EPRI Reviewer (Jon Stewart) Comments on the Coherency Function

Summary of Main Comments

- Why Not Use Other Published Coherency Models?
- Eq. 3-3 is Not Clear
- Why Not Give Models for the Lagged Coherency?

Why Not Use Other Published Coherency Models?

- Coherency is highly variable from event to event
- Most published coherency models are based on an analysis of a small number of earthquakes
  - Tendency to over-interpret the coherency differences that may be random as systematic effects of magnitude, distance, mechanism, site condition, ...
- For EPRI study, use a large data set that gives a robust model of the coherency

Eq. 3-3 is Not Clear

$$\gamma\,(f,\xi) = \left|\gamma_{pw}(f,\xi)\right|\left(\cos(2\pi f \xi_R s) + i\sin(2\pi f \xi_R s)\right)$$

- Cause of confusion is misleading notation
  - LHS looks like the standard complex coherency
  - LHS should be the complex plane-wave coherency
    - This simply accounts for the phase shift due to the systematic wave-passage effect for a plane wave with slowness s.
    - Added a subscript: $\gamma_{cpw}(f,\xi)$

Why Not Give Models for the Lagged Coherency?

- The lagged coherency allows for different frequencies to have their own wave speed and direction of wave propagation
  - Not consistent with SSI applications that use a single wave speed and direction at all frequencies

NRC RAIs for Coherency Model

General Comments

- 1. Report not complete, refers to other reports
  - Attach reference reports as appendices
- 2. Empirical validation of coherency model on large foundation
  - The coherency model is empirical for free-field
  - The SSI model predicts the motion of the foundation
- 3&4. Is the coherency model applicable at depth for embedded foundations?
  - Some array data available at depth (10m, 20m)
  - Previous evaluation (not published) showed similar coherency at depth and at surface

Introduction

- 1. Explain theory and terms
  - This is available in referenced reports that will be attached
- 2. Basis for saying SMART-1 and LSST lead to "well calibrated" models
  - The SMART-1 array has recorded over 50 earthquakes and the LSST array has 10 well recorded earthquakes with 12 closely spaced stations. These large data sets lead to robust models
- 3. Effect of mag, depth, geology, ..
  - Many previous studies has suggested dependence of coherency on these parameters bas on evaluations of a few earthquakes. When larger data sets are used, these trends do not remain.
  - Test is the residuals of the coherency model

Mathematical Background

- 1. State assumptions of physical nature, show parameters that strongly affect coherency, conduct sensitivity studies
  - Not sure what is behind this question
  - The coherency model is empirical for the S-waves
  - Main assumption is stationarity,
- 2. Define terms
  - The report will be modified to define terms.
  - Referenced reports have more background
- 3. Effect of type of seismic waves
  - Coherency model is for the S-waves
  - P waves will have larger coherency at high frequencies
  - Surface waves have little high frequency content

Coherency Models

- 1a. Coherency falls off fast above 15 Hz. Give the correlation coefficients between adjacent recordings.
  - The correlation coefficient is a time domain measure that will be controlled by the moderate frequencies (e.g. 2-3 Hz) and will not provide insight for the high frequencies
  - The correlation coefficient is the maximum of the cross-correction; the coherence is the Fourier transform of the cross-correlation. The coherence allows for a frequency dependent correlation coefficient.
- 1b.Large foundation may modify ground motion differently than free-field
  - The coherency model is not trying to model the coherency on the foundation. That is the SSI task. The coherency model is intended to model the ground motion input to the foundation

Coherency Models

- Strain dependent soil properties are based on coherent ground motion. Provide guidance on modeling of soil properties when calculating SSI effects
  - The coherency changes the phasing of the ground motion at a point, but not the Fourier amplitude. With the same amplitudes, the strain dependent properties should be similar.

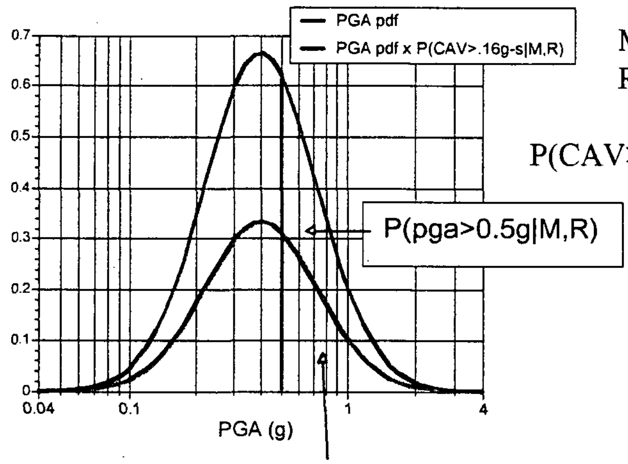
Task G1.2 CAV Model

EPRI Reviewer (Gail Atkinson) Comments on the CAV Model

Main Comments

- Why is CAV dependent on Ground motion? Why not develop model for CAV(M,R) and the just multiply the rate of the event by P(CAV>0.16g-s)
  - This approach is not viable
  - Need the joint probability of Sa>z and CAV>0.16g-s given the earthquake
    - P(x,y) = P(x)P(y|x)
    - Since CAV is correlated to the ground motion, must include the ground motion dependence in CAV
    - Ignoring the dependence would under-estimate the hazard

