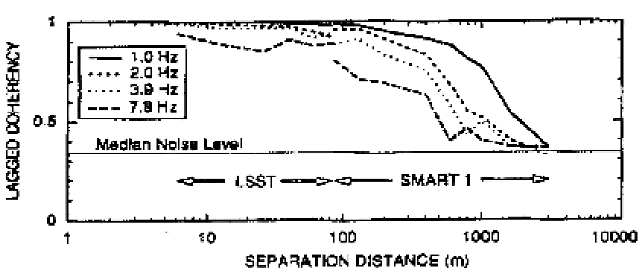


Figure II-1. Comparison of the coherency decay recorded at the LSST array (event 12) and the SMART-1 array (event 43) (from Abrahamson *et al.*, 1991)

Q5-16 - Separation Distance Dependence

- Response:
  - There is a difference in the separation distance scaling at short and large distances.
    - Should not use scaling of low frequencies at large separation distances as a proxy for high frequencies and small separation distances
  - We used empirical recordings to constrain the scaling at short separation distances

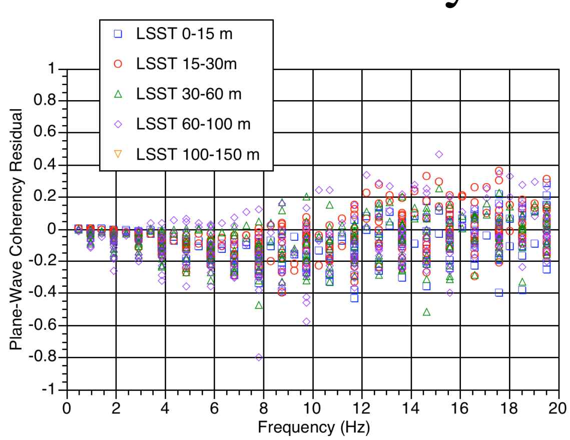
Q5-17 - Site Effects

- Comment:
  - (a) If the rock sites were considered by themselves, would the resulting "rock" coherency model compare well with the EPRI LSST/new coherency models?
- Response:
  - An unpublished report (Abrahamson 1994) which gives the details of the comparisons of the rock and soil site coherency was provided with the first set of responses. This report compares the rock lagged coherency with the coherency function from the EPRI/LSST array.

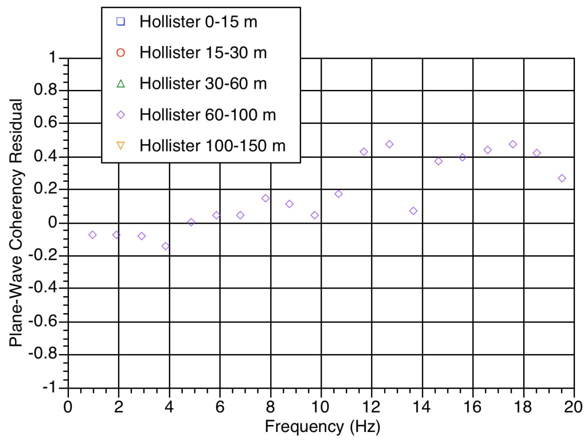
Q5-17 - (b)Site effects

- Comment:
  - Since the number of soil arrays/events is significantly higher than that of the rock arrays/events, can it be that the trend in the data at the rock sites is "buried" within that of the soil sites?
- Response:
  - The plane-wave coherency residuals shown in the report are dominated by soil sites. The basis for combining these data is given in the unpublished report discussed above. The report has been modified to show the residuals separately for each array in figures 3-4a-h.