Using CAV Model Independent of Ground Motion

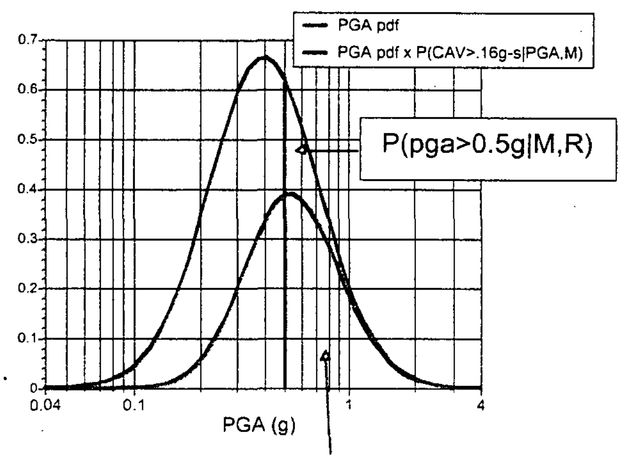


M=5.5
R_{JB}=3 km

P(CAV>0.16g|M,R)=0.5

P(pga>0.5g|M,R) x P(CAV>0.16g|M,R) =0.19

Using CAV Model Dependent of Ground Motion



M=5.5
R_{JB}=3 km

P(pga>0.5g|M,R) x P(CAV>0.16g|M,PGA) =0.31

CAV Model

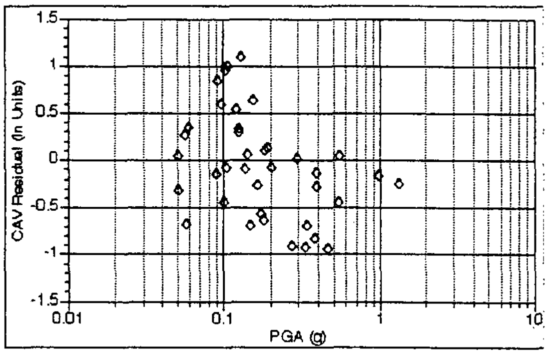
- CAV model goes through 2 steps using duration as an intermediate step. The model is complicated and is difficult to understand how the form of the model was selected. Can it be simplified?
  - Reason for including intermediate step with duration dependence was to allow for a duration difference between WUS and EUS, but no difference found for uniform duration
  - Form of model is based on exploratory analysis and previous models for other parameters with thresholds
  - Model could be simplified which would make it easier to follow

EUS Check of CAV Model

- Additional data is available: Riviere-du-Loup, Quebec, M4.8 March 6, 2005
  - Data will be added to the report
  - This data has been evaluated and is consistent with WUS model

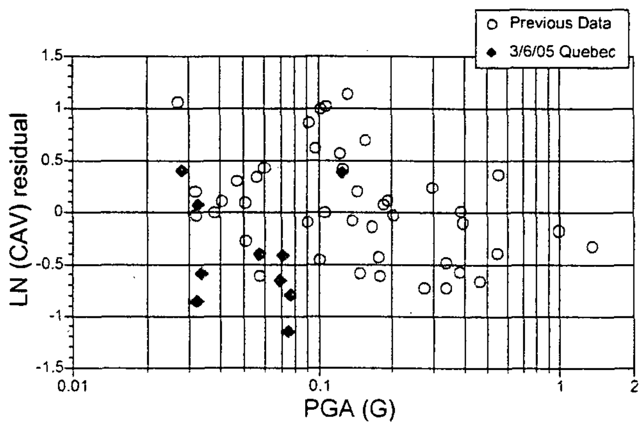
Application of CAV to EUS

- Trend in EUS residuals vs PGA suggests that WUS model may not be applicable to EUS



WUS model is Conservative for PGA > 0.2g

Residuals Including New EUS Data



Mean = -0.03

CAV filtering for Sa

- Using a constant spectral shape is an oversimplification since the spectral shape depends strongly on Mag, distance, and Vs.
  - This is a misunderstanding
    - The model does not use a constant median spectral shape
    - The median spectral shape will be a function of magnitude, Vs as given by the attenuation relation
  - Report recommends using constant correlation of the residuals of the spectral acceleration with the residuals of the PGA
    - Previous studies of these correlation coefficients are very stable

Conclusion from EPRI Review

- Believes that the WUS CAV model is applicable to the EUS, but that a stronger case could be made
  - e.g. additional data
- Would like to see a simpler model
  - e.g. use single step, rather than 2-steps that goes through duration.