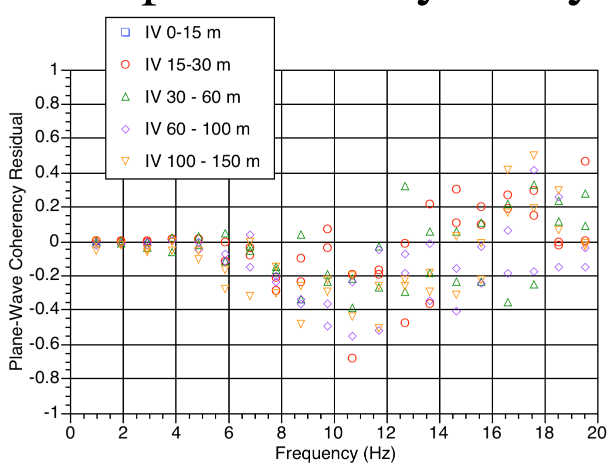
Q5-17 (b)
LSST Array



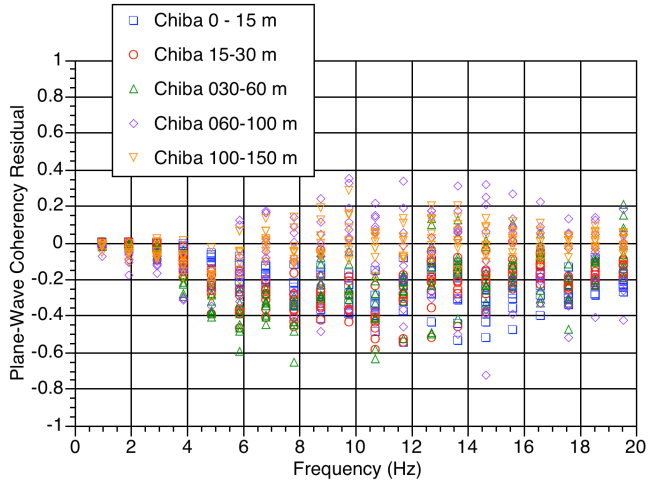
Q5-17 (b)
Hollister Array



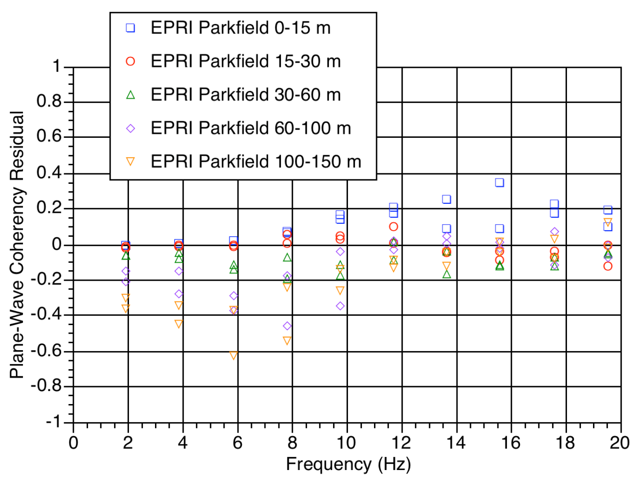
Q5-17 (b)
Imperial Valley Array



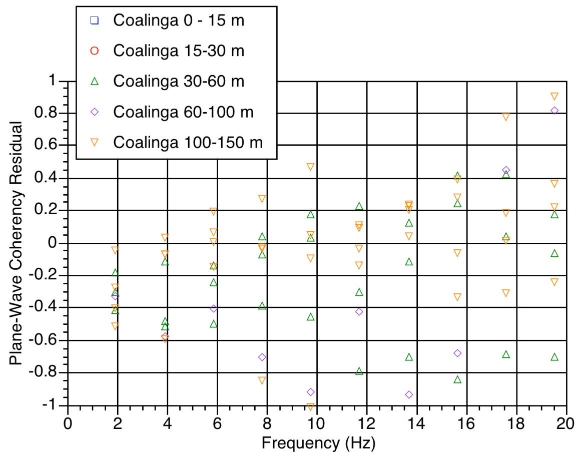
Q5-17 (b)
Chiba Array



Q5-17 (b)
EPRI Parkfield Array



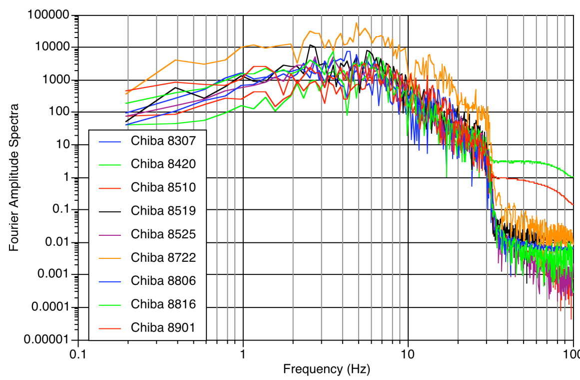
Q5-17 (b)
Coalinga Array



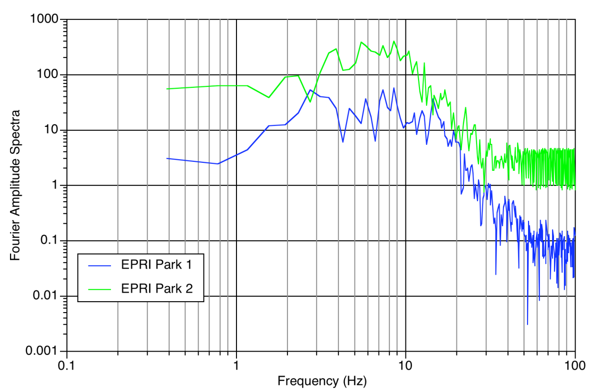
Q5-17 - (c) Frequency content

- <u>Comment:</u>
  - What was the frequency content of the motions for each event?
- <u>Response:</u>
  - The average Fourier amplitude spectra for each event are shown in following plots.

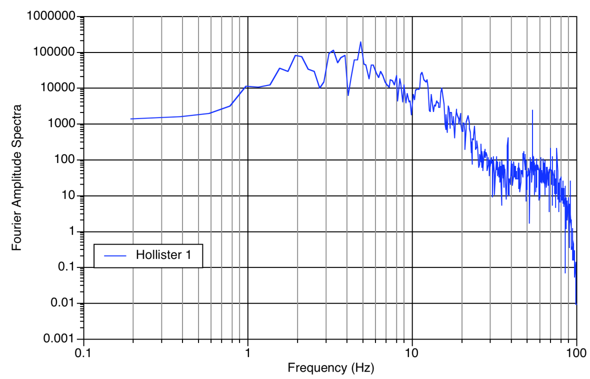
Q5-17 (c)
Chiba Freq Content



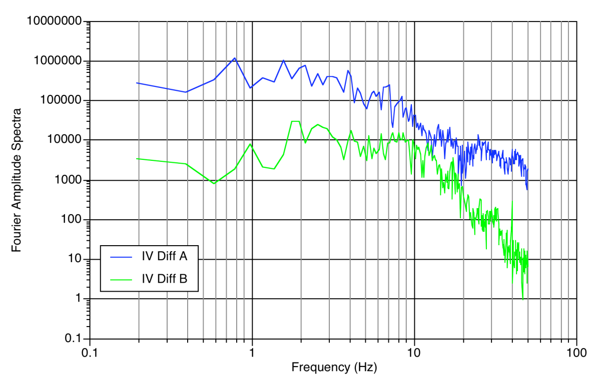
Q5-17 (c)
EPRI Parkfield Freq Content



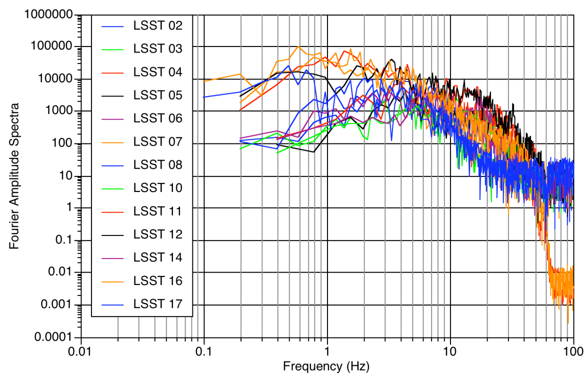
Q5-17 (c)
Hollister Freq Content



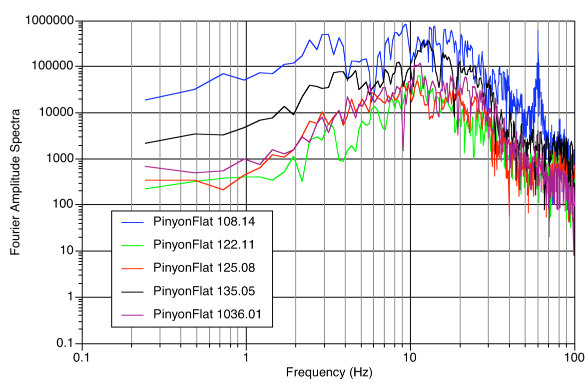
Q5-17 (c)
Imperial Valley Freq Content



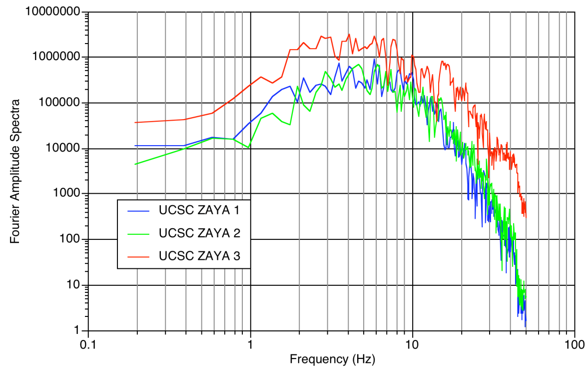
Q5-17 (c)
EPRI LSST Freq Content



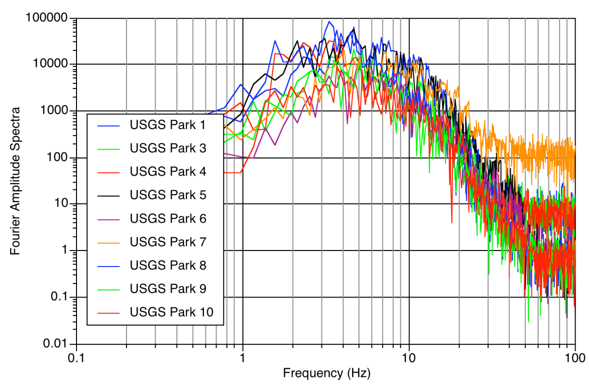
Q5-17 (c)
Pinyon Flat Freq Content



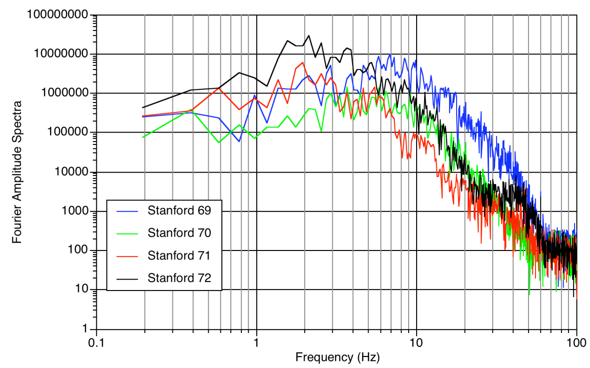
Q5-17 (c)
UCSC ZAYA Freq Content



Q5-17 (c)
USGS PArkfield Freq Content



Q5-17 (c)
Stanford Freq Content



Q5-17 - (d) Slowness Estimate

- Comment:
  - What was the frequency range for which the predominant slowness was identified from the data?
- Response:
  - The slowness was estimated from 2 to 7 Hz.

Q5-17 - (e) Data Set

- Comment:
  - Why were some recorded events not considered in the evaluation of the new coherency model? For example, from the 15 events recorded at the EPRI LSST (Abrahamson et al, 1991) 13 were used for the new model and from the 12 events recorded at EPRI Parkfield and the 19 events at Chiba (Abrahamson et al, 1992) only 2 and 9 events, respectively, were used for the new model.
- Response:
  - Abrahamson et al 1992 has errors in the number of events. There are only 2 (not 12) from the EPR Parkfield array and 9 (not 19) form the Chiba array
  - 2 of the 15 LSST events were excluded since they did not have magnitude estimates.

Q5-18 - Correlation of PSD and coherency

- Comment:
  - The plane-wave coherency in Fig. II-9 decays sharply past the dominant frequency range of the soil PSD. However, it decays sharply from the beginning of the dominant frequency range of the rock PSD. Does this imply that a very significant part of the dominant frequency range of the rock sites cannot be considered as a single inclined wave but energy coming from different paths?