NRC RIAs for CAV (G1.2)

- 1,2,7,13: CAV should depend on Site Vs, tectonic environment, regional attenuation. How can the WUS model be moved to EUS?
  - The CAV model depends on the ground motion level.
  - The CAV dependence on these variables is accommodated through the PGA.

NRC RAIs for CAV

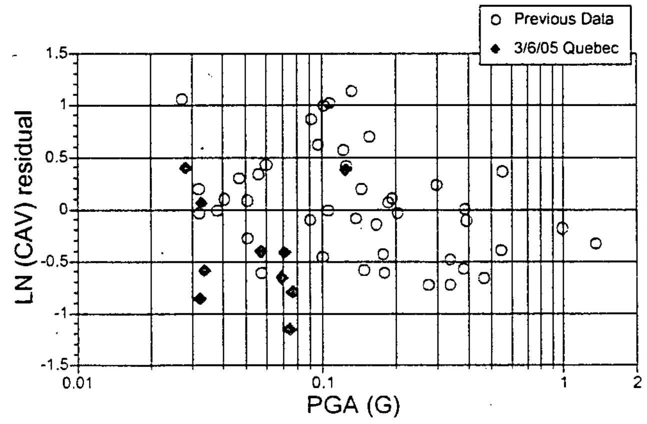
- 3a. The residuals are the estimates of experimental error.
  - The residuals are not experimental error. They represent the variability of CAV that results when a few simplified parameters are used as predictive parameters.
- 3b.How are the CAV distributions with respect to uniform durations and PGAs for the CEUS?
  - Not clear of the question. Residuals shown for EUS CAV as function of duration and PGA

median CAV
vs

NRC RIAs for CAV

- 4. Why the different PGA thresholds used for evaluations of EUS data (0.03g, 0.04g, 0.05g)? How many data points are removed?
  - The goal of the study is to develop a CAV model that is accurate for predicting the P(CAV>0.16g-s).
  - Since CAV is only defined for PGA>0.025g, it varies greatly in terms of the log (CAV) as the PGA just crosses the 0.025g level.
  - Different thresholds were based on evaluations of the residuals
    - No bias for uniform duration for PGA>0.05g
    - No bias for CAV for PGA>0.04g
    - Revised report will show the residuals for all PGA>0.025g

CAV Residuals vs PGA Including New EUS Data



Mean = -0.03

NRC RAIs for CAV

- 5. Inconsistencies between text and excel data files
  - Excel files are correct.
  - Text will be corrected

NRC RAIs for CAV

- 6. Please clarify which component of ground motion recordings is used during the CAV modeling. If both components are used, are their correlations being considered in the modeling?
  - The two horizontal components are used if PGA>0.025g on both.
  - The correlation of components was not considered.
  - The effect of the correlation will have no impact on the median, but will have a small effect on the standard deviation.

NRC RAIs for CAV

- 8. CAV model shown for Vs=600 m/s. Why use only Vs=600 m/s subdata set?
  - 600 m/s used just as an example for dependence on Mag, PGA, duration
  - All of the data were used to develop the model
- 9. In Table 2-2, an earthquake with magnitude of 4.3 was recorded both at the station 2627Aand 2627B. Are these two stations at the same site? If they are, why the Vs30s are different?
  - Same area, but different locations
  - Will add more station information in report

NRC RAIs for CAV

- 10. Explain the rational for the functional forms of Equation 2-1 used to predict CAV based on duration, magnitude, and shear wave velocity, and of Equation 2-2 used to predict uniform duration using PGA, Vs30 and magnitude?
  - Same question as Atkinson
  - Form of models are based on exploratory analysis and previous models for other parameters with thresholds
  - A key feature is that we are focused on the model being accurate for predicting CAV > 0.16g-s. Since this CAV value is well within the range of data from the WUS, we don't have to worry about over-parameterization of the problem.

NRC RAIs for CAV

- 11. Explain the relative significance of different variables in the prediction equations for both CAV and uniform duration (Equations 2-1 and 2-2) and provide the statistics for each of the coefficients (variables).
  - Asymptotic standard errors of parameters will be added to the report

NRC RAIs for CAV

- 12. Explain why the distance factor is not explicitly expressed in the Equation 4-1.
  - Do not understand the question
  - Eq. 4-1 is a general equation that includes a possible distance dependence

Eq. 4-1

$$\nu(Sa > z) = \sum_{i=1}^{N_{source}} N_i(M > M_{\min}) \int_{M=M_{\min}}^{M_{\max i}} \int_{R=0}^{\infty} \int_{\varepsilon_{PGA}=-5}^{5} \begin{matrix} f_{mi}(M) f_{ri}(r,M) f_{\varepsilon}(\varepsilon_{PGA}) \\ P(CAV > 0.16 \mid M, PGA(M, R, \varepsilon_{PGA})) \\ P(Sa > z \mid M, R, PGA) \, d\varepsilon_{PGA} \, dr \, dM \end{matrix}$$