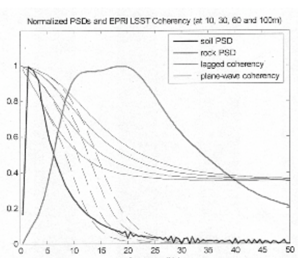
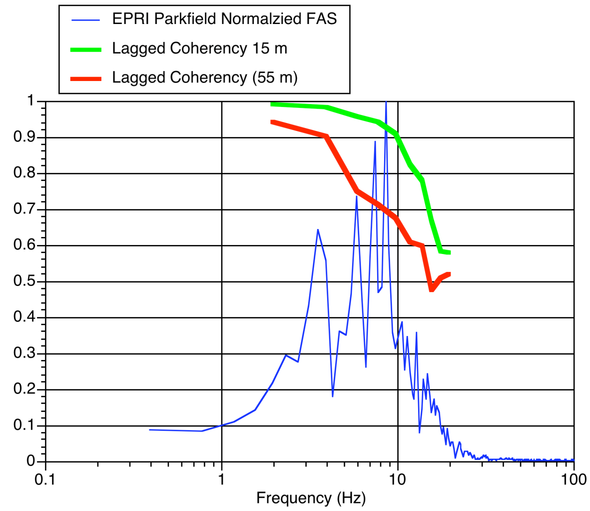


Figure II-9. Normalized power spectral densities at soil and rock sites and EPRI LSST lagged and plane-wave coherency at separation distances of 10, 30, 60 and 100 m.

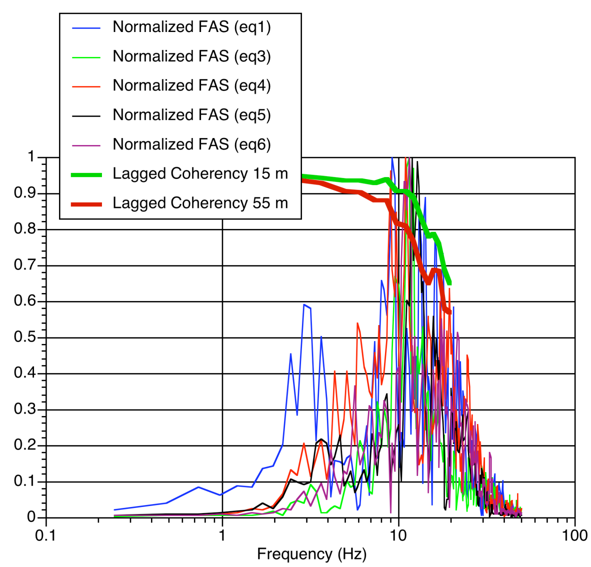
Q5-18

- <u>Response</u>:
  - For EPRI Parkfield, the coherency decays as the FAS increases



Q5-18

- <u>Response</u>:
  - For Pinyon Flat, the coherency decays as the FAS increases for 55 m separation
  - For 15 m separation, the coherency falls with the FAS



Q5-19 - Coherency at High Freq

- Comment:
  - The type of behavior at higher frequencies indicated in Fig. II-10 cannot be extrapolated from the exponential decay at the lower frequencies.
    - Are there additional data available at such high frequencies?
    - Is a similar trend observed for other sites/events?

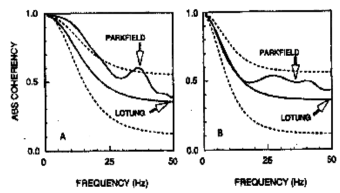


Figure II-10. Comparison of the EPRI Parkfield coherency of a small event with the LSST coherency for (A) 10 m and (B) 60 m station separation distance (from Schneider *et al.*, 1990).

Q5-19

- Response
  - Event 1 from EPRI Parkfield can be used above 20 Hz, but event 2 is near the noise level at 30 Hz.
  - The best data in the current data set for evaluating the coherency model above 20 Hz is the Pinyon Flat data.
    - This has not been done at this time

Q5-20 - residual plots

- Comment
  - If the [residuals] from the different arrays were distinctly presented instead of being grouped together, would there be additional observable trends?
- Response:
  - The residuals have been plotted for each earthquake in Figures 3-5a-h. (See response to Q5-17b)

Q5-21 - residual plots

- Comment
  - Can data [in Figures 3.4 and 3.5] be provided over a range of frequencies centered at 5 and 10 Hz, respectively, so that the trend of the data at the lower and higher frequency can be recognized?
- Response:
  - Figures 3-4 and 3-5 have been revised to use wider frequency bands (2.5 - 7.5 Hz, 7.5 - 12.5 Hz) centered about 5 and 10 Hz. (They are now Figures 3-5 and 3-6)

Q5-22 -coherency at depth

- Comment:
  - Was coherency with depth or coherency at depth investigated?
- Response:
  - This is addressed in the response to Q5.4

Q4.54 - References

- Comment:
  - The basis, range of applicability, and accuracy of major conclusions are not adequately defined in the report material. Provide additional detail on the justification of the physical, analytical, and theoretical conclusions made with respect to the proposed incoherency function and confirm that the references are publically available.
- Response:
  - This is an empirical model since physical models of coherency do not work well
  - Justification of the frequency smoothing are given in the references
  - References: see Q5.1

Q4.55 -Data Set

- Comment:
  - What is the number of earthquakes used and how many records were used for each array and earthquake?
- Response:
  - See Table

Q4.56 - Data Set

- Comment:
  - Provide clarification on the number of stations with separation distances equal to or less than 150 meters.
- Response:
  - See Table

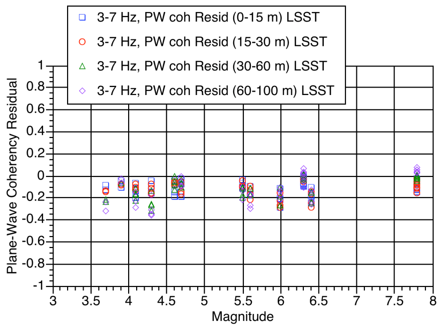
Q4.57 Site Effects

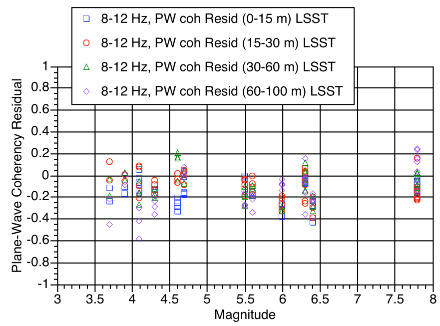
- Comment:
  - Provide a comparison of the results obtained from the two sets of records (Taiwan/Japan and California) or, as a minimum, a detailed explanation of the claimed broad applicability of the results. In addition, describe the comparison of the results obtained by the present and numerous previous studies.
- Response:
  - The basis for the broad applicability for different site conditions is the comparison of the lagged coherency given in the references (unpublished report)
  - The basis for the broad earthquake parameter applicability is the residual plots (vs mag and distance)

Q4.58 -Mag Dependence

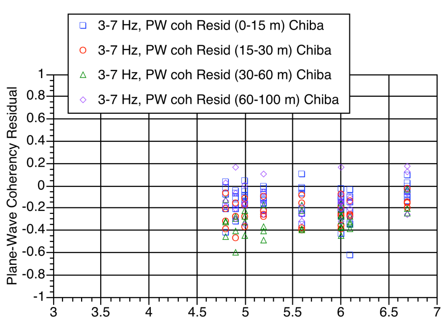
- Comment:
  - Provide a comparison of the coherencies obtained for different magnitude events at the same or comparable sites.
- Response:
  - Mag dependence of residuals is shown for the LSST array and for the Chiba array

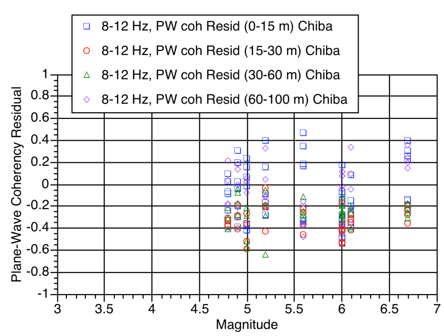
Q4.58 - Mag Dependence
LSST





Q4.58 - Mag Dependence
Chiba





Q4.59 - Site Condition

- Comment:
  - Provide a comparison of the coherency values obtained for earthquakes of comparable magnitudes recorded on rock and soil sites.
- Response:
  - Not done yet

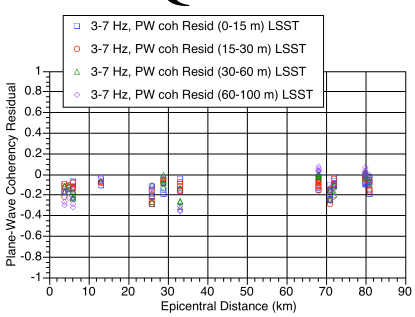
Q4-60 - site condition

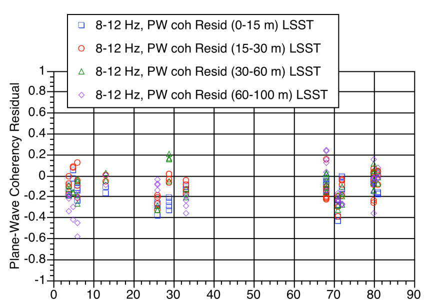
- Comment:
  - The claimed independence of the proposed incoherency function from local site conditions appears to be contradicted by the demonstrated material difference in the results obtained for the horizontal and vertical components of recorded motions. Please explain this apparent contradiction.
- Response:
  - The vertical coherency is higher than the horizontal because it contains significant P-waves, not due to the greater high frequency content
  - The site response changes the amplitude of the ground motion (soil sites damp the high frequencies and amplify the long periods), but the coherency is related to the phase differences

Q4-61 - Source-Site Distance

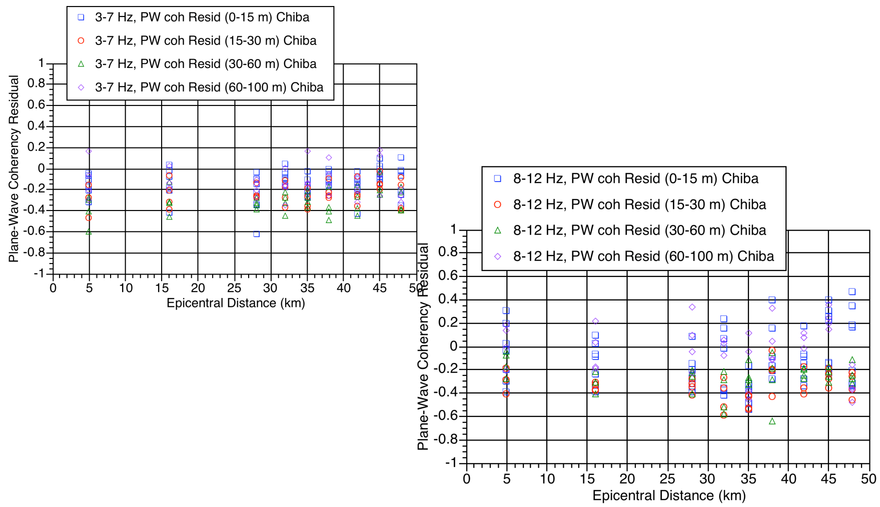
- Comment:
  - Please explain the basis for claiming independence of source-to-site distance on coherency.
- Response:
  - The basis is the plot of the residuals vs distance.
  - We have plotted the residuals for the LSST and Chiba arrays separately in the following plots

Q4-61 - LSST Residuals





Q4-61 - Chiba Residuals



Q4-62 - Coherency at depth

- Comment:
  - The proposed coherency model is based exclusively on motions recorded at the ground surface. It was previously noted that the SMART array in Taiwan includes “8 down-hole accelerometers at depths up to 47 m.” Are there any useful recordings from these stations, and if so, how do the associated incoherencies compare to those obtained at the ground surface?
- Response:
  - See response to Q5.4

Q4-63 - Other Models

- Comment:
  - There is a multitude of incoherency expressions for seismic ground motions in the literature.
  - Please demonstrate the relationship of similar models to the one being proposed and explain the differences.
- Response:
  - We will plot up various model and compare them with the proposed model
  - Not done yet

Q4-64 - Robust model

- Comment:
  - The proposed incoherency model is claimed to be well-calibrated and robust as it is based on recordings from a large array set. This claim, however, is not convincing for the following reasons: First, the spread of the residuals in Fig. 3-3 of the report + which extends from - 0.7 to 0.7 + is by no means small, and second, the comparison includes data sets that are not quite comparable. Please explain this apparent discrepency

Q4-64 - Robust model

- Response:
  - The large variability is why we need to consider as large of data sets as possible. A result can be robust and still have a large aleatory variability.
  - The data sets are comparable in that they cover short distance separations. We consider the separation distance to be the key.

Q4-65 - Time Window Length

- Comment:
  - Please explain the effect of [time window length] on the coherency function.
- Response:
  - The coherency was re-evaluated using shorter time windows.
    - Resulted in larger variability, but no change in the average plane-wave coherency residual
  - Vernon et al (1991) found this same result